AEROSPACE SYSTEMS SERIES

SOME MAJOR IMPACTS OF THE NATIONAL SPACE PROGRAM

VI. Public Health, Medicine, and Biological Research

Prepared for:

I.P. HALPERN
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
WASHINGTON, D. C.

July 1968

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RESEARCH
INSTITUTE

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VI. Public Health, Medicine, and Biological Research

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Mr. R.W. Prehoda prepared this report
as a consultant to Stanford Research Institute

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FOREWORD

This is the sixth in a series of task reports within a brief study of "Some Major Impacts of the National Space Program."

Within this investigation, many candidate impacts were first screened and those that appeared (a) minor or (b) not likely to yield to sufficient study within the short time available were eliminated. The remaining impacts were subjected to further study, and each is separately reported within this series.*

The results of this study are the first concrete assays within a welter of conflicting, incomplete, exaggerated, and frequently unsupported information. Stanford Research Institute considers their objective study an important task and is looking forward to extending the scope of this study in the future by application of the background, methodologies, and initial results obtained to date.

John G. Meitner
Project Manager

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* The titles are: "Economic Impacts," "Identification of New Occupations," "Impacts of New Materials Technology," "Impacts Upon Aviation and Aeronautics," "Impacts Upon Health, Biology, and Medicine," "Some Total Impacts of NASA Capability," "The Impact of the Space Program Upon Science--1. Astronomy."

ABSTRACT

During the past ten years, almost every branch of the physical and biological sciences has contributed to our total space program. Since space R&D has represented a considerable portion of our investment in advanced science, it was assumed that there would be a considerable transfer of this technology to meet the needs of public health, medicine, and biological research. The transfer process has been uneven, with unexpected achievements and barriers.

Manned space missions have caused the normal healthy adult to be intensively studied, in contrast to past biomedical research which principally centered on adults suffering from disease. These base-line clinical data cover almost every environmental parameter, permitting deviations from the norm to be better measured in disease and also allowing optimum performance standards to be set in many occupations.

The impact on biomedical research techniques has been a positive achievement, especially where nonspace R&D is conducted by groups also engaged in bioastronautics. The use of the computer and mathematical models for biological systems has been refined in space R&D and is now widely employed. The research technique transfer includes one significant breakthrough--digital computer processing and enhancement of X-ray and microscope photographs, also of great value in medical diagnosis.

The transfer of specific items of hardware developed for space programs or related research has been unexpectedly slow. There is a very serious time gap between the acceptance at the clinical testing level and the widespread distribution of the system in medicine where the user requirements are to be found. Frequently, five or six years will intervene before a system is installed in a hospital, clinic, or laboratory.

The principal barrier in transferring biomedical hardware lies in the fact that most organizations engaged in bioastronautics, i.e., aerospace corporations, universities, and government agency laboratories, do not have a biomedical equipment manufacturing and marketing capability for systems other than those used in space and military programs. Many items of transfer value are not patentable. Life science is usually of secondary importance in aerospace companies, and management is frequently disinterested in biomedical diversification because past ventures have

been unprofitable. The physician in the hospital or university often thinks of aerospace support as being a philanthropic gesture, and his misunderstanding of the need for profitable product lines presents another barrier.

In almost every case where a system has been successfully transferred from bioastronautics to clinical or research applications, the necessary catalyst has been a "champion" who is able to provide the necessary support. Frequently, the champion is a principal scientist or official whose influence will allow the necessary transfer activities to be conducted on a bootlegged or sub rosa basis. Converting the role of the champion from an unofficial to an authorized participation would greatly enhance the overall impact of bioastronautics.

After ten years, the present impact of the space program on life science and medicine is scattered and only beginning to play a practical role in the public health sphere. Many systems are successfully passing their clinical tests. The impact on research is slowly diffusing and becoming standard practice.

The future impact will depend partly on a better understanding and acceleration of the bioastronautics transfer process itself. It should be possible to revolutionize many clinical and research procedures with systems and techniques initially refined to meet space requirements. The creation of a new biomedical technology transfer agency, under NASA management, is one of several promising options that might be evaluated as a means of optimizing the transfer of bioastronautics technology and research techniques.

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INTRODUCTION AND SUMMARY

This report analyzes the impact of the total U.S. space program on public health, medicine, and biological research. The background information was obtained through in-depth interviews with scientists and officials responsible for various bioastronautics programs in aerospace companies, government agencies (including headquarters groups and laboratories), universities, and hospitals. Scientists and physicians outside the space program who are benefiting from space technology transfer or who are potential beneficiaries were also contacted. Geographic coverage was restricted to the state of California and the Washington, D.C., area including nearby communities in Maryland and Virginia. While this is not a complete coverage of all the organizations engaged in applicable space activities, the organizations that supplied useful data represent approximately half of the nation's ongoing space biomedicine, and they can be considered as a representative sample. Also, many of the interviewees had recently come from other organizations in geographic areas not included in the study. Consequently, the data collected represent a sufficiently broad sample of total space R&D experience to permit the conclusions reached in this report.

The interviews were conducted during a time when space research budgets had already been seriously curtailed, and they now face the prospect of even greater budget cuts in the next fiscal year. It should be mentioned that a feeling of deep pessimism prevailed among most of the people contacted and that this attitude of mind may have unconsciously influenced their evaluation of the present and near term impact of the space program in the biomedical field. In many cases, the budget restrictions in NIH and other agencies not responsible for astronautics resulted in funding cutbacks for programs that would have included technology transfer items. At the present time, it is more difficult to obtain funds for some of promising technology options than it was two or three years ago. The certain pattern of funding in the next fiscal year means that technolog transfer will continue to be adversely affected by the overall cuts in the nation's R&D and public health programs.

Many concerned officials have been disappointed, because many of the most promising items of technology transfer have taken a very long time to reach a practical clinical application following the testing and equipment modification phases. A representative sample of these systems is found in the matrix in Table 1.

Table 1

REPRESENTATIVE LIST OF SPACE SYSTEMS
USEFUL IN MEDICINE AND BIOLOGICAL RESEARCH

	Early Transfer	Delayed Transfer	Bioastronautics Systems	Nonlife Science Space Technology	Serendipity or Item from Unfunded Proposal
Automated Blood Pressure Cuff		•	•		
Wheelless Wheelchair		•		•	•
Spray-on Electrodes	•		•		
Gas Powered Cryoknife		•			•
Computer Image Enhancement	•			•	
Graphite Implants	•			•	•
EEG Helmet		•	•		
Marsupial Biopack		•	•		•
EKG Biotelemetry	•		•		
Laminar Airflow-Sterilization		•	•		

It should be emphasized that the medical profession has been historically very conservative in its adoption of new techniques and technology. It has been frequently observed that there has been a 10- to 15-year lapse before items of advanced technology are fully employed in clinics, hospitals, and biomedical laboratories. One important impact of the space program has been a practical reduction in this time lag, since all the items that have been successfully adopted have at least beaten the historic time lag. Furthermore, the space program has clearly demonstrated that it is possible to achieve very significant state-of-the-art advances in a very short period of time when sufficient talent, funds, priorities, and management direction are provided to allow the early realization of specific goals.

Clinical Data--The Healthy Adult

The astronaut and astronaut substitute working in various space laboratories are normal healthy adults who must function in a completely alien environment to understand what the physical and mental capabilities of man in space would be. A large number of studies have been conducted to uncover physiological data that have not been thoroughly investigated in historic biological research primarily concerned with various pathological processes. To walk effectively in a space suit on the moon, scientists first have to know more about the mechanics of walking here on earth. The chemical composition of saliva and tears was determined for the first time. Sensory deprivation, exotic gas atmosphere compositions, humidity, pressure, circadian rhythms, and work cycles have been but a few of the many physiological parameters where complete or relatively complete information is now available as a space dividend.

The clinical data on the healthy adult are currently scattered among many reports and study summaries of government agencies and organizations who have gathered these data, and it is not readily available to the research physician or scientist who may not be familiar with the space program or the organizations that have been responsible for conducting these investigations during the past ten years. Consequently, access to these data is severely restricted, and in many cases it does not appear in reference tables in recent medical books prepared by scientists operating outside of the space community. One strong recommendation is that a monograph or monograph series be prepared to bring all these pertinent data together and also adequately reference the more detailed coverage of the physiological parameters that appear in the specific reports that provide information obtained through diverse bioastronautics grants and contracts. Several scientists have suggested that a symposium or similar meeting, which would bring together and give attention to data obtained on the

healthy adult, might be seriously considered for NASA support in association with other government agencies supporting biomedical R&D.

Items of Equipment Transfer

The transfer of the systems and subsystems developed as the result of space research to meet the needs of terrestrial biological research and medicine has been slower then originally expected. The most serious time gap exists between the initial clinical testing phase and the subsequent manufacture and distribution of the system to those sectors of the biomedical community where the actual requirements are to be found. Understanding and analyzing the mechanics of this barrier may be the most important contribution of this report. In many cases, we are considering relatively expensive systems that require separate funding by a government agency or outside organization to complete the transfer. For instance, an automated blood pressure cuff was developed by Garrett for the Mercury and Gemini programs. This system was clinically tested in 1961 and could have been installed in a hospital intensive care center at that time. The first actual installation took place in an intensive care center at the National Institutes of Health in 1968. The system is not likely to save a life in the same dramatic manner as less expensive items such as EKG monitors which were among the first automated devices installed in care centers. Garrett was fully occupied during the intervening years and had no internal pressure to attempt to diversify through this transfer option. The traditional conservatism of the medical community was also an important factor.

The most rapid equipment transfer has been made to other user requirements when the development for hardware modifications is conducted by the same organization that engaged in the original bioastronautics program. For instance, Garrett developed a biomedical recording system under NASA contract to evaluate physiological behavior of man under actual flight conditions in our manned space programs. This system was quickly transferred to Air Force requirements to monitor the effects of stress on pilots in Vietnam during actual combat operations. In almost every case where a transfer can be made to a military requirement, it has been quickly made because the organization engaged in space research is almost always cognizant of Air Force, Army, and Navy requirements. The accounting, manufacturing and customer relations patterns are not barriers in transferring space systems to other government agency requirements.

R&D Capability Transfer

The space program has caused interdisciplinarian teams of scientists to be brought together to successfully achieve diverse goals, many of which are only partly related to the life sciences. Frequently, it is the availability of these teams that permits a life science program that would not have been possible without the space program to be successfully undertaken. For instance, SIM One is a revolutionary application of aerospace technology to medical education. It is a computer controlled lifelike mannequin developed at Aerojet General's Von Karman Center to accurately simulate human response in training anaesthesiologists. The basic concept of SIM One is an extension of simulation theory originally developed in Aerojet's space power systems, rocket engine systems, and space satellite systems. Here the research team (rather than the hardware) was transferred to produce a completely new educational technology. The SIM One program is a representative sample of the potential employment of the methodology of space R&D in providing completely new solutions to various problem areas.

Research Techniques

Almost all our space R&D has required completely new instrumentation and methodological approaches, and this has been particularly true of bioastronautics programs. Research techniques developed for space requirements have been most readily transferred within the same organizations that nonspace biomedical research is conducted. In some cases, the transfer has been made by an individual going from a bioastronautics group to a new affiliation where he carries the new techniques with him. In many cases, we are considering components and subsystems, such as better skin electrodes for EKG and EEG measurements.

There has been widespread employment of computer programming techniques including mathematical models of various physiological processes. The availability of third generation computers may be considered as one of the indirect transfer benefits of the space program. This refined computational capability permits complex two- and three-dimensional matrixes to be programmed to determine complex interrelationships between very large numbers of environmental and physiological parameters.

The digital computer processing of optical and electron microscope images promises a quantum improvement in new areas of research emphasis, particularly molecular biology. This technique, coupled with new electron microscopes of near theoretical resolution, which are now being developed, may permit a direct "readout" of the structure of many organic molecules.

Bioastronautics research techniques have been employed in the development of experimental artificial hearts under Dr. Willem Kolff at the Cleveland Clinic. Body cooling procedures refined as a result of NASA's reduced metabolism program have been used in hypothermia research. Automated monitoring of equipment is a space research technique that has been widely adopted.

Technology Transfer Barriers

Where sizable expenses are not entailed, systems and subsystems developed throughout the space program will go through the initial clinical testing phase of technology transfer in a comparatively short period of time. Here we are usually dealing with a single prototype that may have been modified for the nonspace application. The organizations that produced the prototype as a rule do not have the manufacturing and marketing capability required to supply these systems in large numbers for hospitals, clinics, and laboratories. Consequently, there is a serious time gap between the initial clinical or other testing phase and the availability of the system as a manufactured item.

The hospital or university scientist frequently is interested in solving his own equipment needs and regards a prototype system as a philanthropic gift from an affluent company, which the scientist may also regard as a "merchant of death" because of defense contracts. The need for a transfer from the testing phase to profitable product line is frequently not recognized by the scientist, which contributes to the barrier.

In almost every case where there has been a successful transfer in a relatively short time period, a "champion" has served as the transfer catalyst. A thorough analysis of the role of the champion in successful transfer should be undertaken. Converting his role from an unofficial to an authorized function might be one of the best ways to speed technology transfer in all advanced military and space fields. Here we are partly considering the psychology and motivational dynamics of the transfer process itself.

RECOMMENDATIONS AND CONCLUSIONS

Writing from a vantage point of 1968, one can state that space biomedicine has had a gratifying transfer impact on the state of the art of laboratory instrumentation and research techniques for terrestrial life science R&D. Many specific items of technology have been successful in the initial clinical or other testing phase and can be expected to be widely distributed in the future.

The NASA Tech Briefs provide an adequate description of biomedical systems with a transfer potential. Unfortunately, many scientists outside the space and military fields are either not aware of this quick identification service or the Tech Briefs that would be of greatest interest simply do not reach them. It must be recognized that these are extremely busy, overcommitted professionals, and some means should be devised to contact them directly about technology transfer items of potential value in their programs, rather than expecting them to go through the established identification system. It is naive to assume that the potential user will take the initiative in the identification phase of the transfer process.

The principal question regarding the future impact of technology transfer from bioastronautics depends on the possibility of adopting new procedures. The transfer to other life science research requirements can become more effective by a system of monitoring prospective user needs. One solution might be to prepare a programmed "interest profile" of various biomedical professions and specialties and then devise a system by which Tech Briefs are automatically sent to the scientists who are most likely to use the space systems in their research.

More effective future transfer of bioastronautics systems to widespread clinical medical practice will largely depend on the funding available to accelerate such transfer. It is naive to assume that the simple identification of such transfer options will permit their early adoption, especially where relatively expensive systems are concerned.

The severe R&D budget cuts caused by fiscal pressures, primarily stemming from the Vietnamese conflict, may be eased if a negotiated settlement is reached in 1969. Federal R&D funding is likely to resume its historic growth pattern, providing new opportunities for the clinical utilization of space technology.

The solution to optimized clinical transfer was invented by the Phoenicians--MONEY! Stated conventionally, specific funds must be allotted in grants and contracts to complete all the transfer steps where comparatively expensive systems are entailed. The desirability of such transfer programs are evaluated in the section, "Adaptation Problems and Some Possible Solutions." Close cooperation between NASA, NIH, and other agencies, probably facilitated in part through joint committees, would be necessary.

Many potential transfer items in bioastronautics are extremely expensive by the standards of organizations, such as hospitals which are potential users. Frequently, the cost of an automated device will be an order of magnitude over the system it replaces. The fact that the time saved by highly skilled professionals will make the automated device quite economical is frequently not accepted by biomedical specialists until the system has been in operation for a year or more. Consequently, some means of funding the clinical proof-of-principle phase is likely to have a significant impact in reducing the overall lag in the widespread adoption of space biotechnology.

The possibility of establishing a new agency to fund critical phases of the transfer of bioastronautics technology is a possibility that deserves attention. Such an organization could identify the potentially useful systems while they were still being developed before their use in an operational space system.

After ten years, some definite conclusions can be reached concerning the space biomedical technology transfer process. The 10- to 15-year time gap in applying advanced technology to clinical requirements has been broken, but there is still a long delay in transferring operational technology and research techniques. Systems developed for space requirements are extremely expensive by conventional biomedical standards (clinical or research). The expense factor frequently creates a psychological barrier in potential users that is difficult to overcome.

There is a fundamental need for direct or indirect funding support to accomplish the initial transfer steps. Frequently, a champion will use his influence to allow the steps to be conducted sub rosa or on a bootlegged basis. The champion may also assist in obtaining grants or funds from agencies not engaged in space programs for additional equipment modification, and the like.

The clinical proof-of-principle testing is frequently conducted with the original space hardware. There is a serious time gap between this first step and the commercial availability of the system. Most aerospace

organizations do not have a commercial manufacturing and marketing capability for such systems.

The effectiveness of space life science transfer is particularly sensitive to overall funding trends in government-supported R&D. When space budgets are declining, essential personnel are frequently lost, and there is less money for programs outside of major requirements. When federal biomedical funds are not growing, new programs essential for transfer must compete with established programs, and frequently budgets are completely committed. These considerations were very much in evidence and frequently mentioned by interviewees during the study.

Assuming the space program resumes its historic growth pattern in the post-Vietnamese conflict time period, there could be a great increase in items with transfer potential. A Voyager Mars mission, with a fully automated biological lab containing several different bacterial identification systems, would have great clinical potential. As a confirmed national goal, the initial bioastronautics R&D required for manned planetary exploration would provide a cornucopia of transferable technology far in excess of the comparatively modest requirements of the Apollo program.

BIOASTRONAUTICS OVERVIEW

For all practical purposes, space life sciences did not really become a significant branch of biological research until the U.S. space program was established as a major national effort in 1958. The Mercury program, which was also initiated the same year, provided the first requirement in this country to study effects of the alien environment of space and weightlessness on an adult human. In 1959 a new term, "bioastronautics," came into popular usage to describe all studies related to living organisms in space. It has become a field that encompasses every discipline and technology that contributes to the study of living phenomena. In addition to establishing the working parameters of a man in space and providing for his life support and compensating for the hostile effects of radiation and the yet speculative effects of long term weightlessness, our space program has also attempted to identify that living organisms may exist on other planets in the solar system. A number of highly ingenious systems have been developed to detect the presence of such organisms on other planets, principally Mars. This new discipline was given the somewhat exotic name of "exobiology." The life detection systems developed for Voyager-type missions offer great portent for future clinical use on earth. The foreseeable transfer items are included in Table 2.

To sustain a man in space, a small artificial world must be created--an environment that must contain at least a minimum supply of everything that we require to maintain health, mental alertness, and physical fitness including breathable atmosphere, a near optimum diet, exercise in an extremely restricted environment, and a synergistic program of activities that will also allow a sleep cycle permitting alertness and health to be maintained. Consequently, everything that influences the adult had to be studied from both the traditional aspects and the new view of operating in a restricted environment with weightlessness as the principal unknown. Furthermore, we were dealing with healthy adults--initially, test pilots who are assumed to be among the finest physical specimens to be found in a large population. This was an historic departure from the past studies of medicine that have concentrated on pathological processes found in adults who are either ill or showing early signs of illness. Bioastronautics was also concerned with relatively young men as opposed to medical studies in the past that have tended to concentrate on older people. Investigations of children and young adults have usually concentrated on those suffering from various illnesses. At the onset of the space program, it was found that little was known about the

Table 2

MARS VOYAGER BIOMEDICAL TECHNOLOGY TRANSFER OPTIONS

	Already Transferred	Preliminary R&D Stage	Will Be Refined in Operational Voyager System or Will Be a Transfer Fallout
Detection of Single Bacteria		•	•
Laminar Airflow for Burn Victims	•		
Laminar Airflow Drug Manufacturing	•		
Automated Bacterial Detection		•	•
Germ-Free Animal Requirements			•
Heat Sterilizable Components and Subsystems for Medical Requirements			•
CBR Military Detection Systems		•	•
Automated Identification of Bacteria		•	
Sterilization Procedures for Surgery			•

physiological parameters of a normal healthy adult. During the past 10 years, a vast amount of data was obtained, and we are now able to know what the mental and physical performance of a healthy human should be under a given set of circumstances in any one of several different environments. These base-line data are already having, and will continue to have, a great impact on the emerging field of preventative or predictive medicine. They are covered in detail in the section on clinical data.

To determine the physical parameters of astronauts and also to monitor these parameters during space flights, a variety of physiological instrumentation has been developed that has great potential in clinical medicine both for the individual physician and throughout our complex of clinics and hospitals. These hardware devices tend to be the more glamorous, or dramatic, aspects of space life science, because they are perhaps the most easily understood items for the lay public and in many cases for the sophisticated reviewer such as physicians or specialists who work outside the biomedical research fraternity. Many of these devices have gone through clinical trials and are beginning to find their way into general medical practice. They are discussed in detail in the section entitled, "Items of Equipment Transfer."

The space program has produced many items in the serendipity class that are being incorporated in clinical requirements, although they were developed for space needs outside the broad area of bioastronautics. These serendipity items range from tiny motors that are now being used in kidney dialysis machines and heart pumps to prosthetic implants that promise to have a trouble-free life in excess of the probable number of years that the patients will survive after receiving the life-extending implants.

Perhaps the most significant serendipity life-science category is found in the difficult-to-define area of advanced computer development and related programming techniques, especially mathematical models to simulate the life processes. Now the biologists can handle a vast amount of physiological data from experiments and have some understanding of how they interrelate in living systems. Bioastronautics programming techniques will eventually allow biomedical research to become far more of an exact science than it has been in the past. The research technique area of bioastronautics technology transfer is covered in the section entitled, "Research Techniques."

It is widely recognized that the practice of medicine including the use of technology found in our clinics and hospitals is far behind the level of use of technology prevailing in the advanced industries, particularly the aerospace field. Physicians working across the spectrum of

biomedical research are almost unanimous in their contention that historically there has been a 10- to 15-year gap before new technologies that are well established in other fields are brought into common use in clinical medicine. The great challenge and principal goal of bioastronautics technology transfer is to narrow this gap and to make available the sophisticated devices and related methodologies in a reduced time period. To some extent this has been accomplished in the brief decade that bioastronautics has been a significant research field with large budgets. A great deal has been done to transfer the technique devices and new knowledge of clinical medicine. The already measurable impact of space life science is covered in the section, "Items of Equipment Transfer."

The very fact that there has already been an impact is important, because it shows that the traditional 10- to 15-year technology gap has been breached and the public is benefiting from the clinical use of space medicine which will offer important solutions to our mounting clinical problems in our crowded hospitals and other places where people seek needed and preventative medical treatment.

There are other very definite transfer barriers in bringing the results of bioastronautics to the attention of and use by research biologists, physicians, and practitioners of the medical arts throughout our $50 billion a year complex of hospitals, clinics, and biomedical laboratories. This barrier primarily stems from the fact that the corporations, government agencies, and nonprofit institutions that have developed the actual hardware for bioastronautics requirements do not have a commercial manufacturing capability to produce systems for clinical markets. There are other related and unrelated patterns that contribute to the barrier. They are fully explored in the section, "Adaptation Problems and Some Possible Solutions."

The great potential of bioastronautics technology transfer lies in the years ahead. The future clinical and research impact is explored in the final section of the report. There will be the traditional form of transfer carried out as bioastronautics specialists move from space R&D into other research and clinical programs. Currently, this process is going on at a rapid rate, because declining space budgets have caused severe cutbacks in the life science groups primarily oriented toward bioastronautics. In many cases these groups were formed in anticipation of a level of bioastronautics funding that never materialized. Consequently, many people who have worked in the space life sciences for a comparatively short time period, say 3 to 5 years, are disseminating the useful bioastronautics technology as they assume new positions outside the space field.

A determined effort to master the transfer process is likely to be the key to success in the future. The desire of aerospace organizations to diversify outside space markets will help ensure that there will be more effective life science technology in the future than there has been in the past. The medical market is also likely to grow much faster in the next ten years than it has in the past decade.

Federal Biomedical Funding Support

During the past 20 years, federal funding for all biomedical research has grown from $50 million in 1948 to an estimated $1.67 billion in 1968. Table 3 shows the relationship between governmental, industrial, and other private funding for life science R&D during this period. The federal support grew faster than all the other R&D sources. In recent years there has been about a 3 to 1 ratio between governmental and private life science support.

Table 4 shows a breakdown of federal biomedical R&D support among different branches of the government during the past 20 years. The dominant role of NIH can be easily seen. During the past ten years NIH has received more than half the federal biomedical research funds. NASA's impact can be seen in its growing budgets, representing between 5 and 6 percent of the total during the past four years. It should be mentioned that the biomedical transfer potential of astronautics comes from the entire space program, and its potential impact is greater than that suggested by Air Force and NASA bioastronautics budgets.

In considering the total federal support that might affect bioastronautics technology transfer, it is useful to consider federal medical funding in areas outside R&D. Table 5 shows all federal health-related expenditures for FY 1968. These funds create a direct and indirect market for the space transfer areas considered in this report.

Future Space Program Rationale

Only a handful of scientists in the United States were engaged in full-time bioastronautics research before the launching of Sputnik in October 1957. The very rapid growth of both DOD and NASA space activities was accomplished primarily by those who had been concerned with aviation medicine in the years before Sputnik. These flight surgeons and other specialists were able to shift quickly into bioastronautics where the requirements are very similar to those in the aircraft field. During the first five or six years of the American space program (1958 to 1964),

Table 3

NATIONAL SUPPORT FOR MEDICAL RESEARCH
(Obligations in Millions)
1948-1968*

Source of Funds	1948	1953	1958	1963	1964	1965	1966	1967 (est.)	1968 (est.)
Total	$124	$214	$543	$1,486	$1,652	$1,841	$2,057	$2,280	$2,490
Government	50	108	292	964	1,099	1,229	1,377	1,523	1,670
Federal	50	107	279	919	1,049	1,174	1,316	1,458	1,601
State and local	n.a.	1	13	45	50	55	61	65	69
Industry	43	58	170	375	400	450	511	580	640
Private support	31	48	81	147	153	162	169	177	180
Foundations and health agencies	19	23	45	85	88	92	94	100	101
Other private contributors	n.a.	n.a.	6	21	22	25	28	29	30
Endowment	12	15	19	19	19	19	19	19	19
Institutions' own funds	n.a.	7	11	22	24	26	28	29	30

* Covers only medical and health-related research; such activities as research training and construction are not included. Beginning with 1962, data for non-Federal components have been improved and are not strictly comparable with those for prior years.

Source: Basic Data Relating to the National Institutes of Health, prepared by the Office of Planning and Evaluation, NIH.

Table 4

FEDERAL SUPPORT FOR MEDICAL RESEARCH
(Dollars in Millions)
FY 1948-1968*

	1948		1953		1958		1963		1965		1966		1967		1968 est.	
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent
Total	$50	100.0%	$107	100.0%	$279	100.0%	$919	100.0%	$1,174	100.0%	$1,316	100.0%	$1,458	100.0%	$1,601	100.0%
AEC	13	26.0	26	24.3	37	13.3	75	8.2	85	7.2	90	6.8	96	6.6	97	6.1
Agriculture	3	6.0	6	5.6	14	5.0	23	2.5	40	3.4	45	3.4	46	3.2	46	2.9
Defense	8	16.0	23	21.5	31	11.1	88	9.6	101	8.6	119	9.0	117	8.0	114	7.1
DHEW	22	44.0	47	43.9	183	65.6	642	69.9	826	70.4	925	70.3	1,050	72.0	1,166	72.8
NIH	(17)	(34.0)	(38)	(35.5)	(160)	(57.3)	(566)	(61.6)	(715)	(60.9)	(791)	(60.1)	(803)†	(55.1)	(873)†	(54.5)
FAA	--	--	--	--	--	--	3	0.3	3	0.3	3	0.2	2	0.1	3	0.2
NASA	--	--	--	--	--	--	34	3.7	60	5.1	75	5.7	82	5.6	108	6.7
NSF	--	--	--	--	4	1.4	21	2.3	20	1.7	14	1.1	14	1.0	13	0.8
VA	3	6.0	5	4.7	10	3.6	30	3.3	37	3.2	41	3.1	45	3.1	47	2.9
Other	1	2.0	--	--	--	--	3	0.3	2	0.2	4	0.3	6	0.4	7	0.4

* Covers only medical and health-related research; such activities as research training and construction are not included.
† Excludes National Institute of Mental Health and includes Division of Environmental Health Sciences.

Source: Basic Data Relating to the National Institutes of Health, prepared by the Office of Planning and Evaluation, NIH.

Table 5

FEDERAL EXPENDITURES AND LOANS FOR MEDICAL AND HEALTH-RELATED ACTIVITIES BY AGENCY
(Dollars in Millions)
FY 1968

Agency	Total	Development of Health Resources				Hospital Services	Prevention and Control
		Health Research	Training	Construction	Organization and Delivery		
Total	$13,879	$1,444	$732	$481	$159	$10,382	$682
DHEW	9,593	1,056	540	248	144	7,215	390
NIH	1,002	811	165	--	24	--	2
Other PHS	1,323	201	339	244	109	142	289
Social Security	5,064	--	--	--	--	5,064	--
Other DHEW	2,203	44	36	5	11	2,009	99
Department of Defense	1,704	87	91	26	--	1,480	20
Veterans Administration	1,442	48	60	58	2	1,274	--
Department of State	164	1	14	1	10	5	134
Department of Agriculture	153	37	--	--	--	--	116
Office of Economic Opportunity	111	--	--	--	--	111	--
Atomic Energy Commission	100	99	1	--	--	--	--
Other agencies	415	116	26	148	3	100	22
Contributions to employee health benefit funds	197	--	--	--	--	197	--

Source: Basic Data Relating to the National Institutes of Health, prepared by the Office of Planning and Evaluation, NIH.

there was a shortage of experienced people to serve as principal scientists and managers for the many space life science programs that were initiated at that time. One can recall no warning that the space program would be curtailed as drastically as it has been during the past two years. Consequently, everyone in the general field of astronautics expected that the pattern of growth would continue for a time, perhaps leveling off around 1970 or 1971. Therefore, very little thought was given to the subject of technology transfer by those in the organizations engaged in astronautics systems development, even though technology transfer goals were written into the original legislation setting up NASA as the principal agency to conduct nonmilitary space exploration.

From October 1957 through 1965, we were actually in a space race with the Soviet Union. In the spring of 1961, the late President John F. Kennedy decided to make a manned lunar landing the central objective of our space program during 1961 to 1970. The major NASA programs of this decade have been either directly related to Apollo or in support of Apollo. When one considers that we had a relatively late start and that the Russians initially had superior launch vehicles, the period from 1960 through 1965 contained many remarkable successes. The U.S. public was enthralled with the space program. Television viewing of launches allowed a vicarious participation that was assumed would continue throughout the decade. The escalating cost of the Vietnamese war, the crisis in the cities, and the fact that three astronauts were killed in the Apollo fire in January 1967 all contributed to a lessening of public support for astronautics. During the past year and a half, the space program has actually become a whipping boy for individuals who contend that these funds should be spent on public welfare, the problems of the ghetto, and a host of other special causes.

The severe fiscal pressures of the Vietnamese conflict are primarily responsible for the present slowdown in the space program. A prudent man would not predict when such a war is likely to terminate. If the present negotiations in Paris lead to a satisfactory settlement that will allow military expenditures to be eased in 1969, the greatest fiscal barrier to our present space program would be relieved. One can assume that a host of previously scheduled programs such as Voyager that are now in limbo will be resurrected and funded. If there is an astronautic renaissance in the post-1969 time period, we are likely to see a great deal more attention given to the technology transfer potential of all the new space programs as well as increased transfer efforts directed toward the older programs.

A program such as Voyager, with an automated biological laboratory, would have immediate transfer potential even before the first system is

launched toward Mars. If the mistakes of the first decade of space exploration are well understood, then the technology transfer process will be the center of immediate attention throughout the anticipated renaissance in the early 1970s. The potential impact of timely technology transfer in bioastronautics and other space disciplines would help ensure that there would be a continuing level of public support for the space program that hopefully would be continued in the remaining decades of this century without the peaks and valleys that characterized its early years.

CLINICAL DATA--THE HEALTHY ADULT

Medical research has been historically concerned with the study of various disease processes with the goal of curing or favorably modifying these deleterious changes in humans. The emphasis has been placed on studies of people who are already suffering from some illness, principally degenerative diseases such as cancer and cardiovascular disturbances. The healthy adult has been studied in the past to provide base-line data. However, the space program gave a significant emphasis to obtaining data on humans who are in perfect health. It is naturally assumed that astronauts will be selected from a pool of candidates who are not diseased and are representative of near perfect physical specimens. Consequently, NASA biomedical research has been primarily concerned with determining the physiological parameters of a healthy adult in a normal terrestrial environment and also in the various abnormal environments peculiar to space exploration, including weightlessness and lower than normal gravity environments on the lunar surface and on other members of the solar system.

A spacecraft or lunar base must duplicate to a certain extent the essential portions of the terrestrial environment needed to keep an astronaut alive and able to function in an optimum manner. Consequently, every aspect of the environment has been studied, including the effects of gravity, atmosphere composition, confinement, exercise, nutrition, defection, water balance and urine, circadian and work cycles, and synergistic relationships between various environmental factors.

Table 6 lists the specific areas that must be considered in spacecraft design and the evaluation parameters for space suits, lunar bases, or any nonterrestrial environment in which an astronaut may be expected to work, sleep, and perform other normal physiological functions.

The physiological and environmental areas in Table 6 cover almost every important or major parameter necessary for optimum health. Each area was intensively studied before the manned space program with the exception of weightlessness. There had been considerable Air Force research on acceleration before 1958, but it had a partial space orientation.

The important difference or new contribution that is coming out of space research in the areas listed in Table 6 is the fact that all these parameters are being studied together rather than separately. Space

Table 6

PRINCIPAL PHYSICAL AND ENVIRONMENTAL PARAMETERS THAT MUST BE CONSIDERED IN HUMAN EXTRATERRESTRIAL PERFORMANCE AND MAINTENANCE

Atmosphere	Food
Toxicology	Water
Acceleration	Waste
Weightlessness	Size and motion
Impact and vibration	Breathing
Pressure	Hearing
Temperature	Vision
Radiation	Human operation
Combined stresses	Vestibular system
Energy	Circadian and work cycle

Source: Bioastronautics Data Book, Paul Webb, M.D., editor, NASA SP-3006.

requirements have forced scientists to take an interdisciplinarian approach to every design requirement where man is part of the total system. Synergistic relationships between the various parameters are now better understood.

Actually, the 20 areas listed in Table 6 are broad categories that must be broken down into major subcategories for full evaluation of spacecraft design and the man/machine command and control requirements. Dr. Frederic B. Benjamin[3] of NASA OART has prepared a matrix breaking down these areas into 56 major environmental parameters and 136 major psychological/physiological parameters. His approach permits information on the intersection of each point of the matrix to be stored on a computer so that it can be picked out when it might apply to any other item on either the environmental or psychological/physiological side. A representative sample of the items covered in Dr. Benjamin's matrix is presented in Table 7.

The use of the computer to handle a vast amount of environmental and psychological/physiological data relative to a healthy adult is an extremely important transfer contribution of space biomedicine. Dr. Benjamin has observed that a submatrix is actually required to handle all

Table 7

SAMPLE AREAS SHOWING BIOASTRONAUTIC INTERRELATIONSHIP

Environmental Parameters / Psychological/Physiological Parameters	Vol.	Std.		Tissue: Growth and Aging	Tissue: Healing and Repair	Tissue: Genetics and Carcinogenesis	Vision: Acuity	Vision: Spectral Sensitivity	Vision: Visual Fields	Vision: Contrast Threshold	Vision: Dark Adaptation	Vision: Depth Perception	Vision: Color Discrimination	Vision: Flash Blindness (Dazzle)
				01	02	03	04	05	06	07	08	09	10	11
Microwave Radiation	I	1	01		•		•		•					
Electromagnetic Environment														
Light														
Visible	I	2	02				•	•	•	•	•	•	•	•
Ultraviolet	I	2	03	•			•		•	•			•	•
Ionizing Radiation														
X-ray	I	3	04	•	•	•	•		•	•				
Gamma Ray	I	3	05	•	•	•								•
Beta Ray (electrons)	I	3	06	•	•	•								
Protons	I	3	07	•	•	•	•		•	•				•
Neutrons	I	3	08	•	•	•	•							
Alpha Particles	I	3	09	•	•	•	•							
Heavy Nuclei	I	3	10	•	•	•	•							
Strange Particles	I	3	11											
Magnetic Fields	II	4	12	•	•	•		•		•				
Electric Currents	II	5	13		•		•							
Thermal Environment														
Heat	II	6	14		•		•							
Cold	II	6	15		•		•							
Gravitational Environment														
Linear Acceleration														
$+G_x$	II	7	16				•	•	•	•			•	
$+G_y$	II	7	17											
$+G_z$	II	7	18				•	•	•	•	•		•	
$-G_x$	II	7	19				•							
$-G_y$	II	7	20											
$-G_z$	II	7	21				•							
Impact	II	7	22				•		•					
Rotary Acceleration														
$R_{x,y}$ tumbling	II	7	23				•		•					
R_z spin	II	7	24				•		•					
Coriolis Factors	II	7	25				•		•	•				
Subgravity	II	7	26				•		•	•				
Zero Gravity	II	7	27				•		•	•				
Oscillation														
Vibration	III	8	28		•	•	•		•	•	•	•		
Sound and Noise	III	9	29		•		•				•			

the data for each interaction area. A computer program can meet this requirement by treating the entire body of data as a three-dimensional matrix. This has already been done. The same basic approach could permit an even more complex multidimensional mathematical computation of data.

The use of a computer program to pull together all the pertinent data on a healthy adult to provide answers to each predetermined space exploration requirement represents a new approach to basic biomedical problems. The same basic matrix refined by NASA can be modified to provide a total view of all the environmental and psychological/physiological data that influence any single disease or combination of diseases. The methodological approach is now available and can be easily modified for implementation in other areas where there is a need to bring together all the pertinent data from many diverse research efforts.

Bioastronautics has brought the total systems approach into biomedicine. The use of computer programming, data storage, and mathematical manipulation of data is necessary, for no single mind could find or fully understand all the matrix intersection data relationships, even if one were to review all the original reports, papers, and so forth (assuming that one person would be conversant in all the disciplines). The use of similar computerized techniques will be essential in fully understanding the cause and possible prevention or cure of major diseases.

Colonel Hamilton B. Webb[30] of the Air Force has concluded that a similar transfer dividend from space computer requirements in biomedicine exists in the new field of "multiphasic screening." Here, automated systems can measure EKG, EEG, blood pressure, temperature, and the like, and the data can be digitized and stored for permanent record or compared with a mathematical model of what it would be in a normal healthy adult.

Dr. Webb concludes that a space dividend of vital importance to multiphasic screening is the telemetering of such data from active adults, permitting measurements that are significantly different from those obtained from an individual constrained by bulky monitoring equipment (program under way at USAF School of Aerospace Medicine). The miniaturization permits an increasing number of physiological functions to be included in a telemetering backpack of reasonable weight and size.

During the next decade the results of multiphasic testing will be automatically compared with a computer-stored environmental and psychological/physiological profile of what the measurements should be in a healthy adult of a given age. Deviations, even subtle ones, will be identified. This process will permit predictive medicine to be partly automated, and at a sufficiently low cost to be available to the general public.[5]

Huntsville Physiological Monitoring Program

The SysteMed Corporation of Newport Beach, California, has a contract to monitor NASA personnel at Huntsville while they are engaged in normal working activities. A small tape recorder is strapped on, allowing a permanent record of EKG and respiration to be maintained. These are regular employees and not individuals who would be considered in the astronaut class of physical fitness. The monitored personnel wear the tape recorder and other portions of the monitoring system for periods up to 12 hours. The Huntsville program also includes a cardiopulmonary facility for examinations to study physiological stress of people at work in the laboratory. The data are telemetered using equipment developed in the space program. The telemetered physiological data provide better information than that obtained by using hard wires. The people undergoing examination are more or less free to engage in physical activities including tests such as walking on a treadmill. Dr. B. Dwight Culver,[8] the President of SysteMed, has said that one of their preliminary conclusions is that people who are subject to responsibility appear to exhibit greater stress than those with less responsibility. He also cites the conclusions of Dr. James Roman, of Edwards Air Force Base, who is in charge of astronaut training. Dr. Roman is reported to have concluded that responsibility rather than danger produces the greatest stress, and he includes data from the X-15 flights in his analysis.

SysteMed Corporation is a spinoff group from Aerojet General and has been operating independently since April 1, 1968. A principal goal in the Huntsville program is to refine standard physiological models that will allow better measurement of stress in a working environment among normal, healthy adults--not the "exemplary" variety that would be chosen for astronaut training. Eventually, the SysteMed people hope to be able to evaluate as many as 18 separate physiological functions integrated together to show any synergistic relationships between the various functions in the working environment. When this systematic approach to the evaluation of work environment on adults is fully refined, it will permit deviations from the norm during working activities to be identified. Optimized job assignments and the prevention of undue stress leading to disease will then be possible to a far greater extent than by present techniques.

The evaluation of large amounts of physiological data taken over a period of many hours on a single person, day after day, requires the use of third generation computers by SysteMed to provide an evaluation of synergistic relationships between the major functions. The space biomedical use of the computer is again in evidence.

Dissemination of Data

Almost every biomedical specialist interviewed, who was currently active or had been active in bioastronautics, stressed the importance of finding and refining base-line data on the normal healthy adult. They all considered the subjects covered in this section to be one of the most important contributions that the space biomedicine has made from a transfer standpoint. It was of equal interest that the various specialists in hospitals and universities who have not been active in bioastronautics did not consider this as something of value coming out of the space program. For the most part, they were not aware of the vast amount of data that is already being compiled in various NASA and Air Force studies. D. L. Carpenter[7] of McDonnell-Douglas has observed that the base-line data on the healthy adult coming from space biomedical research does not yet appear to be finding its way into reference tables in human physiology textbooks and other medical references. He concludes that the basic problem is that the compilers of such textbooks are not aware of the physiological base-line data compiled in the various space programs.

Serious attention should be given to the possibility of bringing together and summarizing all the physiological data on the normal healthy adult compiled by NASA and the Air Force for space requirements. They might be summarized best in a one- or two-volume monograph presenting the data in the form most useful for medical or biological researchers engaged in a variety of nonspace investigations. Such a monograph could be prepared internally by NASA and possibly published by one of the organizations specializing in the publication of medical textbooks. The monograph might be updated on a five-year basis as information is refined and new data gathered from new studies. The existence of such a monograph could be brought to the attention of biomedical scientists through reviews in appropriate scientific journals. The sales would probably offset publication costs, so the primary funding requirements would be limited to the evaluation and summarization of data already in hand.

ITEMS OF EQUIPMENT TRANSFER

The focus of technology transfer in bioastronautics was initially centered on the primary objectives of modifying the actual hardware developed for life support, exobiology, bacterial detection, physiological monitoring, and other life science systems to meet well identified requirements in clinical medicine and related areas in the broad field of public health. After 10 years, a definite conclusion can be presented regarding the present status of technology transfer of specific equipment items into clinical acceptance and subsequent widespread use of physicians, operating independently or in clinics and hospitals. The principal conclusion that can be clearly defined at the present time is that the transfer process has been reasonably effective through the clinical testing phase, but that THERE IS A VERY SERIOUS TIME GAP OR BARRIER BETWEEN THE ACCEPTANCE OF THE CLINICAL TESTING LEVEL AND THE WIDESPREAD DISTRIBUTION OF THE SYSTEM IN THOSE SECTORS OF MEDICINE WHERE THE USER REQUIREMENTS ARE TO BE FOUND.

Some of the equipment items that have been subject to significant delays between clinical testing and widespread distribution are listed in Table 8.

Table 8

REPRESENTATIVE SAMPLE OF BIOASTRONAUTICS SYSTEMS DELAYED BETWEEN CLINICAL TESTING AND WIDESPREAD DISTRIBUTION

	Delayed Because of System Cost	Reluctance of Physicians To Accept New System
Blood Pressure Cuff		•
Electronic Stethoscope	•	•
Walking Wheelchair		•
Marsupial Biopack		•
Electronic Thermometer	•	•
EKG Monitoring Systems		•
EEG Monitoring Systems		•

A Typical Item--Blood Pressure Cuff

The AiResearch Manufacturing Company, a division of The Garrett Corporation, has been the prime contractor for the life support systems of the Mercury, Gemini, and Apollo spacecraft. One of the prime physiological measurements to be determined in the Mercury and Gemini programs was the blood pressure of the astronauts during all phases of the orbital missions. Garrett developed an automated blood pressure cuff that could measure blood pressure at any time during the flight regardless of the astronauts' physical activity at the time of measurement. This automated system was fully developed in 1961 for the Mercury program. The technology transfer history of this system is covered in the last section of this report.

The automated blood pressure measurement system functioned flawlessly on all orbital missions in which it has been used.[22] Garrett publicized the success of the system widely in full page color advertisements appearing in all the leading aerospace publications including those directed to people in the life sciences. The technology transfer potential of this system in hospital intensive care wards was obvious from the beginning. Before its first use in the Mercury program, the system had been fully tested on healthy adults in Los Angeles, and there was considerable interest seven years ago in the immediate use of such a valuable technique to automatically monitor one of the most important parameters of seriously ill patients.

The Garrett automated blood pressure system was first installed in an intensive care center in Bethesda at the National Institutes of Health in 1968. The enigma is why seven years had to be lost between the initial availability of the system and its first demonstration in an intensive care center. The answers are typical of the pattern that has prevailed in transferring relatively expensive bioastronautics systems to the needs of clinical medicine.

The automated cuff can be said to have passed its initial clinical tests in 1961. During the next four years the Garrett staff associated with the project was busily engaged in system refinement as the cuff was modified for the Gemini program. Garrett's life science activities have been characterized by a steady growth all during the 1960s. There has never been a serious backlog problem or lag that might have required serious attention to be given to some of the obvious technology transfer options well established in their bioastronautics systems, including the automated cuff. Consequently, there was no internal need to find new markets quickly for this system.

During 1961 to 1967, organizations supporting the development of advanced patient monitoring systems for intensive care wards (principally NIH) were severely pressed from a funding standpoint. There were many less expensive systems that could be procured and tested before the automated cuff would become an item on a priority list. Again we must remember the historic 10- to 15-year gap in the application of new technology to clinical requirements. Quite simply, the medical profession was in no great hurry to try this new technique. It was available almost as an off-the-shelf item, and everyone knew it would be incorporated in a suitable system at an appropriate time. Since the system was being debugged on the first two major manned space flight efforts, it could be safely assumed that the longer one waited the better the system that would be obtained for clinical use.

It should be noted that other blood pressure measuring systems relying on simpler, but previously unproven, techniques have been tried in intensive care wards in recent years. One physician mentioned that there may have been an attempt to "leapfrog" from a technological standpoint in solving the blood pressure measurement requirements for intensive care wards. Apparently this has not been entirely successful, and the automated pressure cuff, as opposed to a somewhat exotic approach such as ear lobe blood pressure measurement, is still the most accurate means of obtaining this important data on physiological changes in a seriously ill patient. Almost every case of attempting to leapfrog from a technological standpoint in medical systems is doomed to failure or uncertain acceptance. It seems better to present the physician with data obtained in a manner similar to the one to which he has been accustomed throughout his educational and working career.

The seven-year gap between clinical verification and practical use was primarily due to the fact that no one in the entire loop was in a hurry to see that the technology was fully transferred. Also, the fact that we are dealing with a fairly expensive system must be taken into consideration. Automated blood pressure measurement is not likely to save lives in the dramatic manner of automated EKG systems that can signal a nurse or physician if a heart stops or enters ventricular fibrillation (a quivering state in which no blood is pumped). Funds had to be allotted to systems with the greatest promise of emergency lifesaving value instead of those that would simply refine a measurement that could be obtained manually.

Immediate technology transfer emphasis on the automated blood cuff would have ensured universal availability in every intensive care center throughout all major hospitals in the United States. Perhaps 500 to 1,000 systems might be in daily use at the present time if this program had been

given sufficient attention, emphasis, and funding seven years ago. Unquestionably, the better information would have been a contributing factor in saving many lives. Only a small fraction of the population, far less than one percent of our seriously ill citizens, has ever been placed in an intensive care center. However, it is reasonable to assume that if a large number of automated cuffs had been in operation in the last few years, many patients would have received better treatment because of the option of automatically monitoring blood pressure at any time and in any desired sequence.

It is interesting to compare another advanced technology product line developed by Garrett which has found its way rather quickly into clinical practice. Here we are considering a series of small electric motors with very high reliability which were developed for both life science and other space systems requirements. These small motors can be literally described as off-the-shelf items of comparatively high cost but that are superior to any other systems currently available from a weight, volume, and reliability standpoint. These motors are now being incorporated in the latest kidney dialysis (artificial kidney) systems and heart-lung machines which are used to maintain artificial blood perfusion during heart-lung bypass operations. Small electric motors are used in many other systems in hospitals, clinics, and biomedical laboratories. Unquestionably, these small Garrett motors will play a small but definite role in advancing the general state of the art of biomedical systems throughout the public health sphere. Why was this technology transfer made quickly whereas the seemingly more exotic or dramatic development of the automatic cuff has been so slow?

The people at Garrett responsible for marketing the electric motors were able to explore a variety of potential markets by simply contacting internal specialists within their own organization. Physicians within Garrett knew of the need for better electric motors in kidney dialysis and heart-lung machine systems. It was not difficult to get a list of the manufacturers of such devices. A simple letter stating the availability of a component or subsystem that would enhance the overall effectiveness and reliability of a system is almost certain to bring an immediate response. While comparatively expensive, the motors were better than anything previously available, and their incorporation did not require a redesign of the complete systems. Also, it should be mentioned that kidney dialysis systems and heart-lung machines are relatively expensive. A heart-lung machine with associated instrumentation will cost somewhere between $20,000 and $30,000. A typical kidney dialysis system costs $10,000 or more. These are lifesaving machines, and anything that enhances their reliability may be considered a fairly inexpensive component compared with something that may require a back-up or redundant system as a fail-safe measure.

In summary, the electric motors were comparatively easy to market since they met a critical subsystem need. The automated cuff represents an expensive innovation that will not be fully appreciated until it is installed in a number of intensive care centers.

Digital Computer Photo Processing

The biomedical application of spacecraft image processing techniques is the only life science technology transfer item that can be described as a breakthrough. It also has a significant research application (see section on Research Techniques under "Electron Microscopy Image Enhancement") in addition to its clinical diagnostic potential.

Dr. Robert Nathan of JPL first conceived of the use of digital computers to enhance an image by means of cathode ray film scanning as a possible means of obtaining better electron microscope resolution. He was able first to refine the system to correct various photometric, geometric, and frequency response distortions in the pictures received from the Ranger, Mariner, and Surveyor lunar and planetary spacecraft. Now he has demonstrated this revolutionary technique on medical X-rays, retina photographs, chromosome analysis, heart X-ray movies, bone spectral analysis, microcirculation, and electron microscope resolution. The latter application marked the completion of the full cycle in which the technique was successfully employed in its original conceptual application. The full enhancement can be fully appreciated only by viewing unprocessed and processed medical photos. The complete history of the technology transfer steps in the system is covered in the final section of this report.

Table 9 lists the currently identified medical areas where image enhancement promises to provide better diagnostic data and research results.[3]

The biomedical image enhancement experiments began in January 1966. One of the first X-ray photographs processed was a skull X-ray in which a radio-opaque dye had been injected into the bloodstream to make the blood vessels visible. This technique is used in studying circulatory disorders and also as a means of locating brain tumors that might cause arterial displacement or constriction. Aneurysms, an often fatal swelling of arteries, can also be detected by this technique and corrective surgery performed. In some cases, very small aneurysms in the brain might not be detected without image enhancement.

Other skull X-ray enhancement included the detection of brain tumors by techniques in which air is used to displace the fluid in the ventricles of the brain. Air is a better contrast medium for X-rays than the fluid

Table 9

BIOMEDICAL AREAS THAT WILL BENEFIT FROM IMAGE ENHANCEMENT

Research Application / Clinical Diagnosis		
Skull X-rays	•	
Chest X-rays (image subtraction)	•	
Retina Photographs	•	
Chromosome Analysis	•	•
Motion Picture Heart X-ray Films	•	•
Bone X-rays	•	
Microcirculation Studies		•
Optical Microscopy	•	•
Electron Microscopy		•

and allows inspection of the ventricle shape to detect a possible tumor. Subsequent refinement may allow the tumors to be detected without air displacement, which is a painful process.

The image enhancement technique has also been used to detect lung cancer in the early stages by means of "picture subtraction." Two X-ray photos taken several months apart can be processed so that all the unchanged data, such as ribs, are removed from the final image which emphasizes any differences between the two X-rays. No two X-rays of the same person taken several months apart are going to be identical, because the rib positions would not match. However, image processing by the computer can "force a match" using a geometric distortion correction program originally developed for the Ranger TV cameras. The picture subtraction technique may be used to detect malignancies in other parts of the body.

Retina photographs showing the blood vessels and other tissue in the eye may be enhanced to identify a tumor as being malignant or benign. Enhanced retina photographs may also provide predictive diagnostic information on the numerous diseases of the circulatory system such as arteriosclerosis, nephritis, diabetes, and others that are clearly reflected in the arteries of the eye. The enhancement of optical microscope photos of chromosomes will be of value in identifying congenital abnormalities in human beings, which are frequently caused by an abnormal chromosome count or by partial chromosome abnormalities.

The image enhancement of high speed X-ray motion pictures taken of the human heart immediately after a radiopaque dye has been injected promises to convert this technique from a laboratory curiosity to a practical diagnostic tool. This new processing technique solves some of the focus problems, and computer techniques may also be used to evaluate data from the large number of frames required. Manual calculation for a single patient now requires about three weeks when the work is done by hand. Clearly, this is not an economic procedure that could be widely employed. Image enhancement and computer automatization could provide a better process that will also be within an acceptable cost range.

Bone density changes that may indicate the onset of malignancy or osteoprosis (a bone calcium loss common in old age), has also been subject to image enhancement. The study of the microcirculation using a special light and high speed motion picture camera attached to an optical microscope is now more practical, because the focus can be image-enhanced, and tissue response to light and heat variations can be determined while the experiment is being conducted. These are but a few of the many possible medical diagnostic applications of this revolutionary technique. In almost every case one might say that the application is in the very first step of the clinical transfer cycle. However, these initial transfers have been made and promise to be widely applied in the future.

JPL has been awarded a $900,000 grant from the National Institutes of Health to refine the many medical and research possibilities of computer image enhancement during the next two years. It is reasonable to expect that this level of funding support will allow the computer image enhancement to become a standard clinical procedure in the early 1970s. One advantage of this technique is that X-rays and other photos can be sent from any part of the country to the central computer facility where the image enhancement can be done.

Transfer from Unfunded Proposals

In many cases, the transfer systems may have evolved as an unfunded program. There have been many examples of new biomedical concepts originally presented as solutions to space program problems that later were offered to other agencies for terrestrial requirements.

The Space General Division of Aerojet General developed a six-legged walking machine under IR&D funds called the Lunar-Tic. The original purpose of this system was to serve as an unmanned, radio-directed instrument carrier for exploring the moon's surface.[21] The Lunar-Tic is basically a walk machine. Its further development was outlined in a proposal to

NASA that was not funded because a follow-up unmanned Surveyor program was not initiated.

The technology incorporated in the prototype was in limbo until Dr. Richard Brennaman,[6] then a technology utilization officer at NASA's Western Operation Office in Santa Monica, was informed of its existence. He immediately visualized the use of this technology as a wheelless wheelchair for crippled children, since it could navigate uneven, rocky terrain, and go up steps. Through Dr. Brennaman's efforts, a $50,000 grant was obtained from the Children's Bureau of HEW to refine the technology for the child amputee project at UCLA. Space General received a subcontract from UCLA to build an eight-legged version of their Lunar-Tic. The eight-legged system performed according to expectation, was able to navigate terrain that would stop an ordinary wheelchair, and could even climb a flight of stairs. A crippled child can control it by manipulating an upright stick that could also be modified with a chin cup to serve quadriplegic children who cannot move either their arms or legs. The principal investigator at UCLA, Dr. Charles Bechtol, and the associate investigator, Dr. Mary L. Brennaman, are working with Space General on a proposal to develop a more advanced version of the prototype system.

The important technology transfer consideration here is that the necessary work to complete the initial clinical transfer was permitted by the HEW grant. Without this funding money support, the space technology incorporated in the Lunar-Tic would never have been transferred. Some type of funding support is necessary when a fairly significant equipment modification is required, as was the case in the walking wheelchair.

A similar example can be found in a marsupial maintenance system developed by the Marquardt Corporation. Dale L. Carpenter[7] originally was interested in the problem of determining the effects of prolonged weightlessness on dividing cells in a complete mammal. He concluded that fetal opossums would be the most promising subjects, since they leave the womb and enter the pouch while still in the embryonic stage. Some $50,000 of IR&D funds were expended to refine the technique for removing the embryonic and fetal opossums from the nipple in the mother's pouch and placing them on an artificial nipple in a biopack that would sustain all life functions and provide proper nourishment.

Proposals were sent to both NASA and the Air Force for funds to refine the marsupial biopack for space applications. Great interest was shown, but, as with the Lunar-Tic, there was no suitable program in which to incorporate the marsupial biopack. The Marquardt team then submitted a proposal to a Child Health and Human Development Institute of NIH to use the marsupial biopack technology as a tool in studying the effects

of drugs on developing embryos and fetuses. This proposal was prepared at the time when considerable attention was being given to the limb bud malformations that resulted from the European drug thalidomide. Marquardt received a $50,000 contract from NIH to refine the system further for drug analysis, and a number of drugs were tested during the program including such common household items as aspirin.

North American later purchased from Marquardt the equipment and proprietary patents required in the marsupial biopack, and the system is being further refined at that organization.

The Early Transfer of Skin Electrodes

Monitoring the effects of weightlessness and other unique environmental aspects of manned space flights has caused substantial improvements to be made in electrodes used to measure heart and brain function. In contrast to more complex and expensive bioastronautics systems, the transfer of almost every one of these electrode advances has been comparatively swift. Table 10 lists some of these electrodes and their present transfer status.

Table 10

PRESENT TRANSFER STATUS OF SKIN ELECTRODES

	Still in Clinical Testing Stage	Commercial Availability	Widespread Application
Mercury-type EKG Electrodes			•
Gemini-type EKG Electrodes		•	
Apollo-type EKG Electrodes		•	
Spray-on EKG Electrodes	•		
Sponge-type EEG Helmet Electrodes	•		

During the early phases of the Mercury program, it was decided to use fluid-filled EKG electrodes in which a conductive paste provides the actual skin contact.[31] A silastic housing that contained a stainless steel screen (which was in contact with the conducting paste) was developed. Fabrication problems were uncovered during the Mercury program, and the system was modified for the Gemini program.

The Gemini electrodes had a silver disc with small holes in place of the stainless steel screen.[9] Additional improvements have been made in the Apollo electrodes that make them very easy to apply to the skin.[27]

There has been significant improvement in electrode paste as a result of manned space requirements. The electrode paste used nine years ago could not be tolerated comfortably on the skin for periods over 24 hours; subsequent improvements in the paste composition now allow continuous skin electrode contact for periods to one week.

The various electrode improvements, nonirritating electrode paste, and related attachment techniques were all used in clinical practice shortly after they were developed for space applications. The advanced electrodes can be obtained from several manufacturers. Dr. John H. Aldes,[2] who is in charge of the Intensive Care Center at Cedars of Lebanon Hospital in Los Angeles, states that . . ."Mercury-type electrodes were a great advance, and all the electrodes we now use for critically ill patients are of this type." During the survey, I saw Gemini-type electrodes being used by Dr. Rex MacAlpin at the UCLA Medical Center, which also serves as the hospital for the UCLA Medical School. I have been told that Apollo-type electrodes are being manufactured for clinical requirements and are also being used in medical research.

The electrode improvements for our three manned NASA programs did not add measurably to the cost of similar components for medical requirements. It was a simple matter to manufacture them at an acceptable cost. The fact that they provide much better performance for long term usage ensured their purchase.

Electrodes are relatively inexpensive and are definitely in a different category than a system that might cost hundreds or thousands of dollars. Overall budget tradeoff considerations are not entailed in their purchase; and here again, high quality components can be transferred relatively quickly.

Another electrode innovation has resulted from NASA'a activities in aeronautics. At NASA Flight Research Center at Edwards, California, there was a need for applying electrocardiogram electrodes quickly to pilots just before their training flights. Besides reliability, the electrode requirements were that they should not interfere with the movement or comfort of the pilot. The solution was the result of the cooperative efforts of NASA Edwards and Spacelabs, Inc., in Van Nuys, California. In 1965, a unique spray-on electrode was developed for the requirements in which electrically conductive cement, including silver powder and acetone, is sprayed on the skin by a spray gun or aerosol process (see NASA

Tech Brief 66-10649). The sprayed-on paste covers the electrode wires leaving them firmly in contact with the skin. The subject cannot feel the spray-on electrodes, and they are resistant to normal motion. Frequent application does not cause skin irritation, and there is no need to shave the skin area before electrode application. A spray-on electrode can be attached in less than half a minute.[25]

The NASA Office of Technology Utilization Biomedical Application Team (BAT) at the Midwest Research Institute in Kansas City has transferred the spray-on electrode technique at the University of Kansas Medical Center. There, spray-on electrodes have been applied successfully for recording heart action in more than 1,000 children during exercise.

The fact that one of NASA's three BAT teams was able to direct its attention to the spray-on electrode is partly responsible for its rapid transfer. The success of the transfer can be credited to the amount of attention that NASA has given to this innovation. It is doubtful that the transfer would have taken place in such a short period of time without the BAT teams' direct efforts and other support given to transfer requirements.

Dr. W. Ross Adey,[1] Professor of Anatomy and Physiology and Director of the Space Biology Laboratory at the Brain Research Institute at UCLA has been the principal figure in the refinement of a novel electroencephalogram (EEG) system. Soviet scientists originally conceived the idea of placing sponge-type EEG electrodes in an astronaut's helmet so that the electrode contact could be made simply by putting the helmet on without any special scalp attachment or removal of any of the subject's hair. Dr. Adey was aware of the Soviet concept and developed a similar sponge-type electrode system mounted in a covering similar to a bathing cap or light helmet. The only preparation required for putting the electrodes on is to remove the oil from the skin and hair surface. Dr. Adey and his colleagues have devised several variations of the helmet sponge EEG electrode system.

A group at NASA Ames research center developed a similar system in which the sponge electrodes are also joined by an EEG telemetry system that is completely mounted in a flight helmet.[20] The Ames system has been extensively tested in jet aircraft flights and on centrifuge runs.

Dr. Adey was able to make an immediate transfer of his sponge electrode cap, or helmet, at the UCLA Brain Research Institute. The system has been used with schizophrenic children and has also been useful in obtaining new data on the state of the brain during sleepwalking. There was no technology transfer problem, because a person concerned with space

programs, Dr. Adey, also was responsible for nonspace neurological research and was able to use the same system for both purposes. One might say that the clinical transfer of the sponge EEG electrode helmet system has been made, but there may be a further time gap between its initial clinical use and its widespread availability in other neurological centers where it can be effectively used.

The sponge EEG helmet system is unique in that it might be considered an indirect technology transfer benefit from the Soviet space program. One cannot refrain from speculating on what their technology transfer experience from space exploration has been to date.

Transfer of Capability

For organizations that serve both the space markets and commercial biomedical requirements, there can be a transfer of the technical capabilities derived from the development and production of bioastronautics systems as opposed to transferring the systems themselves. James A. Reeves,[24] President of Spacelabs Inc. in Van Nuys, California, observed that his company has been able to develop a series of patient monitoring systems for use in surgery and intensive care wards. The basic capability to develop these systems was originally brought together to meet similar requirements in the Mercury and Gemini programs. This capability has allowed Spacelabs to develop a series of systems for monitoring EEG, blood pressure, and cardiac output, along with four different oscilloscope systems that allow remote monitoring of several patients at once. Mr. Reeves stressed that the transfer was completely indirect and that Spacelabs has not been able to use any of the same subsystems or circuit boards that were developed for the Mercury and Gemini programs.

The previously mentioned SIM One program in which Aerojet transferred simulation capabilities is another example of what can be done when a capability developed for space requirements is subsequently directed to biomedical goals. Electro Optical Systems, Inc., in Pasadena, California, is developing several very advanced systems for performing automatic laboratory tests on blood and urine. The team that originally conceived the unique (still proprietary) automatic testing techniques was brought together to work on space life science programs. When bioastronautics funding began to drop off, the life scientists turned to nonspace clinical requirements to permit their group to survive.

The Electro Optical experience is unique, because it is a wholly owned subsidiary of Xerox which has had almost unprecedented growth and profits in recent years. Consequently, there was an abundance of internal investment funds available for the automated blood and urine testing development

program. This internal funding option has not been available to most bioastronautics departments in conventional aerospace companies that are primarily dependent on government contracts--principally DOD, NASA, and AEC.

Without question, there could have been many clever systems developed to meet biomedical requirements if substantial government R&D funding had been available to fill the gap when space budgets began to decline in the past two years. This was not the case, and most of the bioastronautics groups have declined in size. There is probably less latent transfer capability today than there was two years ago.

Miscellaneous--Direct Systems Transfer

Transfer barriers are fewer (with the possible exception of cost) when a system can be directly utilized without significant modifications. Consolidated Systems Corporation of Pomona, California, developed a miniaturized mass spectrometer for the NASA Flight Research Center in 1956.[26] A compact 28-pound system can monitor all cockpit and expelled breath gases of a pilot or astronaut with a high degree of accuracy. A commercial version of this small mass spectrometer is now available. It may find clinical applications in anesthesiology, and there would be potential applications outside the biomedical areas.

Laminar airflow techniques developed for space sterilization requirements have been transferred to biomedical requirements. NASA further refined the control of air movement in laminar undirectional downflow, originally an AEC development, to the point where containment can be reduced to one organism (of 3-micron size) per 100 cubic feet of air. The American Sterilizer Corporation of Erie, Pennsylvania, manufactures laminar downflow equipment for pharmaceutical and clinical requirements.

Laminar downflow has been used in hospital operating rooms where it can reduce capital and other costs. Laminar downflow has also been used to maintain zero infection rates in the treatment of severely burned patients. The same technology is permitting the pharmaceutical industry to protect processed material from contamination. Laminar downflow may be used in food processing.

A very large, glass-filament wound, solid rocket case developed by Hercules as an example of how large such a case could be built has found an unexpected application as a surgical room. Hyperbaric chambers are pressure environments in which, at 45 psi, enough oxygen is dissolved in the blood plasma to bypass the red blood cells saturating the body with oxygen. These chambers are used in surgery and in the treatment of many diseases.

Conventional hyperbaric chambers are made of relatively thick steel because of the high pressure. There was a requirement for a hyperbaric chamber to be placed in an upper floor of a hospital. A steel chamber would have required expensive reinforcing of the building. Hercules donated the large, lightweight rocket case which had sufficient interior volume for the medical requirements and was light enough that no reinforcing of the building was necessary. This application of rocket case technology may lead to mobile hyperbaric chambers on ground vehicles or possibly in aircraft.

James A. Benson[4] of the Rocketdyne Division of North American unexpectedly discovered that dense forms of graphite are tolerated surprisingly well by the body as implants. This was a serendipitous discovery from rocket nozzle research when a small fragment of graphite was imbedded in skin (details are covered in a case history in the final section). It now appears that the forms of dense graphite developed for high temperature space propulsion requirements may be used as bone and joint replacements. Graphite does not corrode in the body in the same way as do most metals used for internal prosthetics. Graphite may be particularly suitable as the ball in artificial heart valves; it is light and can be the same density as the body tissues.

Sterilization for planetary quarantine is a comparatively recent space requirement, and the full technology transfer potential will not be realized until the Voyager program, or its equivalent, has been fully developed through initial operational flights. The transfer success of the laminar downflow technology may be due to the fact that it was developed for AEC requirements before NASA's intensive concentration on sterilization, permitting time to influence the situation favorably.

George G. Edwards of the NASA Ames Research Center delivered a lecture at the University of California on December 2, 1967, in which he described the incorporation of tiny thermocouples into cryoknives. A quartz-insulated, metallically-sheathed thermocouple with an outside diameter of six-thousandths of an inch was developed for a plasma probe. These tiny thermocouples were subsequently incorporated in the slender probes of cryoknives. In cryosurgery, tissue is destroyed by lowering the temperature of the uninsulated tips of a thin probe, causing tissue to freeze and be destroyed. The thermocouple permits the surgeon to know the tip temperature and have a far better control over the rate of freezing.

The cryoknife thermocouple is another example of a small component that can be easily added to an existing system. Components can be transferred easily, and the most important requirement is to make the existence of the component known to potential users.

Conclusions

This section analyzes a representative sample of items that have been transferred to clinical biomedical requirements from the space program. Transfer to biomedical research requirements is covered in the next section. The most important factor is the relative cost of the system. A component such as an electrode can be transferred without an appreciable lapse of time. A relatively expensive system may face a basic cost barrier that will prevent early transfer unless some supplementary funding is made available to complete the transfer. For many expensive systems, widespread application will also depend on government funding to partly offset the purchase of the equipment itself.

The transfer of capability, rather than components or systems, has been demonstrated in some organizations, but its full potentiall will not be realized until more government R&D funds are available to develop advanced biomedical systems.

RESEARCH TECHNIQUES

Space exploration is the most ambitious undertaking, from a technical complexity standpoint, that man has yet attempted. The successful research planning, program definition, systems development, and operational phases of the space program in the past ten years have also permitted the interdisciplinarian scientific team approach to be greatly refined. As long as these teams are kept together, they can frequently serve as research problem-solving task forces for many difficult technological goals outside the space R&D. The transfer of research techniques by directing the attention of these teams to nonspace objectives may prove to be more important than the transfer of the specific hardware items described in the previous section.

Many components, subsystems, and systems developed for some space objectives have found unexpected applications in life science research. One must keep in mind that total life science R&D funding has been only about 12 percent of that allocated to the physical sciences. As a result, much of the instrumentation used in life science research is modified from equipment originally developed to meet research needs in the physical sciences. There have been many serendipitous and deliberate transfers to meet a variety of biomedical research needs.

Table 11 lists representative equipment items or research capabilities that have been transferred to biomedical research outside the space program. They are diverse, and not all of them are the result of bioastronautics requirements. In fact, over half are research transfers from space technology that has nothing to do with life science requirements.

Artificial Organs Transfer Experience

Artificial organs would seem to be far removed from space exploration. However, NASA has supported research that has contributed directly to the refinement of the artificial heart. The history of aerospace involvement with artificial organ development is given in some detail, because it is representative of both equipment and scientific skills transfer of research techniques.

Table 11

REPRESENTATIVE SAMPLE OF ITEMS OR RESEARCH CAPABILITIES THAT HAVE BEEN TRANSFERRED FROM THE SPACE PROGRAM TO OUTSIDE LIFE SCIENCE RESEARCH REQUIREMENTS

	Deliberate Transfer	Serendipity Transfer
SIM One Simulation Mannequin	•	•
Marsupial Biopack		•
Electron Microscopy Image Enhancement		•
Automated Light Microscope		•
Hyperbaric Chamber Technology for Both Oceanology and Clinical Research	•	•
Ethylene Oxide Sterilization		•
Improved Bacterial Detection Cultures		•
New Experimental Animals	•	
Pure Oxygen Physiological Effects	•	
Computer Biomedical Research Techniques	•	•
Anabolone Metabolic Inhibitor	•	•

In 1962 and 1963, OART funded "The Cyborg Study" in two phases at the United Aircraft Corporation Systems Center in Windsor Locks, Connecticut.[10] The term cyborg, a contraction of cybernetics and organism, implies that man's capabilities in an alien environment might be extended through artificial organs, drugs, and reduced metabolism. Many bioastronautics experts regarded the cyborg study, under the supervision of Robert W. Driscoll, as the most exotic of the life science studies that NASA has supported to date.

An experimental artificial heart device was part of the cyborg program, which included a study of the engineering aspects of flow turbulence and pressure characteristics of the heart pumps and valve assembly. A mathematical model of the human cardiovascular system that has research applications to artificial organ development was included in the work. Richard T. Allen, who was associated with the study, stated that the results have been made available to scientists working on the development of the artificial heart.

Dr. Willem J. Kolff[17] has recently joined the faculty of the University of Utah Medical School in Salt Lake City. Dr. Kolff invented the

artificial kidney in his native Holland in 1944. For many years he was in charge of artificial organ development at the Cleveland Clinic in Cleveland, Ohio, and he has been a leader in the development of the artificial heart during the past 11 years. Dr. Kolff told me that the cyborg study provided useful research transfer data for his efforts. He has received direct assistance from NASA scientists that has had a great impact on his program. Electrically driven pumps used in Dr. Kolff's early artificial hearts were unsatisfactory and caused the formation of blood clots that killed the experimental animals.

Engineers at NASA Lewis suggested that air powered pumps might produce a closer simulation of natural heart action. The result was a production pump of low weight, high reliability, and low heat that was suitable to artificial circulation. The air driven heart depends on pulsating air pressure generated outside the body and brought through the chest wall by small flexible tubings. The NASA engineers were able to use a servomechanism originally developed for rocketry to meet the artificial heart adjustment requirements.

In an article, Dr. Kolff wrote: "Kirby Hiller and his associates at the Lewis Research Center built us a sophisticated driving mechanism for the artificial heart that makes it possible to simulate the pumping pattern of a natural heart. The machine writes an electrical function in the form of a wave and this wave form is then translated into a cycle of air pressure that has the same form. . . The magnificent equipment built for us by the NASA laboratory and other collaborating groups has enabled us to carry on an intensive study of the physiological factors and requirements for an artificial heart. A calf with an artificial heart implanted in its chest has survived as long as 33 hours and 30 minutes. The mechanical pump maintained the calf's blood circulation at a normal level and caused no formation of clots."[16]

The research phases of artificial heart development have benefited by technology transfer from rocketry. The goal of an implantable artificial heart is much closer, because the NASA personnel were allowed to work with the Cleveland Clinic. Dr. Kolff also mentioned "other collaborative groups." J. Lewis Reynolds of the Marquardt Corporation in Van Nuys, California, assisted Dr. Kolff, and Marquardt's Bioastronautics Department supplied components for Kolff's research program. Other aerospace corporations have assisted Dr. Kolff and others engaged in artificial organ research. Much of this effort was performed sub rosa or on a bootlegged basis.

It is not surprising that space scientists should be interested in artificial organ development. They are accustomed to working on projects

that were considered impossible a few years ago and are challenged when presented with the technical problems of another new exotic impossibility such as a reliable artificial heart. More important, space scientists are accustomed to working in interdisciplinarian teams that are able to evaluate the entire system, as well as come up with entirely new means of duplicating a function.

Aerospace organizations have also contributed to the refinement of heart-lung machines used to replace the heart temporarily during surgery. In 1961, the Marquardt Corporation constructed a heart-lung machine and accompanying hypothermia unit for the Department of Thoracic Surgery at the UCLA Medical Center under the direction of Dr. James V. Maloney, Jr. The system incorporated aerospace fail-safe design principles and contained a number of other innovations. The equipment was donated by Marquardt to the UCLA Medical Center, and the company also sent copies of blueprints and other design details to many other organizations interested in constructing similar systems.

I was associated with the Marquardt heart-lung machine and hypothermia unit development and can testify that it was a clear example of the transfer of space research capability to a new medical requirement. Marquardt's bioastronautics department had been formed to work on space life science; the other engineering skills that were brought into the effort were primarily space oriented. The equipment at UCLA has functioned without failure through thousands of human operations and experimental procedures carried out on dogs. It has influenced the design of other heart-lung machines that are now used at other medical centers.

In 1965, the National Heart Institute at NIH instituted a major program to "develop an implantable heart with a ten-year reliability within the next ten years." While the program was under way, NIH gave a number of study contracts to aerospace companies. The program was cut back severely in 1967, and the present level of artificial heart funding is about the same as it was before the program was started. Circulatory assist devices and a better understanding of the effects of blood on materials are now stressed as primary research objectives.

In 1965 and 1966, a series of six major studies explored various parameters of the feasibility of developing a ten-year reliability artificial heart by 1975. The organizations that performed these studies are listed in Table 12. Four of these six organizations are primarily aerospace organizations; one of the others, SRI, has had a close association with the space program. As a result of these studies, it was concluded that the original ten-year crash program was unrealistic, and the program was redefined along more modest goals.

Table 12

ORGANIZATIONS THAT CONDUCTED STUDIES EVALUATING
NEAR TERM FEASIBILITY OF THE ARTIFICIAL HEART

Organization Is Primarily a Space Contractor		
Bioastronautics Group Performed the Actual Work on Heart Program		
Hamilton Standards Division of United Aircraft, Farmington, Conn.	•	•
Stanford Research Institute, Menlo Park, Calif.		
Thermo Electron Corporation, Waltham, Mass.	•	•
Westinghouse Corporation, Pittsburgh, Pa.		
AiResearch Laboratory, AVCO, Everett, Mass.	•	
Convair Division of General Dynamics, San Diego, Calif.	•	•

There was a direct transfer of space research skills in those artificial heart investigations. Dr. William A. Shafer, the program director of the artificial heart investigation at the Convair Division of General Dynamics, stated that ". . . Our artificial heart program relied on personnel who have been working on space programs."[12] The Convair group had been part of General Dynamics Astronautics before it was merged into the Convair Division.

Table 12 clearly shows that space life science organizations provided the basic research capability that allowed a thorough evaluation of the feasibility of the artificial heart program to be made. Bioastronautics groups performed four of the six major studies. Both SRI and Westinghouse have had a close relationship with the space program, although neither is primarily engaged in space R&D and related production.

Some of the social and moral dilemmas raised by heart transplantation may cause an accelerated artificial heart program to be revived when the present governmental fiscal pressures on R&D funding are eased. Aerospace organizations could again provide the technology transfer of interdisciplinarian research capability to meet the total program requirements. Miniaturization and systems reliability would be likely areas of space research transfer to artificial requirements.

Other aerospace companies have worked on artificial organs. North American Rockwell has developed an artificial kidney in its Aerospace and Systems group. It has also developed a compressed air valving mechanism for a partial heart replacement system used on human patients by Houston's Dr. Michael De Bakey. Dr. Toby Freedman[11] of North American states that the research capability developed for bioastronautics enabled the company to undertake the artificial organ work successfully. Almost all the aerospace companies with large life science departments have investigated artificial organs as a possible diversification objective. Many of them have sponsored small proprietary programs that have a direct relationship to artificial organ requirements.

Electron Microscopy Image Enhancement

The promising medical applications of computer enhancement of images were reviewed in the previous section. Electron microscopy was only briefly mentioned, because it is a research capability transfer and the one that promises to make the most important contribution to overall biomedical scientific progress.

Our present electron microscopes can at best resolve images down to a range of 5 to 8 Ångstroms. If the resolution could be improved to one Ångstrom, individual atoms in organic molecules would be visible. Such a resolution would permit a "direct readout" of the structure of the complex molecules that make up living organisms.[14]

Computer image enhancement was originally conceived in the late 1950s by Dr. Robert Nathan[23] of the Space Science Division of JPL as a means of improving electron microscope images. The technique was subsequently developed to meet the requirements of Ranger, Mariner, and Surveyor photo processing. During the past two years, Dr. Nathan's group has been directed to biomedical applications with a clinical and research potential.

Dr. Nathan has refined the requirements that would allow image enhancement to improve the operation of electron microscopy by an order of magnitude permitting a one-Ångstrom resolution. To obtain this goal, the present image processing techniques must be applied and also combined with a new principle, synthetic lens aperture formation. With this later method, a series of photographs will have to be taken wherein the existing electron lens must be tilted relative to the normal optical axis to give rise to "dark field" images. The application of a relatively complicated mathematical treatment to these images permits them to be recombined in such a manner as to simulate a single large lens that is necessary for the increased resolution.

The combination of techniques entailed in electron microscopy-image enhancement has gone through proof-of-principle experiments using simple organic compounds. Many technical requirements must be satisfied before the technique is perfected. The entire process will probably require complete automation under direct computer control to permit the necessary steps to be carried out in a shorter period of time than human dexterity would permit.

Organic compounds studied in contemporary electron microscopy are low in contrast. Details are seen by shadowing or immersing the specimen with a heavy metal such as platinum or tungsten. This method provides only superficial details. The image enhancement using synthetic lens apertures should permit images to be obtained from the original organic materials without heavy metal shadowing. One-Ångstrom resolution images of unstained biological molecules will permit us to see the individual atomic arrangements in the compounds--hence, a direct readout capability that would enable us to know the precise structure of every molecule in an organism. The new field of molecular biology would have the requisite instrumentation to permit it to become an exact science.

The potential contribution of electron microscopy image enhancement promises to place it in the true research breakthrough category. Dr. Nathan observes: "the process was originally a singular application to a specific need. . . . As I see it now, the technique offers endless possibilities which we feel compelled to explore. . . . Seeing the atom should open the door to the structure of DNA--the molecule of life. The exciting possibility is that we may soon see the atom by using those ideas which helped us to see the Moon and Mars." This research transfer would have an impact on every branch of biomedical research. A complete understanding of the structure of DNA and related molecules may provide the key to a full understanding of the causes of, and possible cures for, all forms of malignancy.

The electron microscopy effort has the highest priority among the items to be explored in the $900,000 NIH two-year program scheduled to begin in the summer of 1968. The program also will include optical microscopy. The JPL group has already begun to automate the light microscope. The positioning of the slide, adjustment of the light, and focusing are to be placed under computer control while the magnified image is being examined by a television camera whose output is fed into the computer. This should prove to be important from a research transfer standpoint and will be useful in both the physical and biological sciences.

Dr. Nathan's group plans to use automated light microscopy for research on chromosome analysis and to reconstruct a three-dimensional model

of the neural network of the brain of a fly, which should be useful in pattern recognition and artificial intelligence research. The techniques may also permit a complete understanding of blood circulation at the cellular level. Many other light microscopy applications can be envisioned.

Other Research Transfer Experiences

There are many small research applications that may not all be in the breakthrough class but that collectively amount to a significant advance in biomedical laboratory state of the art. Alexander S. Irons[13] of JPL points out that ethylene oxide developed for spacecraft sterilization has been used in sterilizing plastics that cannot be heat sterilized.[15] This technique may also find widespread applications in hospitals where many items of plastic must be discarded after one use. Mr. Irons also believes that the sterilization requirements, which cause more sophisticated bacterial detection systems to be developed, will have an important research impact. New means to culture and, thereby, identify bacteria are among the technologies benefiting from the sterilization program. These will be useful in many disease research programs and may find applications in clinical diagnosis.

Dr. Robert G. Lindberg[19] of the Northrop Corporate Laboratories has investigated the pocket mouse as a possible subject for an orbital biosatellite.[18] Pocket mice require no water; they obtain all their water by reabsorption from feces and urine. This animal is now being used in nonspace research including radiation and hibernation studies.

Other Northrop scientists have found that equipment developed for space research can be adopted for other requirements without significant modification. Small acceleration sleds have been used to examine safety parameters in an automobile safety program. Guinea pigs and rhesus monkeys were used on the sleds.

Northrop spacecraft simulation chambers have been used for oceanographic requirements. Northrop is responsible for analyzing physiological data from the Navy's Sealab II program in which aquanauts remained at a 200-foot depth in a high pressure helium-oxygen atmosphere for periods to one month. The Northrop space simulation chambers are just as suitable for the simulation of high pressure ocean depths as they are for the subnormal pressures of a spacecraft environment. Almost every major space facility (in governmental labs and in industry) has comparable chambers that could be used in either space or oceanographic research.

The pressure chambers can also be used in medical hyperbaric research in which larger than normal amounts of oxygen are dissolved in the blood plasma, bypassing the hemoglobin in the blood cells. The effects of high pressure oxygen could be studied in association with many disease processes.

Space research on various artificial atmosphere gas mixtures has uncovered data useful in disease research. Subjects maintained in pure oxygen at ordinary sea-level pressure for several weeks developed symptoms similar to emphysema. This is the closest that science has come to artificially inducing emphysema in the laboratory. The research transfer to pulmonary diseases may be significant.

It has also been discovered that a pure oxygen atmosphere often causes blindness in rabbits. This has been a useful research transfer to scientists investigating the growth of fibrous tissue behind the lens of the eyes (resulting in blindness) of premature babies who have been placed in a high oxygen environment.

The effects of radiation have been a major space exploration area of concern. There has been research in many laboratories that is equally applicable to many AEC research requirements. Northrop scientists have found discernible changes in monkey urine after high radiation exposure, which may be of value in cancer therapy research. Since charged radiation particles are of primary concern in space, high magnetic fields have been proposed for lightweight radiation shielding of astronauts during planetary missions. Studies on the biological effects of high magnetic fields could lead to many research applications in other biomedical fields, since the field of biomagnetics is in its infancy.

Vernon Rogallo of NASA Ames Research Center developed an extremely sensitive device to detect the impact of micrometeoroids hitting a spacecraft in orbit or on an escape trajectory. The sensing elements are piezoelectric beams attached to a flat plate target. The instrument is so sensitive that it can detect the impact of one-thousandth of a gram of sodium chloride falling three-eighths of an inch.

Biologists had traditionally measured the heartbeat of chicken embryos by passing electrodes through the shell into the embryo or by breaking a window through the shell to permit the beat to be seen. Rogallo's instrument was so sensitive that it could measure the small movement caused by the chick embryo heartbeat when the sensor's target was replaced with a small egg basket. The total egg movement produced a very good ballistocardiogram on the cathode display tube.

Vernon Rogallo's device has also been modified to detect the tiny muscle tremors associated with the onset of Parkinson's disease. The chicken embryo application is a good example of instrumentation transfer from space physical sciences to biomedical research, and it should have many applications.

Miniaturization is providing many space transfer options to biomedical research. Another Ames development, an ultraminiature manometer-tipped cardiac catheter (see NASA Tech Brief 67-10669), was a research transfer from a highly accurate miniaturized instrument for measurements in wind tunnels. This device has been implanted in a chamber of a living human heart, providing better pressure data than could be obtained through older measurement techniques. An accurate measurement of heart chamber pressure is important in research on cardiac disease and in artificial heart development.

The use of the computer in handling large amounts of physiological data is an important research transfer that cannot be as easily identified as a specific sensor that may find a new research application with little or no modification.[29] Almost every research scientist interviewed in the study mentioned computer techniques as being one of the major contributions that the space program has made to biomedical research. The past ten years of space exploration have coincided with intensive development and application of high speed digital computers for all research applications. NASA requirements have made an important contribution. It is questionable whether comparable progress would have been made without the space program.

Dr. Adey at the UCLA Brain Research Institute has stated that computer processing procedures for EEG recording, refined for space requirements, have proven to be useful in other ongoing brain research at the institute. He also cites the use of telemetering systems, developed for space requirements, that, when used in connection with the sponge-type electrode helmet, (described in the previous section), are providing usetul research data on active patients subject to schizophrenia, sleepwalking, and so forth. These EEG data are computer processed.

In some cases, NASA-sponsored research promises to provide research transfer when all the future research steps in the program are completed. NASA has supported an imaginative program in reduced metabolism with a primary objective of permitting astronauts to enter a state of human hibernation during manned planetary exploration missions.

Dr. Henry Swan of the Research Institute for Biological Studies in Denver has completed the first phase of a NASA program that may have

widespread applications in research and clinical treatment.[28] Dr. Swan was able to extract a substance from the brains of African lungfish that, when injected into rats, caused them to enter a partial state of hibernation with a metabolic drop of 30 to 40 percent. Dr. Swan has named this extract anabolone, and it should be useful in research on cancer, shock, fatigue, sleep, and the aging process.

Research Transfer Summary

This section has presented a representative sample of research techniques that are being transferred from diverse space requirements to meet the needs of medical investigation outside of astronautics. One of the most important avenues of research transfer cannot be easily measured--the astronautics R&D skills that scientists are taking with them as they go from a space organization to an outside biomedical research position. Unfortunately, much of the research transfer at the present time may be due to this process, since space budget cuts are causing a higher turnover than would be the normal pattern of attrition in a stable or growing field.

The transfer of interdisciplinarian team capabilities will continue as more ambitious medical research programs are selected for major funding support. Unmanned and manned planetary surface exploration will cause many new instruments to be developed that will be useful in outside biomedical research. The use of the computer to monitor and control space research is leading to a partial automation of many biomedical research functions.

The diversity of research transfers illustrates the fundamental unity of all scientific investigation. Well supported space exploration should continue to provide a cornucopia of research transfers to all branches of biomedical investigation because (1) space exploration covers almost all the physical and biological sciences and (2) advanced space missions press the existing state of the art through every technological interface. New instruments and research methodology must be constantly devised. Space economic tradeoffs cause miniaturized instrumentation systems to be developed that could not be easily justified for other requirements. The ingenuity of space scientists has been most impressive and can be expected to continue to provide unique solutions to a host of biomedical research problems in many disciplines.

ADAPTION PROBLEMS AND SOME POSSIBLE SOLUTIONS

The previous sections have detailed the time (frequently several years) that has elapsed from the initial availability of a specific item with life science technology transfer potential, its initial clinical testing, and the rather long time period elapsing before it enters standard clinical practice. In most cases, these items have not been produced in quantity and can only be identified as existing transfer items inasmuch as they have passed all the initial clinical testing and can be expected to be used on a limited basis or in widespread application during the years ahead.

It can be positively stated that space life science has, in fact, broken the historic 10- to 15-year technology gap or cycle that has prevailed in the adoption of new methods and proven technology in clinics and hospitals and by physicians operating independently. However, for the full impact of the space program to be accepted by the general public, it will be necessary to reduce this time lag further so that basic physiological data, specific hardware items, and the other advances in the biomedical state of the art stemming from bioastronautics research will be dispersed more rapidly throughout the research establishment and employed in clinical practice. Furthermore, there is a well recognized crisis pending in the broad field of public health. Medicare has aggravated the overcrowded conditions in our hospitals today. The public is demanding better medical attention. It is impossible to train nurses, physicians, and technicians in a reduced period of time. In fact, the greater body of knowledge that they must now absorb may actually extend the period of education, which is already extremely intensive.

We must turn to advanced technology to satisfy the requirements that are coming up in the field of public health and clinical practice. It is the only way in which the decreasing ratios of physicians, nurses, and technicians to the population are able to provide even the existing standard of medical diagnosis, treatment, and related services. There will be fewer of these highly skilled individuals per capita in the future. They must rely increasingly on new means of making their time and skills more effective and selective. There is no challenge or promise throughout the spectrum of space technology transfer options greater than this pressing need. If it can be satisfactorily solved, then we will have an understanding of the transfer process that should allow us to vastly accelerate the

true rate of progress in our society. We would be able to obtain an optimum benefit from our increasing R&D investment in fields outside astronautics (current total of $25 billion per year).

Clinical data available on the healthy adult have been widely published in reports, papers, and appropriate scientific journals. The names of scientists who would have additional data not yet published are sufficiently well known that they can be easily contacted by other research investigators. The principal barrier to the more widespread application of this information is the fact that it is widely dispersed throughout many reference sources and has not yet been brought together in a single document that could serve as a standard library reference source also available for purchase by the physician or research specialist.

There is enough information at the present time to warrant the preparation of a detailed monograph on the subject that might be published as a two- or possibly a three-volume set. NASA has the internal capability of producing such a monograph. Alternatively, an appropriate outside group of scientists in a university, hospital, or specialized bioastronautics organization such as the Lovelace Clinic might be selected by grant or contract for the commission of such a monograph. Several scientists with whom the author has discussed this subject in depth have suggested that this would be not only an extremely useful program but that it would bring the benefits of past bioastronautics programs to the attention of many scientists throughout the biological fields who are prone to constantly criticize the space program because their own fields of specialty have been neglected from a funding standpoint for the past ten years.

The internal or external costs of preparing a monograph that provides the known clinical data on the healthy astronaut or astronaut substitute would probably fall in the $25,000 to $50,000 range. These exclude the actual publication costs that are traditionally high for medical books. The publication costs would be more than offset by the actual sale of the volume or volumes to libraries, medical schools, research libraries, and individuals. Ideally, such a monograph would be updated every five years and would logically become the standard compendium of physiological parameters on the adult who is in excellent physical condition and is not suffering from pathological processes. The author strongly recommends the consideration of the preparation of such a document when NASA life science funding permits this level of effort. Perhaps another agency such as NIH might sponsor the program.

Scientists who have employed techniques developed for bioastronautics requirements have usually also been active in the space programs. In other words, they are the company, hospital, or university scientists

who have engaged in a mix of activities. The transfer process is immediate, since the same individual employs techniques refined for space research in his other on-going activities. In many cases, research colleagues who are in immediate contact with space life scientists have been able to make immediate use of the research techniques developed for bioastronautics requirements in adjoining laboratories. The author was not able to make an in-depth investigation to learn if these research techniques are also being widely employed by scientists who have had no direct or indirect contact with various space programs. However, the consensus among research specialists who have discussed the subject seems to be that these research techniques are filtering slowly into laboratories that may be physically removed from bioastronautics R&D.

The transfer of research techniques may be considered the software side of the subject to which this report is addressed. Scientists working in various branches of biology and medicine have also experienced a similar state-of-the-art technology gap concerning the equipment they use to pursue their research objectives. By this is meant a gap similar to the 10- to 15-year gap in the application of advanced technology overall clinical requirements. Historically, this has been due to the fact that biomedical research has always been sparsely funded, compared with research in the physical sciences.

For the past 20 years, the total national R&D investment in the biomedical sciences has remained approximately 10 to 12 percent of the total commitment made in the physical sciences. These percentages are somewhat deceptive, because the total physical R&D includes a much larger portion of the development funds as opposed to basic and applied research. In the life sciences, more funds are actually allotted to basic and applied research than to development, a reversal of the usual R&D funding pattern. Present trends suggest that in the next five years life sciences basic and applied research may grow more rapidly than the rate of growth in physical science research.

If individual life science research budgets reach an average funding level that permits the use of sophisticated instrumentation and computer time, then the research methodology side of technology transfer could be more important than it is at the present time. Some intermediate and long range planning is warranted in this area. Properly directed, it would enhance the overall effectiveness of the transfer process and also convince many skeptical scientists of the ancillary R&D benefits of the space program.

Research Dissemination Options

The dissemination of life sciences research techniques cannot become a more effective process simply by preparing a monograph or series of monographs describing these new laboratory procedures and hardware items and how they may be applied to fields outside bioastronautics. Unlike physiological data on the healthy adult, the field of research techniques we are dealing with is very fluid, with new things being proven and applied on a real time basis. We are primarily dealing with the software side of technology transfer. In some cases, specific items of equipment, primarily laboratory lash-ups that lack permanancy, are required. But basically, it is the method of doing things that is important rather than the tools employed to accomplish a research objective. Several possibilities are open to further analysis that may make this aspect of technology transfer more effective.

A joint NASA-NIH committee might be established to disseminate space bioastronautics research techniques further throughout the life sciences programs carried out under the auspices of NIH. The latter agency's support is important, because it internally and externally provides the funding for well over half the biomedical R&D in the United States. This joint committee should be a fairly effective means of accelerating the application of new research techniques. Such a committee could be expanded to include representatives from the other government agencies responsible for various life science research fields.

A symposium could be held in some appropriate place, probably Washington, to identify further for the biologist and physician with no previous acquaintanceship the specific research techniques that have come out of bioastronautics. Initially, such a symposium might be offered as a one-day addition to one of the heavily attended meetings of some society within the life science field. Cooperation of the Aerospace Medical Association as the sponsoring group for such a symposium might be considered. If successful, the symposium might become an annual event, or it could evolve into something that would be held separately on a periodic basis and not as an adjunct to scheduled meetings of the other organizations.

The NASA Tech Briefs adequately bring to light specific hardware items and some research techniques. However, there are many research techniques that are not covered in the present technology transfer identification activities. Scientists developing these new techniques should be encouraged to identify them specifically and also to mention other fields of biomedical investigation where, in the view of the individual scientist, they might be used in new laboratory procedures. After such data are compiled, additional thought could be given to the best means

of bringing it to the attention of perspective users who may not even be aware of the NASA Technology Utilization Program.

The greatest present technology transfer barrier in bioastronautics lies in bringing the specific hardware items from the space laboratory and operational systems to the hospital, clinic, and other uses where these items can enhance performance and in many cases measure physiological data in a way that has never before been done. In short, the greatest barrier is in transferring hardware and the related ways of using it. To understand this significant barrier fully, one must first analyze the unique features of the organizations that develop such hardware. We are talking about government agency laboratories, nonprofit organizations, university laboratories, hospitals operating under NASA grant or contract, and, most important of all, aerospace companies.

Aerospace organizations operate different chapters, ownership, and traditional areas of responsibility. The one thing that they all have in common is that they are primarily dealing with services or products funded by or sold to some branch of the government--federal, state, or local. This is as true of the aerospace company as it is of the government laboratory producing some system to meet the requirements of the space program. The executives and scientists within all such organizations are accustomed to thinking in terms of a somewhat unique market, that funded by government agencies as opposed to the larger markets in society within the private sector of the economy. The marketing capabilities of all such organizations are government agency-directed. The accounting procedures they employ and various items that enter into the general, administrative, and related overhead costs are unique to an industry that must adjust to the peaks and valleys of government funded activities whether space oriented or otherwise. This influences everything from marketing to the actual design and production of equipment.

It is well known that an aerospace company or division of a company cannot competitively manufacture items that must compete in the commercial field. A separate organization or division must be set up to accomplish this goal within a company. In many cases, design engineers must be retained so they will not "gold plate" items. During the past ten years, aerospace companies have desperately attempted to diversify outside of their traditional government markets. For the most part they have not been successful except in cases where diversification was achieved by a merger or acquisition. Consequently, one can still say that aerospace organizations are not familiar with nongovernmental markets. Here we are primarily concerned with a broad medical market that serves hospitals, clinics, and physicians. We are thinking next of organizations that also serve the laboratory whether it be in an academic environment, nonprofit organization, government agency, or a corporation.

A Hypothetical Example

To understand some of the transfer barriers in bioastronautics, it may be useful to review a hypothetical example. The electronic stethoscope is an interesting item to consider, because almost every aerospace company with a significant bioastronautics capability ha designed and constructed a prototype electronic stethoscope. In most cases it was not constructed in anticipation of a space life science requirement. Usually the effort was proposed as a diversification activity. Constructing an electronic stethoscope was feasible, because a life science group had been brought together in anticipation of bioastronautics requirements. A number of prototype electronic stethoscopes were given serious consideration by companies between 1959 and 1964.

The total market actually extends far beyond the number of physicians in the United States, since such an electronic stethoscope might be effectively used by nurses and nonmedically trained people caring for the ill at home.

When the electronic stethoscope is perfected, it goes through initial clinical testing, which can usually be easily accomplished by a physician working in the bioastronautics department. Next comes the question of who will produce and market the device. It is a one of a kind item and no division in the company sells within the nongovernment medical market. Furthermore, there may be no proprietary patents necessary for the design of this system; it can be easily copied, or designed around, by any other organization that decides to compete in the market.

The success of the electronic stethoscope prototype usually warranted a market research analysis, probably conducted by in-house people who were not knowledgeable about the hospital, clinic, and physician markets. They were likely to give far less attention to such an assignment than they would to areas that lie within their customary expertise. Assuming that a favorable report reached the company management, there were probably three alternatives for further action.

1. The company can attempt to license the stethoscope to some qualified manufacturer of biomedical equipment, which would not be a satisfactory solution if the device did not have some patentable or other proprietary features.

2. The company can consider the possibility of acquiring an independent manufacturer and marketer of biomedical equipment who would handle the stethoscope line and also serve as an outlet for other technology items developed as a result of space life

science efforts. Here the problems are somewhat formidable. A major commitment of company resources is being considered and there has been a definite scarcity of available companies that would meet the profit and other requirements that have been established for acquisition purposes.

During the early 1960s there was a medical electronic craze that swept through industry, and most of the attractive independent medical equipment companies available at that time were acquired by larger industrial concerns, principally those not engaged in aerospace activities. Some contend that not enough time has elapsed to allow a new family of independent medical equipment manufacturers to come along to meet what seems to be an obvious acquisition requirement.

3. The third possibility would be to manufacture a limited number of electronic stethoscopes and then attempt to sell them by advertising in appropriate publications or through some other indirect sales means. Such a proposal is likely to be dismissed out of hand, because it violates all the standard procedures used in manufacturing and marketing a product line. The end result is that the electronic stethoscope is likely to be set aside and forgotten. If some attempt has been made to find a market for the device, then the failure to do so will likely be mentioned every time a proposal is presented to transfer some comparable item from space life science to nonspace market requirements.

In summary, the aerospace companies lack a manufacturing and marketing organization to transfer bioastronautics hardware items quickly into initial clinical testing and later widespread use within all the sectors of the medical market. The time required to achieve such an objective competes with other proposed activities that lie within the mainstream of the aerospace company's goals, corporate objectives, and areas of historic success.

The Role of the Champion

It is interesting to note the many cases in which the technology transfer has been made in spite of what may seem to be an insurmountable barrier. In almost every case, this transfer has been made only because it has found a champion somewhere within the organization who has managed to carry it through to eventual success. Frequently, this champion may be a company officer or high ranking executive who becomes interested in,

or intrigued by, the technology itself as opposed to the possibility of profit from manufacturing and marketing such an item. In other cases, the individual scientists responsible for the technology may spend their spare time attempting to achieve the transfer. The investigation disclosed that a large percentage, if not most, of the successful technology transfer items has been achieved sub rosa or by bootlegged time and effort, although usually with the tacit approval of management. Here we are dealing with one of the interesting advantages of the transfer process in the life sciences.

The average technically oriented person tends to be intrigued by the application of new technology to health problems. WITHOUT THIS VERY SIGNIFICANT PSYCHOLOGICAL FACTOR, LIFE SCIENCE TECHNOLOGY TRANSFER WOULD BE A DISMAL FAILURE TODAY. However, if one recognizes the tremendous advantages that this attitude of mind brings to life science technology transfer, then the application of a little "Machiavellian cunning" can significantly increase the rate of life sciences transfer in a large organization. The solution is--simply find more champions.

The Physician Barrier

The barriers to hardware transfer do not entirely lie within the aerospace company or other developing organizations. In many cases we are dealing with the prejudice or lack of knowledge of physicians and other scientists working in hospitals, university laboratories, and similar institutions. They will readily cooperate with a company in the clinical testing phase of some hardware item, and its use will be appropriately reported in a paper delivered before some learned society. However, they tend to think of the company activities as being a philanthropic effort that may partly stem from a collective corporate guilt complex arising from the fact that much of the companies' efforts may lie in the development and production of weapons for military applications--in other words, the old "merchants of death" identification.

Dealing with the aerospace company is a new experience for most hospital and university physicians. During the clinical testing phase, they observe very generous investments of time and equipment resources in a new program. Measured from a dollar standpoint, they are probably dealing with a far larger expenditure than they are accustomed to in dealing with other organizations, particularly manufacturers of biomedical systems outside of the space field.

As a result of initial misinterpretation of the realities of the business world, many of these physicians and scientists simply do not

understand that an aerospace company cannot regard the development and manufacture of any item of advanced technology as a philanthropic gesture to society. In some cases limited activities might be carried in the interests of public relations. But one should not confuse that endeavor (which may cover the clinical testing phase of a system) with the requirements of manufacturing, distributing, and marketing. Consequently, the attitude of specialists operating outside aerospace organizations has been detrimental to achieving a faster or more effective technology transfer of hardware systems. This may be a somewhat difficult barrier to surmount, but it definitely exists and points to the need to educate these physicians and scientists with the realities of aerospace modus operandi.

First it must be clearly pointed out that these organizations are not attempting to bring the bioastronautics hardware items into the clinical and nonspace research spheres because of some conscious or subconscious guilt complex stemming from their association with military programs. Furthermore, consideration should be given at the very beginning of a clinical testing phase to the many subsequent problems entailed in manufacturing and marketing the device if successful. Bringing the nonaerospace physician and scientist into this analytic and decision-making loop should be of great benefit in achieving the desired education process and also in obtaining knowledge that would not be available within the aerospace organization.

Adaption Problems and Solutions Summary

The adaption problems in space life science transfer are primarily related to communications and funding. Such areas as distributing clinical, physiological, and psychological data are clearly communications problems. Once the communications barriers are well understood, alternative steps will be undertaken automatically to ease and possibly eliminate them. As a rule, the solution of communications barriers does not require large amounts of money.

The role of the champion should be analyzed relative to all technology transfer activities including those efforts outside of the life sciences. An agency with specific funds for space life science transfer would elevate the role of the champion to an official function, freed from the barriers that exist when work must be carried out on a quasi-clandestine basis.

The existence of the champion underscores a mental attitude that could be exploited in space life science transfer. Stated briefly, it is the fact that most engineers, scientists, and officials with technical

backgrounds are fascinated by biomedical problems for which they can see a solution within their own experience spectrum. Once they are convinced through appropriate review with biomedical specialists, they have the motivational satisfaction of having made a discovery, small or large. In some cases, the discovery may simply be the need of support from an influential person in the organization.

The first decade of space exploration has clearly demonstrated the important adaption problems in bringing space developed capabilities to broad biomedical needs. The next ten years could witness a smooth technology transfer flow based on our experience to date.

THE PRESENT AND FUTURE TECHNOLOGY TRANSFER BIOMEDICAL IMPACT OF THE SPACE PROGRAM

During the first decade of the American space program, there was a diverse pattern of technology transfer to requirements in clinical medicine and biological research. Ten years of experience clearly indicate that much needs to be known about the dynamics of the transfer process itself. Progress will undoubtedly be made in understanding how best to initiate the transfer process when a promising item can be first identified.

It would be misleading to suggest that there has been a massive transfer of space technology to the biomedical area. However, experience shows that the transfer has not been restricted to bioastronautics systems but has been derived from almost every branch of advanced space technology.

Some of the most important transfers have come from space programs with no biomedical content. The computer image enhancement technique may prove to be the most important or these transfers, and its original space applications were completely devoid of any biological content. The wheelless wheelchair and measurement of chick embryo heartbeat were transfers from nonbiological requirements. Rocket technology has been transferred to applied research on the artificial heart. Graphite implants promise to be a serendipitous transfer from rocket nozzle technology. Instrumentation used in biomedical research has come from the nonbiological side of astronautics as frequently as from bioastronautics programs.

Almost all the disciplines that may contribute to biomedicine are represented in a vigorous space program. Applicable technology will be developed for transfer to almost every outside area, including the life sciences. There are three factors that influence the quantity and quality of technology transfer from the total space program to all sectors of medicine and biological research. They are:

1. The total size, funding, and diversity of the space program itself (NASA, DOD, and others).

2. The amount of government agency funding for biomedicine (clinical R&D), along with private expenditures for biomedical equipment and R&D.

3. The funding level and sophistication of formal technology transfer efforts directed to space transfer options.

The present impact of space life science technology transfer is viewed against the somewhat unique background of the first decade of our space effort. Programs before 1968 were inconsequential compared with the subsequent level of effort. The early part of the decade saw rapidly rising NASA budgets with adequate funding to support a very wide range of space exploration goals. Increasing budgets with a high percentage devoted to R&D will create far more transfer options than a relatively level budget with most of the funding in support of operational programs.

The diversity of identifiable space biomedical transfers clearly demonstrates that a well funded space program will produce a variety of innovations and systems that will meet biomedical needs. The extent to which they may be widely used will also depend on programs to introduce advanced technology into the biomedical fields.

In October 1965, a program (Public Law 89-239) was initiated to establish RMP (Regional Medical Program) centers that would contain the most advanced equipment to treat heart disease, strokes, cancer, and related diseases. The RMP program was originally scheduled to spend several hundred million dollars to equip regional centers with advanced systems. The RMP program was under the direction of NIH, and its budget has been severely cut along with other reductions in NIH budgets.

The present impact of space biomedical transfer has been adversely affected by the fact that federal funding for biomedical R&D and clinical support was declining at the same time space funding was being reduced. The transfer picture would be more favorable if funds that would have gone into space had been diverted to the biomedical programs instead of to other areas.

We see that the present technology transfer picture has been adversely influenced by negative funding trends in factors 1 and 2 during the past two years, and this pattern is likely to prevail during the next year.

Many imponderables are entailed in evaluating factor 3. Technology transfer was written into the space act in 1958, but no body of experience really existed as a guide in initiating technology transfer. The years 1958-63 were characterized as a period of almost unlimited public support for space exploration, and there was no foreseeable need to find justification for the program outside successful space missions. Technology transfer budgets have been relatively modest during the first ten years of NASA's existence.

Aerospace corporations and other organizations where the technology is actually developed have not placed great importance on technology transfer. Responsible people have expected it to occur, but markets in the biomedical field are much more difficult to define than markets in other areas of space technology transfer. With the exception of areas influenced by an internal champion, support was expected to come from the outside.

In assessing the present impact of space on the life sciences, mention should be made of developments that cannot be clearly identified as transfers derived from space technology. Almost everyone interviewed in this study mentioned the advanced solid state computers that are now widely employed throughout the nation's R&D facilities. The use of sophisticated computer techniques in biomedical research and clinical organizations is regarded by many leading scientists and physicians as a space technology dividend. There have been many favorable trends influencing advanced computer development and application during the past ten years. The requirements of space have unquestionably been one of the most important influences on computer development. It is doubtful that computers would be as advanced as they are today if there had been no U.S. space program.

The Future Impact

The majority of the transfer items identified in this study are still in the initial clinical testing phase. Most of them are likely to be successful and to be widely employed in the next few years. The extent to which this optimistic forecast will be verified depends to a great extent on factor 2. How much government funding will be available in the next few years to support development and clinical acquisition of sophisticated biomedical technology? A prudent man would expect to see an increase in such funds when the fiscal pressures of the Vietnamese war are eased. There is a continuing demand for medical research and the very best clinical treatment. The health field is certainly not expected to experience a public support crisis similar to the present pattern affecting the space program (which could be reversed). Therefore, factor 2 should exert a favorable influence on transfer items that are in the early stages of acceptance. The near-future impact of space on biomedicine would likely be greater than the present impact even if the space program were suddenly terminated.

The future impact of the total space program on biomedicine will also be influenced by factor 1. A well financed, diverse space program would produce an increasing number of life science transfer options. An intensive manned space effort would probably produce the greatest amount of biomedical fallout. The simultaneous development of advanced space

stations, lunar bases, and life support requirements for manned planetary missions would produce an ideal environment for technology transfer. The details of space exploration beyond 1971 are extremely speculative at the present time. Unquestionably, advanced manned orbital, lunar, and planetary missions will be imitated, but their timing now appears less certain than it was a few years ago--say in 1965. When these programs are all in full development, technology transfer into the life sciences would experience a dramatic increase.

Unmanned and manned planetary exploration should be especially fruitful relative to biomedical transfer. The present unmanned planetary exploration concepts are centered on Martian life detection. The transfer areas that can now be identified in our present concept of the Voyager program were summarized in Table II. There would likely be a number of unexpected or serendipitous transfers from Voyager.

Manned planetary exploration would present the requirements that can be expected to have the greatest transfer potential. The long term physiology monitoring of the astronauts would demand an on-board spacecraft reliability two orders of magnitude beyond present requirements. On-board computer analysis of data would probably be necessary. Miniaturized equipment to analyze samples of Martian soil for the presence of life would be developed even if unmanned soft landing probes came up with inconclusive results.

We will probably have a much better understanding of the dynamics of technology transfer by the time manned planetary exploration programs become a major part of the space program. Thus, factor 3 can be expected to play an important role during the development of systems required for manned exploration of the inner planets.

A dynamic space program during the 1970s and 1980s combined with a well funded technology transfer program could provide transfer options of benefit to almost every branch of medicine and biological research. The extent to which this rich promise is realized will depend partly on how well the experience of our first decade in space can be used to allow us to improve technology transfer to the life sciences. Imagination and understanding combined with good planning are likely to be as important as the level of technology transfer funding.

THREE TECHNOLOGY TRANSFER CASE HISTORIES

Three case histories of completely different space technology transfers are presented to illustrate the diverse origins and evolutionary pattern of technology transfer in the life sciences. Two examples are the product of specific programs. The third is a serendipitous discovery that was not carried out sub rosa outside of established programs. The two transfers that have made the greatest progress have both had champions whose tireless efforts are primarily responsible for progress to date. The program without a champion is the senior development historically and the one at first glance that we would suppose should experience a smooth transfer pattern.

The Automated Blood Pressure Cuff

In 1958 it was clear that manned space missions would be given a high priority within the newly formed NASA. The Air Force also has a number of plans for manned space flights. Dr. James N. Waggoner, now the Director of Life Sciences at the Garrett Corporation, realized that an automated blood pressure measurement system would be a logical requirement for both NASA and military manned space missions. The development of the automated blood pressure cuff was initiated early in 1958 as part of Garrett's IR&D program. The system was subsequently refined under a NASA contract to be included in the Mercury Program, which was the first of several different models that have been modified for the major manned space programs.

A system was completed early in 1961 and went through its clinical testing phase at that time. Garrett discussed the possibility of using the machine for standard clinical requirements as soon as it was perfected. The initial reaction of the medical community was that the machine was simply too expensive for its modest capital investment budget. At that time the price estimated for the machine in serial production of perhaps 10 or 20 units was in the range of $2,500 to $3,000 a unit. The recent models of the space flight system developed by Garrett included the system for Gemini and the other for the Apollo program. The automated blood pressure cuff functioned flawlessly on all Gemini flights.

In 1963, Garrett used its own funds to repackage the blood pressure system and constructed two clinical demonstration units. There has been

a concerted effort to market the automated cuff for the past five years using these demonstration models.

One demonstration system has been at the Lovelace Clinic during the past four years and has functioned according to expectations during that time. One cannot really define this installation as the initial clinical transfer, because Lovelace has a very close association with Garrett and was able to purchase the unit for a fraction of its real cost. Also, the unit has been primarily used for research and application directly related to the space program.

After nearly five years, a demonstration unit was tested in an intensive care ward at the National Institutes of Health in January 1968 where it functioned satisfactorily. This unit has been subsequently returned to Garrett where it has been installed in a movable EKG cart that automatically takes EKG readings and places them on tape for subsequent computer analysis. The EKG cart with automated blood pressure cuff was demonstrated at the American Medical Association meeting in San Francisco in June 1968.

Garrett has been informed by Dr. Howard Hockberg of the Field Instrument Unit of the U.S. Public Health Service that it will receive a $50,000 contract to install ten automated cuffs in the mobile EKG carts. It is assumed that these systems will be sent to ten NIH field hospitals throughout the country for subsequent clinical evaluation and daily use. This program was to have been initiated in April 1968. Because of NIH funding restrictions, the program now appears to be delayed until August.

The present production cost estimated for the system suggests that it can be sold for $2,000 per system in serial production quantities of 10 or 20 units. The production costs of several hundred units should come down to a range as low as $1,000 per system.

Some mention should be made of what the automated cuff will actually do in both intensive care wards and for the standard physical examinations. Used as an integral part of the EKG cart, the automated cuff will allow an untrained person to supervise the blood pressure measurement that will be included on the tape containing the EKG data. The tape can be automatically processed through a computer in the hospital or at a distant location to provide a predictive medical analysis of any abnormalities that should warrant the attention of a cardiologist. Since the basic concept behind the EKG cart is to automate a procedure that currently requires the time of a doctor or skilled nurse, there is no substitute for the automated cuff. As many as 300 patients a day might be processed on a single cart, which a relatively unskilled person can operate.

The other principal application of the automated cuff promises to be in hospital intensive care centers. Here we are concerned with critically ill patients including postoperative cases, heart attack and stroke victims, and persons suffering from a variety of illnesses where speedy attention often means the difference between life and death. Blood pressure is an important parameter to be measured in all these patients. At the present time, this is accomplished either by the nurses manually pumping up the old hand blood pressure cuff or through an intravenous pressure transducer that requires that the skin be punctured. The old manual pressure cuff costs between $60 and $80 and the intravenous system costs about $300. The automated cuff is far superior to these systems, since it can be tied into a computer along with EKG, temperature, and other basic data to provide an automatic warning that the critical phase for a patient was approaching. Also, considerable amounts of valuable time on the part of nurses and physicians would be saved by the availability of this system.

The present $2,000 sales price is the major barrier to the widespread use of this system in intensive care wards. Every physician contacted, who was associated with intensive care wards, has raised the price question when discussing the automated cuff and other relatively expensive systems coming out of aerospace technology. At the present time, they simply do not have the budget to support such capital investments. The system could be leased, but we are still dealing with a fairly sizable investment over a period of time. Federal programs to supply funds for purchase of capital items by hospital intensive care centers have also been curtailed because of the fiscal pressures of the Vietnamese war.

It is doubtful that the automated cuff will be widely employed in intensive care centers in the next five years without some new government program to provide specific funds for the purchase of such equipment in hospitals throughout the country. Here we would be dealing with thousands of units and the widespread deployment of the automated cuff would be a multimillion dollar program.

The automated cuff is representative of expensive advanced technology biomedical systems in that there is likely to be a 10- to 15-year time gap between the availability of the system and its widespread distribution throughout our hospitals. The basic lag all the way through this technology transfer effort has been caused by a simple economic barrier. Everyone agrees that the system provides information that currently requires the manual efforts of highly skilled personnel. The system is also not subject to human error, which may in the long run prove to be the principal reason it is adopted for both patient screening and intensive care requirements.

The automated cuff development has not been influenced by the attention of a champion in its technology transfer evolution. Many individuals at Garrett and various agencies have been interested in its clinical potential, but no one has stepped into the champion's role.

Graphite Implants

In 1967, an unexpected discovery at the Rocketdyne Division of North American Rockwell opened the way to what may prove to be a significant advance in prosthetic materials for the human body. James A. Benson noticed that a small fragment of graphite had become imbedded just under the surface of his skin as the result of his work with graphite lined rocket nozzles. At the time it was removed there did not appear to be any infection around the graphite splinter.

The Space Systems Division and Rocketdyne have had a NASA contract to formally report technology transfer from their many programs, principally propulsion and Apollo spacecraft development. James Benson became part of that program, which allowed him to incorporate his serendipitous graphite discovery as part of his technology transfer activities. He had two graphite implants placed in his arm. One is still there and the other was removed after several months. A biopsy revealed that there were no abnormal cells around the removed implant which consisted of tightly wound graphite threads.

James Benson clearly played the role of the champion in the graphite implant transfer. It was a serendipitous discovery that could have been ignored and forgotten without his persistent and dedicated efforts. The champion role has also been played by his superiors who have assisted and encouraged his efforts. In less than one year nine graphite biomedical transfer applications have been clearly indicated and research is under way at two hospitals.

Benson is working with Dr. C. O. Bechtol, the head of orthopedic surgery at the UCLA Medical Center, on the use of graphite components for hip joint replacement. Metals currently used corrode, producing toxic substances, and the corroded surface prevents the artificial joint from moving. Graphite holds the promise of providing an artificial hip joint that would remain in an unchanged condition as long as any patient would normally be expected to live. In addition to its resistance to corrosion, graphite has excellent lubrication properties for the requirements of an artificial hip joint.

Benson is also working with Dr. Warden Wering at the Rancho Los Amigos County Hospital in Southgate, California. Dr. Wering believes that graphite can be used in microelectric probes to control a prosthetic hand. An amputee could operate the artificial hand through direct mental control rather than the awkward movements currently required for prosthetic hands. The outcome of this application will depend on the compatibility of various forms of graphite with nerve tissue when they are in direct contact.

Another promising application is the use of hollow graphite balls in artificial heart valves. At the present time metallic balls (moving in an implanted framework) are used. Blood is highly corrosive, and after seven or eight years many of these balls suddenly crack, which starts a blood clotting sequence that quickly kills the patient. Hollow graphite balls can be made to easily match blood density and should not be subject to corrosion.

Other biomedical applications that have been identified for graphite include cosmetic bone replacement--filling in jaw bones and other bones damaged in accidents, military combat, or removed because of malignancy; permanently implanted bone splints on the outside of the bones; bone pins in the marrow spaces of the bones; bone extensions going outside the skin for amputees, permitting a 20 percent increase in the number of leg amputees that can be fitted with prosthetic legs; electrodes for cardiac pacemakers; and permanently implanted tapoff vein ports for kidney dialysis.

The transfer pattern of James Benson's discovery has enjoyed an unusually rapid pattern of progress in a comparatively short period of time. The availability of NASA technology funds through Rocketdyne's rather sizable contract to report transfers was undoubtedly an important factor. It allowed Benson to assume the role of the champion and rapidly push the graphite applications from the conceptual to the research stages.

Image Enhancement

The biomedical computer image processing technique being refined by Dr. Robert Nathan and his colleagues at JPL has been mentioned in the text of this report as being considered the most significant technology transfer item identified in this study. The details have been described in the preceding sections of the report. Dr. Quentin Hardwig originally suggested to Dr. Nathan that the image enhancement technique could be used to process medical X-rays and other medical images. In January 1966, Hardwig began to send X-ray data and other pictures to Dr. Nathan to be used in the first biomedical image enhancement efforts. The

procedure was an immediate success and culminated in an impressive variety of applications during the past two and one-half years.

From a transfer standpoint the important consideration is that, until recently, there were not any specific NASA funds earmarked for this effort and there was no redirection of internal funds at JPL in the early stages of the program. Dr. Nathan and his associates simply worked at night and on the weekends refining the procedures necessary to apply to the image enhancement technique for the biomedical applications. Here we see a clear example of Dr. Nathan serving in the function of the champion in a transfer activity. Other members of JPL management might also be considered to played a champion role, but Dr. Nathan is clearly the one whose efforts allowed the image enhancement technique to be applied to so many applications in such a short period of time. It should be mentioned that this time period coincided with the most active phase of the Surveyor program when Nathan and his group were extremely busy processing the many pictures coming from the successful lunar soft landings.

In April 1968, Dr. Nathan was informed by National Institutes of Health that he would be receiving a $900,000 grant to refine the various techniques over a two-year period. In June, the NIH Division of Research Facilities and Resources had all its grants frozen because of the current uncertainty over federal budget cuts, especially those affecting the Department of Health, Education, and Welfare. To tide over Nathan's group during the interim time period until the grant comes in, $70,000 has been allotted for the biological application. This is the first NASA money to be directed toward this effort. One might describe this simply as a "holding action," because it is not enough to get the program started as originally planned. Much expensive equipment must be ordered for the full scale exploitation of all the different options which the JPL group has uncovered.

It should be mentioned that while Dr. Hardwig originally thought of the X-ray application, the electron microscope resolution improvement was a concept that originally occurred to Dr. Nathan in 1954 when he was working in crystallography at Cal Tech. The electron microscopy application promises to be the most revolutionary of these developments, and it represents a full cycle for Dr. Nathan, since he started out in biological research. He believes that the electron microscope enhancement would have an immediate medical "fallout" giving data on the exact structure of DNA and allowing scientists to have a much clearer understanding of malignancy. He considers it the most important of the applications, and if his NIH funds are reduced he will place it ahead of the other image enhancement options. As stated before in the report, the electron microscope enhancement appears to be the closest thing to a biomedical research breakthrough coming out of our space program to date. Fully developed, it could give scientists

a "direct readout" capability at the molecular level. Quite probably, many fields of biological investigation would be revolutionized by the availability of such an image resolution capability.

The requirements of a biomedical image enhancement program shows the funding levels necessary to achieve really significant transfers from the space program. Nathan estimates that they will need a minimum of 12 to 13 professionals during the two-year period. Direct labor costs would be on the order of $250,000 a year. The remainder of the $900,000 would be spent on equipment. Of course, many items of expensive equipment including the computer facilities, the electron microscope, and so forth, are already available. Without a question, this is expensive research as measured by the standards of biological funding. However, it could provide improved medical diagnosis for every segment of the population along with instrumentation which promises to greatly accelerate progress in fundamental biomedical research. It is ironic that a development that has already been clearly demonstrated in most of its applications is being held back by funding cuts and uncertainties at the present time.

The present success of the image enhancement technique is due to the presence of several champions among those who could influence its initial refinement. Its future success depends almost entirely on the amount of direct funding that comes from NIH or some other source.

Appendix A

ORGANIZATIONS CONTACTED IN THE STUDY

Information for this study was obtained from many sources, including interviews with officials in government agencies in the Washington, D.C., and Bethesda, Maryland, area. Brig. Gen. Don D. Flickinger, U.S.A.F., Ret., was especially helpful in arranging meetings with NASA, Air Force, Navy, Federal Aviation Agency, and National Institutes of Health specialists who have been concerned with biomedical technology transfer. The following organizations in California were visited during the study:

Jet Propulsion Laboratory
Pasadena, California

California Institute of Technology
Pasadena, California

UCLA Medical Center
UCLA Brain Research Institute
Los Angeles, California

University of Southern California Medical School
Los Angeles, California

Cedars of Lebanon Hospital
Los Angeles, California

City of Hope Hospital
Los Angeles, California

Long Beach Naval Hospital
Long Beach, California

SysteMed Corporation
Newport Beach, California

General Dynamics Convair Division
San Diego, California

Beckman Instruments Inc.
Fullerton, California

The Garrett Corporation
Los Angeles, California

The RAND Corporation
Santa Monica, California

Systems Development Corporation
Santa Monica, California

Aerojet General Corporation
El Monte, California

Hughes Aircraft Company
Culver City, California

Lockheed Aircraft Corporation
Burbank, California

The Marquardt Corporation
Van Nuys, California

Electro Optical Systems, Inc.
Pasadena, California

McDonnell Douglas Corporation
Missile & Space Systems Division
Santa Monica, California
Huntington Beach, California

North American Rockwell Corporation

Aerospace and Systems Group
El Segundo, California

Autonetics Division
Anaheim, California

Rocketdyne Division
Canoga Park, California

Space Systems Division
Downey, California

Northrop Corporate Laboratories
Hawthorne, California

TRW Systems
Redondo Beach, California

SpaceLabs Incorporated
Van Nuys, California

Bioscience Planning Inc.
Anaheim, California

Appendix B

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