

ECONOMIC IMPACT OF STIMULATED TECHNOLOGICAL ACTIVITY

FINAL REPORT - SUMMARY
7 April 1970 - 15 October 1971

Contract No. NASW-2030

MRI Project No. 3430-D

For

National Aeronautics and Space Administration
Headquarters
Technology Utilization Division
Washington, D. C. 20546

|

Preceding page blank

PREFACE

This is one of five volumes which present the findings of a research inquiry into the Economic Impact of Stimulated Technological Activity. The titles of the volumes are:

Part I - Overall Economic Impact of Technological Progress--Its Measurement

Part II - Case Study--Technological Progress and Commercialization of Communications Satellites

Part III - Case Study--Knowledge Additions and Earth Links from Space Crew Systems

Summary Volume--Economic Impact of Stimulated Technological Activity

Bibliography

The research was sponsored by the National Aeronautics and Space Administration Office of Technology Utilization under the terms of Contract NASW 2030. The project staff of Midwest Research Institute included: Robert E. Roberts, Howard M. Gadberry, Robert E. Fleisher, Lawrence L. Rosine, E. Duane Dieckman, and Linda L. Crosswhite.

Principal consultants were Dr. M. Jarvin Emerson and Dr. Thomas J. Weiss for Part I, Mr. Edwin J. Istvan for Part II, and Mr. R. A. Bambenek for Part III. The project team benefited from the suggestions of an advisory panel composed of Dr. Randall T. Klemme, Dr. Charles N. Kimball, Dr. Kenneth C. Wagner, Mr. James A. Alcott, Dr. Richard Marsten, and Dr. Werner Z. Hirsch. The contributions of Dr. Donald Silverman, an ex officio member of the panel, are also acknowledged.


Acknowledgement is also made to the vital contributions of perhaps one hundred or more scientists and engineers interviewed during the course of the study. Their cooperation and that of their employers--NASA Centers and private contractors--was essential.

Special thanks are due to Joseph M. Carlson, the NASA Project Officer, and Ronald J. Philips, Director of the Technology Utilization Division, throughout most of the project life.

The findings and judgments expressed in the report are those of the MRI project team and do not necessarily reflect the view of the National Aeronautics and Space Administration or those of any company or individual surveyed.

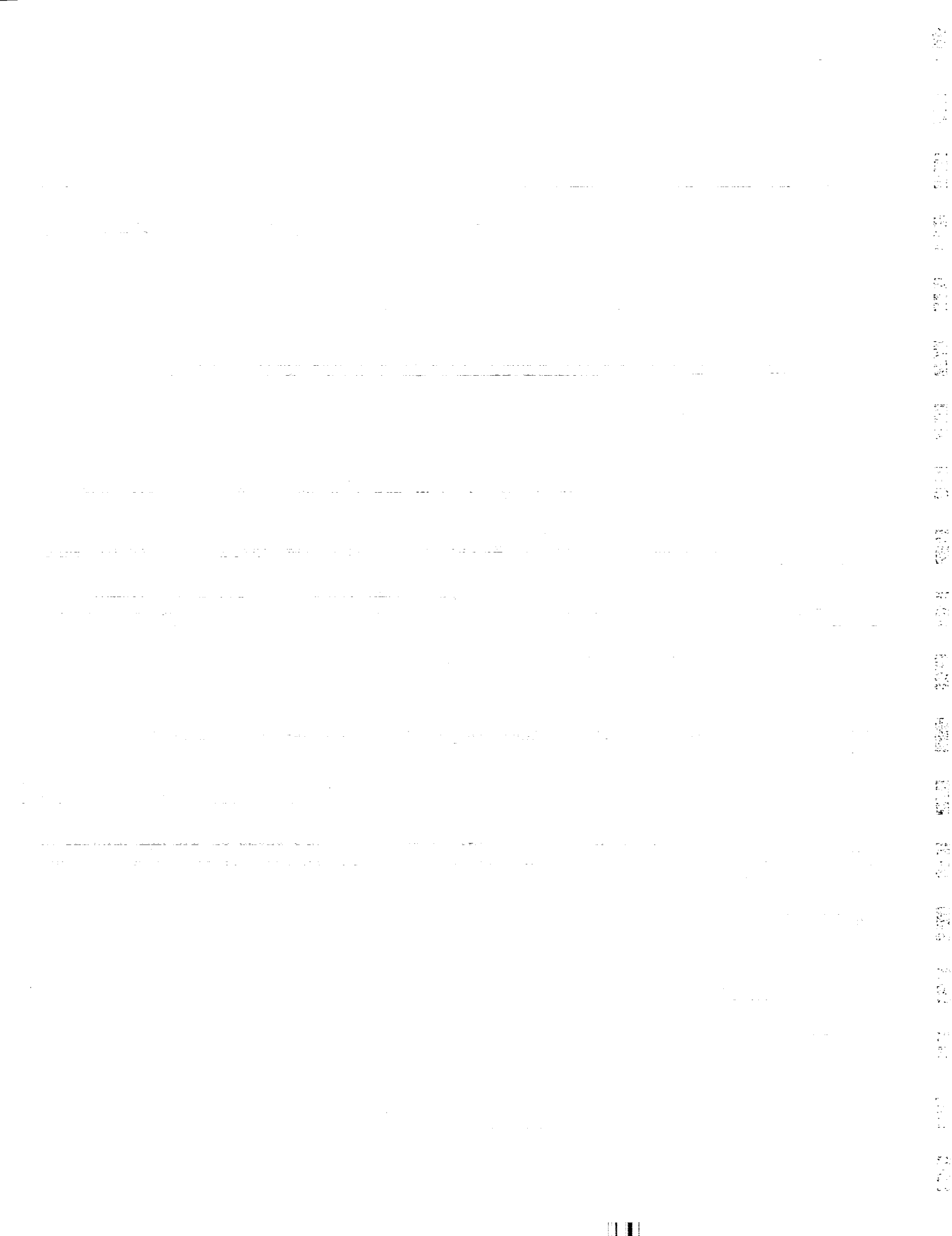
Approved for:

MIDWEST RESEARCH INSTITUTE


John McKelvey, Vice President
Economics and Management Science

22 November 1971

PRECEDING PAGE BLANK NOT FILMED



Preceding page blank

TABLE OF CONTENTS

	<u>Page</u>
Overview	1
Scope of Research	2
Part I - Overall Economic Impact of Technological Progress-- Its Measurement	4
A. Background	4
B. Research Approach	5
C. Findings and Conclusions	7
Part II - Case Study-- Technological Progress and Commercialization of Communications Satellites	12
A. Study Construction	13
B. Research Procedure	13
C. Findings Summary	14
Part III - Case Study--Knowledge Additions and Earth Links from Space Crew Systems	34
A. The Knowledge Bank	34
B. Why Study Crew Support	35
C. Research Procedure	36
D. The Findings	37

PRECEDING PAGE BLANK NOT FILMED

ECONOMIC CONSEQUENCES OF STIMULATED
TECHNOLOGICAL ACTIVITY

"The nation's technological capacity, which is conceptually analogous to the capacity of its physical plant, is unquestionably a nation's most important economic resource. By the same token, the rate at which its technological capacity grows sets what is probably the most important ceiling on its long-term rate of economic growth.

The rate of growth of a nation's technological capacity depends jointly upon the rate at which it produces new technology and the rate at which it disseminates the old."

Jacob Schmookler
Invention and Economic Growth
1966

OVERVIEW

The degree to which a nation can satisfy its collective and individual wants is dependent upon the wealth of the nation and its citizens. The accumulation of economic wherewithal is obtained through combinations of labor, capital, and technology. All three inputs are essential but it is through technological progress that the productivity of labor and capital are increased to obtain more output per unit of input and, consequently, greater per capita wealth. The United States leads the world in the generation and application of technology. Our technological progress poses certain dilemmas, but is also the source of much of the economic power we are bringing to bear on societal deficiencies--deficiencies that many less wealthy nations cannot afford to consider, much less mount assaults upon.

This volume highlights the findings of a research inquiry into the relationships between technological progress and economic development, with emphasis on the several ways in which NASA research and development has aided in the accumulation and commercial application of new or improved scientific and technological knowledge.

Scope of Research

The research undertaken had three separate, but related parts: Part I was an examination of the importance of technological progress in the generation of national economic growth. The focus was on aggregate economic effects of technological progress--with technological progress being viewed abstractly as one of the principal growth-inducing forces operating in the economic milieu. Part I was concerned with effects: the economic effect of technological progress, the effect which R&D has on technological progress, and the effect of NASA on the nation's R&D spending. Specifically, this portion of the study was based on an econometric examination of the U.S. economy during the last 20 years to identify and measure the portion of growth which can be attributed to technological progress. Part I also examined the relationship between R&D and technological progress and, finally, made some tentative estimates of the relative effectiveness of NASA R&D expenditures in generating economic growth via technological progress.

Part II was a case study of the process whereby technology is developed and commercially applied. It was designed to undergird--by example-- the findings of the econometric study. It was also intended to illustrate the extreme complexity of the application process--in particular, that any large technological undertaking produces both direct and indirect commercial applications, that these come in a wide variety of forms and types, that countless individual increments of technological progress are combined in any application, that there are many participants in the process--no one of whom can claim sole credit--and finally to examine the several roles that a mission-oriented research and development agency such as NASA plays in the application process.

The specific case study undertaken was of the R&D programs and application endeavors which have culminated in commercial communication via satellite.

Part III of the report was an illustration of ways in which a NASA undertaking has contributed to the nation's scientific and technical knowledge reservoir--the reservoir which is drawn upon and extended by any move toward application. The intent was to demonstrate that a large body of knowledge is accumulated in the process of satisfying mission-oriented program requirements and that this knowledge is retained for use by others for other purposes. The research procedure was again a case study. In this instance the focus was on what we had to learn to keep man alive and productive in space--with emphasis on those things which have relevance in one form or another to earthly problems.

Thus, in three separate but interlocked studies, MRI attempted to touch upon major elements in the progression from science through technology to viable application in the economic realm: Part I measures the economic effect of technological progress. Part II illustrates the process whereby technology is developed and commercially applied (covering the invention/innovation portion of the spectrum). Part III shows that an inherent aspect of mission-oriented R&D is the generation of new or improved knowledge--in many fields; basic phenomena, applied science, engineering, design, materials, processing, etc. And, that this knowledge is added to the nation's knowledge bank for withdrawal when demand and the state of industrial practice evolve to the point where the technology will be applied.

PART I

OVERALL ECONOMIC IMPACT OF TECHNOLOGICAL PROGRESS--ITS MEASUREMENT

A. BACKGROUND

The central questions toward which this phase of the report was addressed are:

1. What is the role of technological progress in national economic growth?
2. What factors determine the rate of economic growth due to technological progress?
3. Can the relationships between technological progress, its determinants, and subsequent economic growth be measured--quantitatively?
4. And, how do the research and development activities of the space program tie into the preceding questions?

Before World War II, there was little need to ask such questions at the national level. Most development was performed by the individual inventor or by industrial laboratories supported by company funds. Choices as to whether or not to allocate resources to development and how to distribute resources among projects were made within individual companies. Most of the nation's research effort was performed at universities as an adjunct to graduate education. National priorities had little direct influence on the allocation of resources to R&D, and the scale of R&D was small enough that the formulation of precise relationships between R&D and the economy lacked urgency.

R&D grew dramatically following World War II under the stimulus of the Cold War and the race to combine atomic weapons with rocketry. Massive mission-oriented R&D programs were mounted, using as their model the Manhattan Project of World War II. All facets of research--basic and applied--as well as development and sophisticated production plus scientific and engineering education underwent huge federally funded expansions. A strong scientific and technological capability became an essential instrument for national survival--decisions to allocate resources to R&D were made on the basis of necessity.

By the late 1950's, when the nation's first large-scale civilian mission-oriented R&D agency--NASA--was created, the economic effects of such undertakings were receiving explicit, if imprecise, recognition. At about the same time, the short-term and regional economic impacts of expanded R&D began to receive widespread recognition. Community after community strove to become another Route 128, or San Francisco Bay Area, or Huntsville. The immediate benefits of a local R&D complex were clear. Less clear were the processes whereby R&D led to new or improved processes, products, and services. But more important to the purposes of the present portion of this report, the theory, methodologies and empirical data needed to measure quantitatively the cumulative effect over time of the product and process advances were notably deficient.

During the 1960's a number of theorists and researchers undertook to improve our ability to measure the economic impact of technological advances, for it had become clear that technology was a large and powerful force in the accumulation of national wealth. Pioneering work by Solow, Kendrick, and Denison was amplified and extended by a number of others. Much progress has been made, but the fact remains that we got to the moon in a decade, but are, as yet, unable to fully measure the present and future economic impact of the science and technology accumulated on the way to the moon (or the aggregate effect of technological progress in general). Our present capability to measure the relationship between technological progress and R&D is even less precise.

Yet, national decisions with respect to the allocation of resources to and within R&D are being and will be made. These decisions cannot be postponed until precise measurements of their effects are possible. Thus, the intent of this part of the study was to provide--from within the existing state of the art--some measurements of technology's contribution to this nation's wealth during recent years and the role of R&D in generating growth through technological progress.

B. RESEARCH APPROACH

The investigations were performed at the national economic level. We were exploring the aggregate effects of technological progress rather than those stemming from the individual inventions or innovations. Inadequacies in all existing macro-economic yardsticks forced the study to focus on the "cost savings" effects, i.e., increases in the productivity of labor and capital achieved through technological progress. The many improvements in the quality of goods and services due to research and development are not adequately reflected in existing aggregate economic series and cannot be directly measured.

Given these restrictions on the scope of the study, six research tasks were performed:

First, we adopted a definition of technological progress that is consistent with how progress occurs and how it is generally perceived to occur. The definition presumes that all increases in output not attributable to added quantities of labor and capital are due to technological progress; i.e., all quality improvements in labor and capital are traceable to technological progress.

Second, within the framework of the definition of technological progress and neo-classical economic growth theory, a suitable macro-economic production function was structured.

The adopted production function states that technological progress acts in a multiplicative rather than an additive fashion in augmenting labor and capital in the output-generating process. The general form of the production function employed is:

$$Q_t = A_t f(K_t, L_t)$$

where:

Q_t = Output in time period t

K_t = Capital utilized in time period t

L_t = Labor expended in time period t

A_t = Level of technology applied in time period t .

Third, the technology index^{1/} implicit in the production function was used to assess quantitatively the impact of applied technology on economic growth and output.

Fourth, having determined the level of technology and resulting output, we related technological progress generating activities such as research and development, economies of scale, education, etc., in a mathematical model. Here, the determinants of technological progress were linked to the effect of their stimulus in terms of incremental economic output.

^{1/} The index, A_t , represents the technology being applied in the production process through time. It is arrived at through analysis of actual output and output possible with labor and capital quality--i.e., embodied technology--fixed at a base year.

With respect to growth in output in the private, non-farm sector of the economy traceable to R&D--which was denoted $G(R\&D)$ --we hypothesized the following relationship:

$$G(R\&D)_t = f(R_t)$$

where:

R_t = The weighted sum of past R&D expenditures for year t .

Mathematically, the weights are expressed:

$$R_t = w_0 r_{t-0} + w_1 r_{t-1} + w_2 r_{t-2} + \dots + w_i r_{t-i} + \dots + w_{18} r_{t-18}$$

where:

w_i = Weight for the i th year lag, and

r_{t-i} = R&D expenditures in the year $t-i$.

Thus, R_t is a reflection of the current year's R&D activity plus the effective value of each of the past 18 years of R&D expenditures. Conceptually, R_t can be considered the effective investment in R&D "at work" in year t . The 18-year payout period and the payout pattern within the period were derived from several comprehensive and respected surveys of industry's pay-back expectations for R&D spending and new product lifetimes.

Fifth, through the use of statistical analysis, we empirically determined quantitative relationships existing between growth due to technological progress and determinants of technological progress.

Finally, within the preceding analytical framework, we examined the economic impact associated with the technological stimulus provided by the space program.

C. FINDINGS AND CONCLUSIONS

As have others before us, we found technological progress has been a powerful force in economic growth. Our study considered:

* That technology is one of the factors of production--along with labor and capital--with which the output requirements of the nation are satisfied;

* That what we term technological progress is responsible for improvements in the quality or productivity of labor and capital;

* That technological progress results from the introduction of new or previously unused knowledge into the production process;

* That there are many mechanisms by which knowledge is productively applied, including: Improved worker skills, improved machine design, improved management techniques, and so on.

Measuring the effect of technological progress--so defined--during the 1949 through 1968 time period, we found that:

** The technology added to the nation's production recipe after 1949 accounted for 40 percent of the real increase in private, non-farm output during the period.*

** Cumulatively, total output for the period was about \$8.2 trillion. If there had been no increase in the level of technology used after 1949, the stock of labor and capital applied would have only yielded a cumulative output of \$6.9 trillion. Thus, the leverage on the other two factors of production by technological progress permitted almost 20 percent more output than might otherwise have been achieved with the same quantity of labor and capital.*

** Throughout the period the technology factor in the production function increased at a compound rate of 1.7 percent per year. By the end of the period--in 1968--the compounding growth of technology had reached a point at which technological improvements beyond 1949 levels were accounting for 37 percent of output (Figure 1).*

Although it is possible to dissent on certain grounds about the exact amount of productivity gains due to technology, the major conclusion is clear. Without the increase of technology and its introduction into the production recipe, this nation would be substantially less wealthy than it is. Much of the economic wherewithal we are now attempting to apply toward the solution of pressing domestic problems is the product of applied technological progress. To expand this economic capacity for problem resolution, this nation must continue to allocate resources to enterprises which generate technological progress and encourage its productive utilization.

This brings us to the second set of findings--those related to the sources or determinants of technological progress. The theoretical and empirical foundation for these assessments is less definitive than for the preceding findings. However, there is general agreement on a list of forces important in the generation of technological progress. The forces are highly interactive but, for analytical reasons, were treated independently. Our findings indicated that most of these forces were of insignificant effect during the relatively short time period under study.

OUTPUT AND GAINS RESULTING FROM TECHNOLOGICAL PROGRESS
(1949-1968)

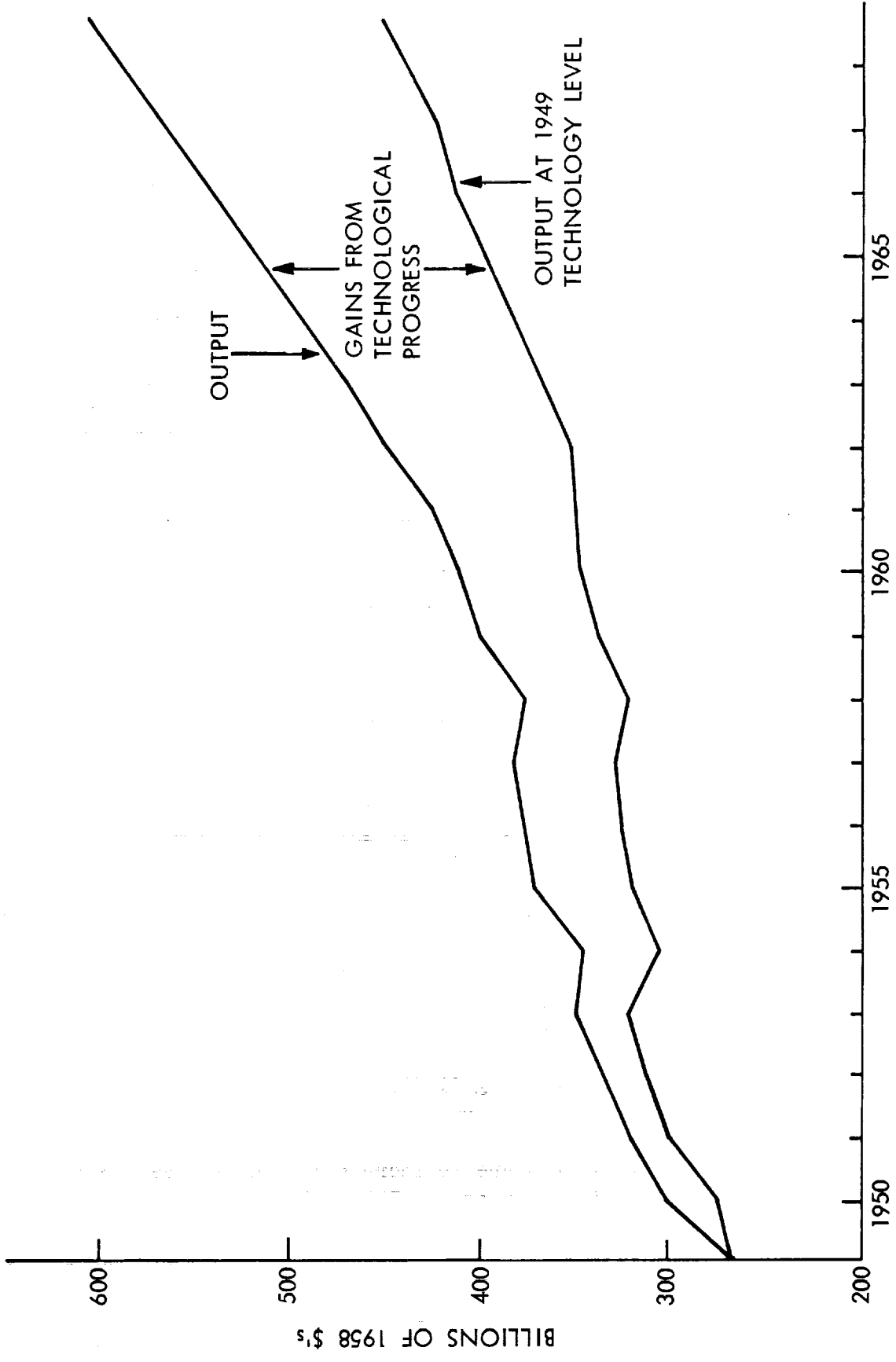


Figure 1

However, three factors--the sex mix of the workforce, education, and R&D--were found to be important determinants of economic gains through technological progress during the Post-World War II period. The first, sex mix, is the product of increasing participation by females in the workforce and increasing productivity by distaff employees. Improvements in this factor during the period accounted for 4 percent of the total gains due to technology. Improved worker productivity through higher educational levels contributed approximately 36 percent. The balance of the technology-induced gain--60 percent--was attributed to R&D after having ascertained that other possible determinants had no measurable or identifiable impact.

The relationship between R&D- and technology-induced economic gains was explored on a distributed-lag basis. Lag distributions between R&D expenditures and initial pay-back and final pay-out in the form of national economic gains were constructed from industry estimates and experience, but when subjected to statistical tests the relationships exhibited reasonably good explanatory power. The findings were that:

On the average--each dollar spent on R&D returns slightly over seven dollars in technologically induced economic gains over an 18-year period following the expenditure.

This finding leads to the strong conclusion that, on the average (including good, bad, and indifferent projects), R&D expenditures have been an excellent national investment.

The final set of findings relates to the economic impact--via technological progress--of NASA's R&D programs. Assuming that NASA's R&D expenditures had the same pay-off as the average, we found that:

The \$25 billion, in 1958 dollars, spent on civilian space R&D during the 1959-1969 period has returned \$52 billion through 1970 and will continue to produce pay-off through 1987, at which time the total pay-off will have been \$181 billion (Table 1). The discounted rate of return for this investment will have been 33 percent.

As noted, the preceding finding was based on the assumption that NASA R&D spending has an average pay-off effect; there is strong preliminary evidence that the exacting demands of the space program may produce greater than average economic effects due to increased technological leverage. This comes about because NASA allocates its R&D dollar to the more technologically intensive segments of the industrial sector of the economy. The weighted average technological index (A_t) of the industries which perform research for NASA is 2.1, while the multiplier for all manufacturing is 1.4. Although there are a number of conceptual and procedural limitations to the construction of industry-level technological multipliers, the spread seems large enough to support the view that highly technological undertakings, such as the space program, do exert disproportionate weight toward increased national productivity.

TABLE 1

G(R&D) GENERATION PATTERN RESULTING FROM HASA R&D
(1958 \$'s in Millions)

Annual NASA R&D	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	Annual C	Cumulative C
	128	351	602	1,261	2,446	3,315	3,982	4,283	3,414	3,116	2,518		

G (R&D) Generated

1959	1											1	1
1960	6	2										8	5
1961	21	16	4									41	18
1962	48	57	28	8								141	57
1963	84	132	97	58	16							389	115
1964	118	231	227	204	113	22						915	1,909
1965	138	324	397	475	395	153	26					1,909	3,454
1966	138	378	556	852	922	536	184	28				3,574	6,978
1967	120	378	649	1,165	1,614	1,250	644	198	22			6,040	13,015
1968	93	331	649	1,359	2,259	2,187	1,501	692	158	21		9,250	22,267
1969	64	256	567	1,359	2,636	3,062	2,627	1,615	552	144	17	12,898	35,167
1970	40	177	439	1,187	2,636	3,572	3,678	2,826	1,287	504	116	16,462	51,639
1971	22	109	305	919	2,305	3,572	4,291	3,956	2,253	1,175	407	19,311	70,359
1972	11	61	188	634	1,782	3,122	4,291	4,615	3,153	2,056	949	20,864	91,802
1973	5	31	105	393	1,231	2,415	3,750	4,615	3,679	2,878	1,661	20,764	112,566
1974	2	14	53	219	763	1,668	2,901	4,033	3,679	3,358	2,326	19,016	131,582
1975	1	5	24	110	426	1,054	2,003	3,121	3,215	3,358	2,713	16,010	147,592
1976		2	9	50	214	577	1,242	2,155	2,487	2,934	2,713	12,394	159,975
1977		1	3	20	96	290	693	1,336	1,718	2,270	2,371	8,797	168,772
1978			1	7	38	130	348	745	1,065	1,568	1,855	5,737	174,502
1979				2	13	52	156	374	594	972	1,267	3,430	177,942
1980					4	18	62	168	298	542	785	1,878	179,816
1981					1	5	21	67	134	272	438	939	160,757
1982						1	6	23	53	122	220	426	181,187
1983							1	7	18	49	99	174	181,353
1984								1	5	17	39	65	181,419
1985									5	5	14	19	191,458
1986									1	1	4	5	191,457
1987											1	1	181,444
TOTAL	914	2,506	4,298	9,002	17,462	23,665	28,427	30,576	24,372	22,245	17,976	181,444	

PART II

CASE STUDY: TECHNOLOGICAL PROGRESS AND COMMERCIALIZATION OF COMMUNICATIONS SATELLITES

The process whereby technology is developed and applied in the economic realm includes one of the most complex sets of interactions encountered in today's world. Three elements must be present before new technology is applied: the technology itself must be in existence, there must be a need for the technology, and some organization or combination of organizations must be willing to undertake the risk and investment necessary to bring the technology to the market. In addition, technological progress is a continuous process with no discrete beginning or ends. It is composed of a few major and countless small incremental advances which are constantly being combined and recombined in a bewildering array of ways to satisfy public and private demand. Technology also follows a variety of paths--direct and indirect--in its movement toward application. Only rarely is the application of a technological advance confined to the use for which it was originally developed. The speed and direction of early and subsequent applications is largely conditioned by the mix of participants--public and private--and the roles each adopts in the process. The evolution of needs into viable markets and the structural characteristics of relevant industrial sectors are also important in the pace of technology's application; as a consequence, multiple relationships among consumers, industry and government are inherent in the process.

In short, the technology application process, by which the economic effects measured in Part I come about, almost defies an organized, comprehensive treatment. But, some appreciation of the application process and its complexity is necessary if we are to insure a continuing flow of economic benefits from technological progress and avoid the widely discussed penalties of such progress. Faced with this situation the present researchers chose to undertake a case study of a significant technological endeavor, the intent being to illustrate--with specific examples--significant facets of the process, something of its pervasiveness, the kinds of contributions a national R&D agency, like NASA, makes to the process, and the several types of economic applications which flow from or are accelerated by such a technological undertaking.

Since communication via satellite is clearly an example of technological progress made during the last decade and a half, an examination of the R&D effort culminating in this commercial application was selected for case study. In addition, communication via satellite is the first major direct commercialization of technology to result from the national space program.

A. STUDY CONSTRUCTION

As noted, any application of technology is the gathering together of many technological threads to meet the objective at hand. And, most of the individual technological threads also find applications beyond those of the original objective. A principal purpose of the case study was to illustrate that both of these characteristics of the process do occur and how they occur.

Thus, Part II had two segments: the first being an examination of the technological requirements which had to be satisfied before the several types of communication by satellite could be achieved, an examination of the national R&D program which has and is leading to the satisfaction of the requirements, and the technical contributions of and roles played by NASA in this R&D process; the second being an examination of ways in which participants (NASA contractors) in the NASA portion of the R&D effort (in particular the SYNCOM, ATS, and companion supporting research programs) have applied the technological capabilities they acquired or augmented during the R&D phase in the resulting commercial communication by satellite market and other markets.

B. RESEARCH PROCEDURE

The major research steps undertaken were:

1. An examination of the several categories of services which can be provided by communications satellites.
2. A grouping of these services into four broad types for subsequent investigation. The types selected were: International--Intelsat/Comsat; Broadcast Distribution--transmission via satellite to major centers with transmission to ultimate users via conventional terrestrial links; Direct--transmission to many users direct from the satellite; and Mobile--communication via satellite with mobile users, such as in air traffic control.
3. A delineation of the major technical characteristics or requirements associated with each of the four types of applications.
4. An examination of the contributions which NASA programs--particularly, SYNCOM and ATS--have made to the satisfaction of the requirements.
5. Estimates of the economic impact associated with the four types of applications.

6. Identification and interview of a representative set of contractor companies that participated in the SYNCOM and ATS programs to identify the extent and ways in which they participated in the commercialization of satellite communications, and in the indirect application of the technological capabilities they accumulated during their participation in this facet of the space program.

Although at least 277 firms have participated, as prime contractors, in the communications aspects of NASA's SYNCOM and ATS programs, the resources allocated to this project dictated that only a few could be included in the survey sample. Fourteen were chosen following an intensive sample selection process. Sample selection was governed by the need to obtain as representative a cross section of participating companies as possible, i.e., large and small firms, satellite and ground station contractors, aggressive and not so aggressive firms, etc. Two firms which were not prime NASA contractors were added to the sample. One is a direct spin-off from one of the prime contractors; the other is a newly formed company that has utilized satellite communications technology in a rather unusual way to assemble and market a marine navigational system. The firms selected were:

Ampex Corporation, Redwood City, California
Bendix, Towson, Maryland
Electronic Communications, Inc., St. Petersburg, Florida
General Dynamics, San Diego, California
General Electric, Valley Forge, Pennsylvania
Hughes Aircraft, Culver City, California
International Telephone and Telegraph (IT&T), Nutley, New Jersey
Martin-Marietta, Orlando, Florida
Rantec Division of Emerson Electric, Calabasas, California
Satellite Positioning Corporation, Encino, California^{1/}
Sylvania, Waltham, Massachusetts
TRW, Redondo Beach, California
Watkins-Johnson, Palo Alto, California
Wavecom, Northridge, California^{1/}
Westinghouse, Baltimore, Maryland
Wiltron, Palo Alto, California

C. FINDINGS SUMMARY

It is extremely difficult to summarize the findings of this case study because the intent was to provide many concrete examples of the forces operating in the technology application process. However, some of the major elements reported on in Part II are:

^{1/} Not prime contractors.

1. Commercial applications and technological requirements. The four general types of commercial application of communication via satellite are described in terms of the generic technological requirements or characteristics of each. The first commercialization was in the International system which came in the form of the Intelsat Consortium of which the Comsat Corporation is the U.S. partner. Since the beginning of service in 1965, this system has grown to serve over 40 nations and plans call for service to almost 60 nations by 1974.

The first domestic Broadcast Distribution system will be the Canadian Telesat system scheduled for operation in 1973. In the U.S., eight applications to provide various mixes of domestic service are pending before the Federal Communications Commission. There are no commercial plans for Direct domestic systems, as yet, although a demonstration experiment for such a system in India is planned for 1974. The first all-commercial system of the Mobile type will be in air traffic control and navigation. A prototype system for trans-Atlantic flights is planned for 1975, with service over the Pacific following a year later.

Table 2 summarizes the technological requirements of the four classes of application.

2. Technological history of communications satellite research and development. The significant programs which contributed to the satisfaction of the technical requirements are described in the basic MRI report, as are the technical content of each program, and the advances associated with each. Particular emphasis is placed on the ECHO project--a passive communications satellite, TELSTAR and RELAY--medium altitude active repeater satellites and the ADVENT, SYNCOM, and ATS programs--synchronous communications satellites.

The purpose of this historical review is to illuminate some of the key technical developments that led, cumulatively, to our present knowledge and capability in the communication satellite field. The review demonstrates that dramatic progress has occurred across a broad technological front. This is illustrated by the fact that we have had a commercial communication satellite system in operation for six years, while only slightly more than 10 years ago many experts had serious doubt that:

- * Satellites could be placed in synchronous orbit before 1970.
- * Satellites could survive in space, and operate long enough to be economically viable.
- * The quality of satellite communications transmissions would be acceptable.
- * The cost of satellite systems would be competitive with traditional earth-based communications.

[Faint, illegible text covering the majority of the page, likely bleed-through from the reverse side.]

110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200



TABLE 2 - REQUIREMENTS FOR FOUR TYPES OF COMMERCIAL COMMUNICATIONS SATELLITES

TYPE OF SATELLITE	TOTAL SYSTEM					SPACE SEGMENT					EARTH SEGMENT				
	SYSTEM LIFE (Yrs. Min. to Max. to 1)	OPERATING CHARACTERISTICS	ORBIT STATION TURNING	SATELLITE POWER	SATELLITE ANTENNA	SATELLITE TEMPERATURE	CHANNEL CAPACITY	DOWN-LINK FREQUENCY	GROUND STATION BANDWIDTH ANTENNA	UP-LINK FREQUENCY	GROUND STATION BANDWIDTH ANTENNA	GROUND STATION RECEIVER			
INTERNATIONAL SATELLITE (Point-to-Point)	All types of service used for international service (e.g., tele-voice, data).	Multiple modes, multi-rate access. System must be able to handle a wide range of services. Power consumption must be low.	Spot beam, geostationary or low-orbit. 10-12 degrees of stabilization tolerance.	Medium power (100-1000 W). Has been power limited in past. Future may be bandwidth limited.	May be bandpass or high density. High density could use 4-degree beam to ground. Medium density could use 2-degree beam to ground.	Multiple access. Non-linear components. Non-linear components must be minimized.	Multiple channels. Bandwidth utilization of satellite: 10-20 TV channels per transponder. (Future possibility.)	3.700-4.200 GHz. Higher frequency, higher gain than lower frequency. (Future possibility.)	Large high gain antennas (10 ft. diameter) with steerable elements. Interference to other systems must be minimized.	3.700-4.200 GHz. Higher frequency, higher gain than lower frequency. (Future possibility.)	Large high gain antennas (10 ft. diameter) with steerable elements. Interference to other systems must be minimized.	High gain, high resolution, wide bandwidth receiver. High resolution, wide bandwidth receiver. (Future possibility.)			
BROADCAST SATELLITE (Point-to-Multipoint)	Primarily voice and data. May be used for other services. (e.g., TV, data, facsimile, etc.)	Specialized equipment. High power (100-1000 W). Multiple modes. High power consumption. High power consumption.	Spot beam, geostationary or low-orbit. 10-12 degrees of stabilization tolerance.	Medium power (100-1000 W). Has been power limited in past. Future may be bandwidth limited.	May be bandpass or high density. High density could use 4-degree beam to ground. Medium density could use 2-degree beam to ground.	Multiple access. Non-linear components. Non-linear components must be minimized.	Multiple channels. Bandwidth utilization of satellite: 10-20 TV channels per transponder. (Future possibility.)	3.700-4.200 GHz. Higher frequency, higher gain than lower frequency. (Future possibility.)	Large high gain antennas (10 ft. diameter) with steerable elements. Interference to other systems must be minimized.	3.700-4.200 GHz. Higher frequency, higher gain than lower frequency. (Future possibility.)	Large high gain antennas (10 ft. diameter) with steerable elements. Interference to other systems must be minimized.	High gain, high resolution, wide bandwidth receiver. High resolution, wide bandwidth receiver. (Future possibility.)			
DIRECT BROADCAST SATELLITE (Point-to-Point)	TV and voice direct to home. May be used for other services. (e.g., TV, data, facsimile, etc.)	Mixed system, multi-rate access. High power (100-1000 W). Multiple modes. High power consumption. High power consumption.	Spot beam, geostationary or low-orbit. 10-12 degrees of stabilization tolerance.	Medium power (100-1000 W). Has been power limited in past. Future may be bandwidth limited.	May be bandpass or high density. High density could use 4-degree beam to ground. Medium density could use 2-degree beam to ground.	Multiple access. Non-linear components. Non-linear components must be minimized.	Multiple channels. Bandwidth utilization of satellite: 10-20 TV channels per transponder. (Future possibility.)	3.700-4.200 GHz. Higher frequency, higher gain than lower frequency. (Future possibility.)	Large high gain antennas (10 ft. diameter) with steerable elements. Interference to other systems must be minimized.	3.700-4.200 GHz. Higher frequency, higher gain than lower frequency. (Future possibility.)	Large high gain antennas (10 ft. diameter) with steerable elements. Interference to other systems must be minimized.	High gain, high resolution, wide bandwidth receiver. High resolution, wide bandwidth receiver. (Future possibility.)			
MOBILE SATELLITE (Point-to-Point)	For military, commercial, and other services. (e.g., TV, data, facsimile, etc.)	Diversity or spread spectrum. High power (100-1000 W). Multiple modes. High power consumption. High power consumption.	Spot beam, geostationary or low-orbit. 10-12 degrees of stabilization tolerance.	Medium power (100-1000 W). Has been power limited in past. Future may be bandwidth limited.	May be bandpass or high density. High density could use 4-degree beam to ground. Medium density could use 2-degree beam to ground.	Multiple access. Non-linear components. Non-linear components must be minimized.	Multiple channels. Bandwidth utilization of satellite: 10-20 TV channels per transponder. (Future possibility.)	3.700-4.200 GHz. Higher frequency, higher gain than lower frequency. (Future possibility.)	Large high gain antennas (10 ft. diameter) with steerable elements. Interference to other systems must be minimized.	3.700-4.200 GHz. Higher frequency, higher gain than lower frequency. (Future possibility.)	Large high gain antennas (10 ft. diameter) with steerable elements. Interference to other systems must be minimized.	High gain, high resolution, wide bandwidth receiver. High resolution, wide bandwidth receiver. (Future possibility.)			

PRECEDING PAGE BLANK NOT FILMED

16

17



3. Progress inducing roles of a mission-oriented R&D agency.

Several specific solutions to selected technical requirements, traceable to the SYNCOM, ATS, and companion supporting research programs, are described. Table 3 summarizes some examples. The examples were examined to illustrate the several roles and functions played by NASA in promoting the application of advanced technology to communications needs.

Often the public fails to grasp the multiplicity of roles which governmental R&D agencies play in the technological progress processes. Only in instances where complete NASA-developed systems are commercially applied in toto, is the link to the space program readily apparent. Such clear-cut transfers do occasionally occur, e.g., NASA's SYNCOM III became the commercial INTELSAT I, but they are rare. More subtle relationships are more often the rule. Less obvious roles played by NASA in the development and commercial application of technology include:

Conducting in-house research--An example would be the mechanically despun antenna used in INTELSAT. The initial idea came from Kampinsky's laboratory group at Goddard Space Flight Center. Subsequently, Sylvania laboratories did the actual design and fabrication with key assistance from Ball Brothers, Kearfott, and Mechanical Technology, Incorporated. Antenna performance was validated on ATS III and after additional work Intelsat incorporated the mechanically despun antenna in its third generation of satellites.

Generation of new knowledge and understanding--This is achieved by the performance of scientific experiments which provide the basis for technological improvements. The findings of the earth's triaxiality and the mapping and location of "gravitation grave yards" underlay the selection of positions for geostationary satellites so that they might be maintained on station much longer than their station keeping expendable supplies would otherwise permit.

Classic RFP process--In this process application requirements are defined, technical planning is undertaken, these needs are made known in research organizations and the industrial community through the procurement process. This is a traditional and well established way of motivating innovations which often advance the state of the art.

Initial user or initial adopter--Given knowledge of NASA mission and technical requirements, aggressive firms often undertake developments in anticipation of marketing the results to NASA. Cassegrain feed systems, for example, received early impetus via this role and are now the standard approach for large ground stations. Suppliers now enjoy the Intelsat market.

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is crucial for ensuring transparency and accountability in the organization's operations.

2. The second part of the document outlines the various methods and tools used to collect and analyze data. It highlights the need for consistent and reliable data collection processes to support effective decision-making.

3. The third part of the document focuses on the role of technology in data management and analysis. It discusses how modern software solutions can streamline data collection, storage, and reporting, thereby improving efficiency and accuracy.

4. The fourth part of the document addresses the challenges associated with data management, such as data quality, security, and privacy. It provides strategies to mitigate these risks and ensure that data is used responsibly and ethically.

5. The fifth part of the document concludes by summarizing the key findings and recommendations. It stresses the importance of ongoing monitoring and evaluation to ensure that data management practices remain effective and aligned with the organization's goals.

6. The sixth part of the document provides a detailed overview of the data collection process, including the identification of data sources, the design of data collection instruments, and the implementation of data collection procedures.

7. The seventh part of the document discusses the various methods used for data analysis, such as descriptive statistics, inferential statistics, and regression analysis. It explains how these methods can be used to interpret data and draw meaningful conclusions.

8. The eighth part of the document focuses on the importance of data visualization in presenting complex data in a clear and concise manner. It discusses various visualization techniques, such as bar charts, line graphs, and pie charts, and their applications in data analysis.

9. The ninth part of the document addresses the ethical considerations surrounding data management and analysis. It discusses the need for transparency, informed consent, and data protection to ensure that data is used in a fair and ethical manner.

10. The tenth part of the document provides a comprehensive overview of the data management process, from data collection to data analysis and reporting. It emphasizes the importance of a systematic and organized approach to data management.

11. The eleventh part of the document discusses the role of data in strategic decision-making. It explains how data can provide valuable insights into market trends, customer behavior, and organizational performance, enabling leaders to make informed decisions.

12. The twelfth part of the document focuses on the importance of data security and privacy. It discusses the various threats to data security and the measures that can be taken to protect data from unauthorized access and disclosure.

13. The thirteenth part of the document discusses the role of data in performance management. It explains how data can be used to track and measure organizational performance, identify areas for improvement, and implement effective performance management strategies.

14. The fourteenth part of the document provides a detailed overview of the data management process, including the identification of data sources, the design of data collection instruments, and the implementation of data collection procedures.

15. The fifteenth part of the document discusses the various methods used for data analysis, such as descriptive statistics, inferential statistics, and regression analysis. It explains how these methods can be used to interpret data and draw meaningful conclusions.

16. The sixteenth part of the document focuses on the importance of data visualization in presenting complex data in a clear and concise manner. It discusses various visualization techniques, such as bar charts, line graphs, and pie charts, and their applications in data analysis.

17. The seventeenth part of the document addresses the ethical considerations surrounding data management and analysis. It discusses the need for transparency, informed consent, and data protection to ensure that data is used in a fair and ethical manner.

18. The eighteenth part of the document provides a comprehensive overview of the data management process, from data collection to data analysis and reporting. It emphasizes the importance of a systematic and organized approach to data management.

TABLE 3 - NASA'S PROGRAM CONTRIBUTION TO REQUIREMENT SATISFACTION

TYPE OF SERVICE	TOTAL SYSTEM				SPACE SEGMENT				EARTH SEGMENT			
	SYSTEM CAPABILITY (Data, Etc.)	OPERATING CHARACTERISTICS	ORBIT, STABILIZATION, STATION-KEEPING	SATELLITE POWER	SATELLITE ANTENNA	SATELLITE TRANSDUCER	CHANNEL CAPACITY	DOWN-LINK FREQUENCY	GROUND-STATION TRANSMIT ANTENNA	UP-LINK FREQUENCY	GROUND-STATION RECEIVE ANTENNA	GROUND-STATION RECEIVER
INTERNATIONAL SATELLITE SYSTEM	SYNCOM First Synchronous Transoceanic TV	ADVANCED SYNCOM (Single Access) SSBT (Coding and Modulation) (PCM-FM)	SYNCOM III (Stability and Gravity Potential)	A15-I (High Power) (Power Amplifier)	A15-I (Electronic Beam Array) A15-III (Mechanically Dependent Array)	SYNCOM III (Bandwidth 25 MHz) A15-I (Dual Mode)	SYNCOM II & III (Building Block) (Channelization)	SYNCOM II & III (Millimeter Wave)	SYNCOM II (Cassegrain Feeds) A15-I (Parabolic Monopoles) SSBT	SYNCOM II	SYNCOM II (Parabolic) A15-I SSBT (Small Stations)	SYNCOM II (Parabolic) A15-I SSBT (Small Stations)
BROADCAST DISTRIBUTION (Point-to-Multi-Point)		SSBT (Multi-path Protection)	SYNCOM III (Stability and Gravity Potential)	SSBT (High Power Beamforming) (RF Pre-amplifier) (Final Pipe Cooling)	A15-III (Electronic Beam Array) (Global Area Coverage)	SSBT (High Output TWT)			A15-III (12 I/W Multi-Beam Klystrons)	SYNCOM III	A15-I A15-II (Small Stations)	A15-III (Parabolic) A15-I SSBT (Small Stations)
DIRECT BROADCAST SATELLITES (Point-to-Wide Area)	A15-F	SSBT (Digital Multiple Access)	A15-F&G (Low Thrust Jet) SSBT (Flexible Body Effects)	A15-F (High Power Array) (Ship Bump)	A15-F&G (DFT) Deployable Array	SSBT (200 Watt TWT) (Multiplexing High Power RF Components)	A15-F	A15-V (SHE and Millimeter Wave Propagation)	SSBT A15-F (Small and Low Gain)	A15-V	A15-F SSBT (Small, Low Gain)	SSBT A15-F (Small, Low Gain) (S100 Converter)
MOBILE Air Traffic Control (Satellite Communication and Positioning)	Advanced VME SYNCOM III A15-F (Phase)	A15-III (Modem Code) A15-IV SSBT (Coding and Modulation) (Error Correcting Code)	A15-F (Precision Wheel) (Dual Spin) (0.1 Degree)	A15-F (Two Ash Army Drive)	A15-III A15-F	SYNCOM III A15-III (Low Power) (40 Watt Band)	A15-I A15-II	SYNCOM I/II/III A15-F (L-Band)	SYNCOM III A15-I (OPRE)	A15-III (Modem)	A15-F A15-I SSBT (Low Drag Design)	A15-F SSBT (Low Noise Direct)



Preceding page blank

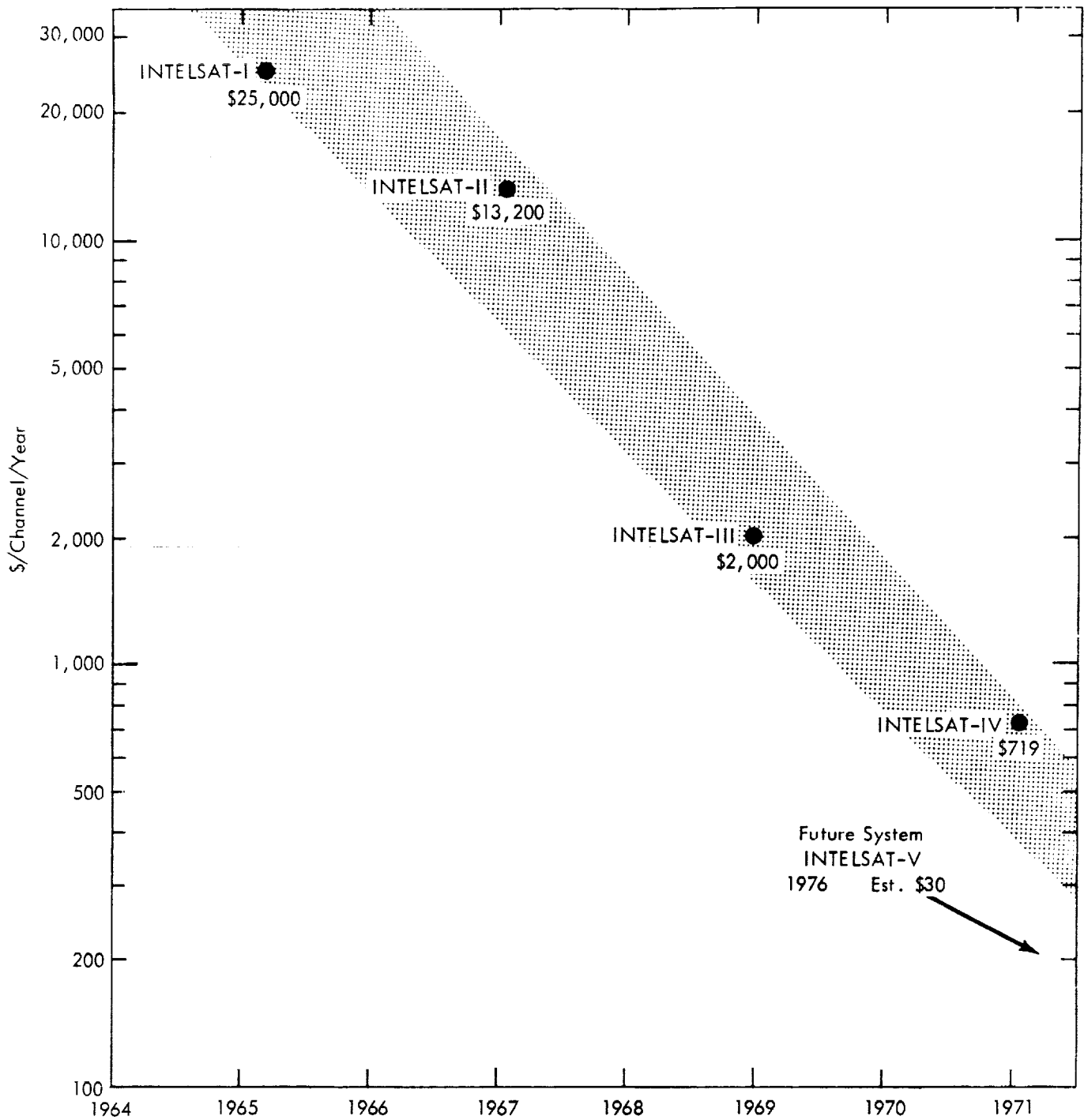
Alternative evaluation--There are almost always alternative, technical paths by which a requirement can be satisfied. NASA in its role as an R&D agency has provided the wherewithal for exploring the competitive advantages of alternatives. Tests of cryogenic masers versus cooled parametric amplifiers is a case in point.

Demonstration to acquire confidence--An important aspect of technological progress is the reduction of uncertainty; NASA flight programs have made many contributions of this type--through the accumulation of operating confidence and predictability. The replacement of earlier pressurized nitrogen and hydrogen peroxide station keeping systems by hydrazine systems depended largely upon acquiring confidence that poppet-valve control systems could be designed to operate trouble-free for several years. The demonstration that this was possible was accomplished on ATS programs. ATS is providing similar demonstrations of the capabilities and limitations in millimeter wave propagation. It should also be noted that demonstration of technical capability often permits the recognition that market demand exists. For example, many experts in 1962 indicated that there were not foreseeable demands for transoceanic television before 1980. AT&T's TELSTAR and NASA's RELAY demonstrated that a viable market demand existed. The ATS India TV experiment is in part designed to demonstrate the existence of another market area.

4. Economic impact of commercial communication satellite applications. Indicators of the present and future economic impact of the development of communications satellite technology and its application in the commercial sphere are provided in the MRI report. Figure 2 compares early estimates of the cost of communication by satellite with the dramatic cost declines actually experienced as the technology evolved. The reductions are striking. Similar cost declines have been experienced in earth station costs (see Figure 3).

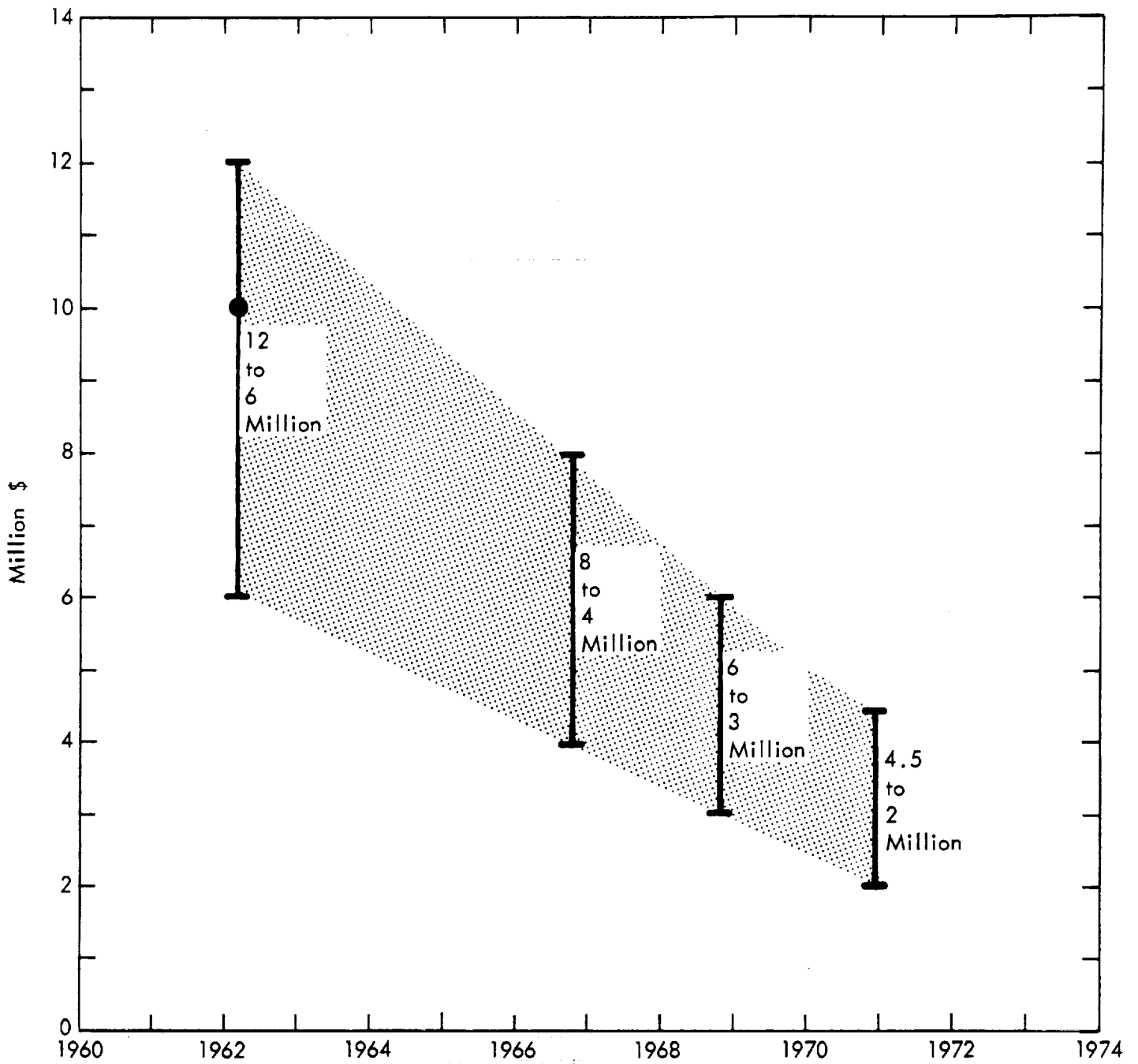
Because satellite communication offers both range of services and cost advantages over preexisting modes, growth in the International application has been dramatic. In its eight years of life prior to 1971 the Comsat Corporation has invested almost \$200 million in equipment and facilities; revenue grew from just over \$2 million to nearly \$70 million between 1965 and 1970. In addition by 1965 Intelsat had reduced its early per channel rental charges over 50 percent and an additional cut of the same magnitude is expected by the mid-1970's.

In spite of the rapid growth of the International application, the economic impact of domestic Broadcast Distribution will be much greater. The total overseas telephone and telegraph traffic is on the order of 50 million messages per year, while over 8 billion domestic long distance messages are carried annually. A total of eight applications for domestic satellite networks is pending before the FCC. The proposed initial investments range from about \$100 million to over one-quarter billion. Several



Source: Jack Eldred Cole, International Telecommunications Policy, Planning and Regulation. Doctoral Thesis, George Washington University, February 1971. Comsat Corporation, Pocket Guide to the Global Satellite System. December 1969 and Comsat Corporation Planning Document, January 1971.

Figure 2 - Dollars per Channel Year vs. Date of First Launch



Source: James B. Potts, Commercial Communication Satellite Earth Stations - Past, Present and Future. AIAA Paper 70-421. Presented at AIAA 3rd Communications Satellite Systems Conference, Los Angeles, April 6-8, 1970. "Satcom Earth Station Business Booming." Aviation Week, Vol. 90, No. 10, March 10, 1969, p. 264+.

Figure 3 - Basic Earth Station Costs

of the applicants have pledged to have their systems in full operation in less than 3 years after FCC approval. In Canada, a \$90 million domestic system will be in full operation by mid-1973. The bulk of the equipment is being supplied by U.S. firms.

The first commercial Mobile application will be an aeronautical satellite system providing communication links for transoceanic airline flights. Current expectations are for an investment in the \$125 million to \$150 million range for a two-ocean system for 1977.

5. Indirect economic impact on aerospace contractors. Most of the firms that performed substantial technical work in developing or experimenting with the NASA communications satellite systems were themselves affected--in a variety of ways--some organizations to a greater extent than others.

Conceivably the most significant finding from study of these contractors is simply that every firm interviewed indicated that their performance of space communications work had produced some residual economic effect. Not all effects were easily identifiable, but the challenge of high technology and the response by the company was stated to have influenced the firm or "left its characteristic mark."

The lasting consequences identified, fell broadly into three classes or types of influences:

a. Internal effects: Some firms modified their processes and procedures, the internal structure of the division, the ways they operated, their management systems, tighter quality control; or perhaps introduced new procurement policies or more efficient production methods. Economic effects from these internal changes are usually known as efficiency or increased productivity.

b. Direct commercialization: The majority of firms studied found ways to utilize the knowledge, expertise, and product capabilities that were augmented through NASA satellite work to establish or to strengthen their position in supplying the needs of commercial satellite systems. Early leaders, having demonstrated experience, became qualified suppliers partly by virtue of the "grandfather clause." However, much more was involved than a simple decision to sell satellite systems to another customer. Procedural as well as technological changes are also required as part of the changeover effort needed to sell to new markets or to commercial users having non-NASA requirements. But all contractors interviewed felt that the economic rewards derived from switching over to commercial sales were worth the efforts.

c. Transfer to non-space, non-satellite markets: Other firms utilized new knowledge, experience, and heightened perception of changing market needs, to transfer emerging or developed skills into new, non-space markets. New ventures, new services, non-governmental markets needing similar skills, and most of what has traditionally been called "spin-off" was found in this category of company effects. The economic effects are hardest to trace here. Seldom was there a direct one-to-one transfer; more commonly the transfer was feasible only because the contract suddenly perceived that a need, a technology and a market were approaching conjunction.

The major ways by which change affects progressive firms, and some of the points at which technical challenge and management response can induce innovations that lead to economic gains is shown schematically in Figure 4.

Technical change does not occur spontaneously; people have to make it happen. The "internalized costs" of innovation are not trivial. These costs include:

- (1) The cost of acquiring new knowledge--about market needs, about external situations, and about the availability of new technology.
- (2) The cost of learning to apply this new knowledge to the satisfaction of economic wants--education and training of production and marketing personnel; feasibility demonstrations and trial marketing.
- (3) The "changeover" costs (obsolescence and sunk-costs) of abandoning old ways and adopting new ways of performing the firm's economic function.

Recent scholarly studies of innovation have unmistakably shown that the force that induces industrial innovation is the economic pull of the marketplace, not primarily the forward thrust of new technology. The costs and barriers that impede the adoption of new technology (such as those cited above), are never easy to surmount. Within large organizations possessing considerable inertia, powerful forces are necessary for the successful introduction of any innovation.

Yet the fact is that innovation does occur, regularly--in both large and small companies. Firms do learn, adopt new techniques, improve designs and enter new markets--because technical change and innovation offers handsome economic benefits. A number of specific examples of this economic force at work were found during the survey of sample contractors.

SOURCES AND TYPES OF TECHNOLOGICAL OR ECONOMIC INNOVATION

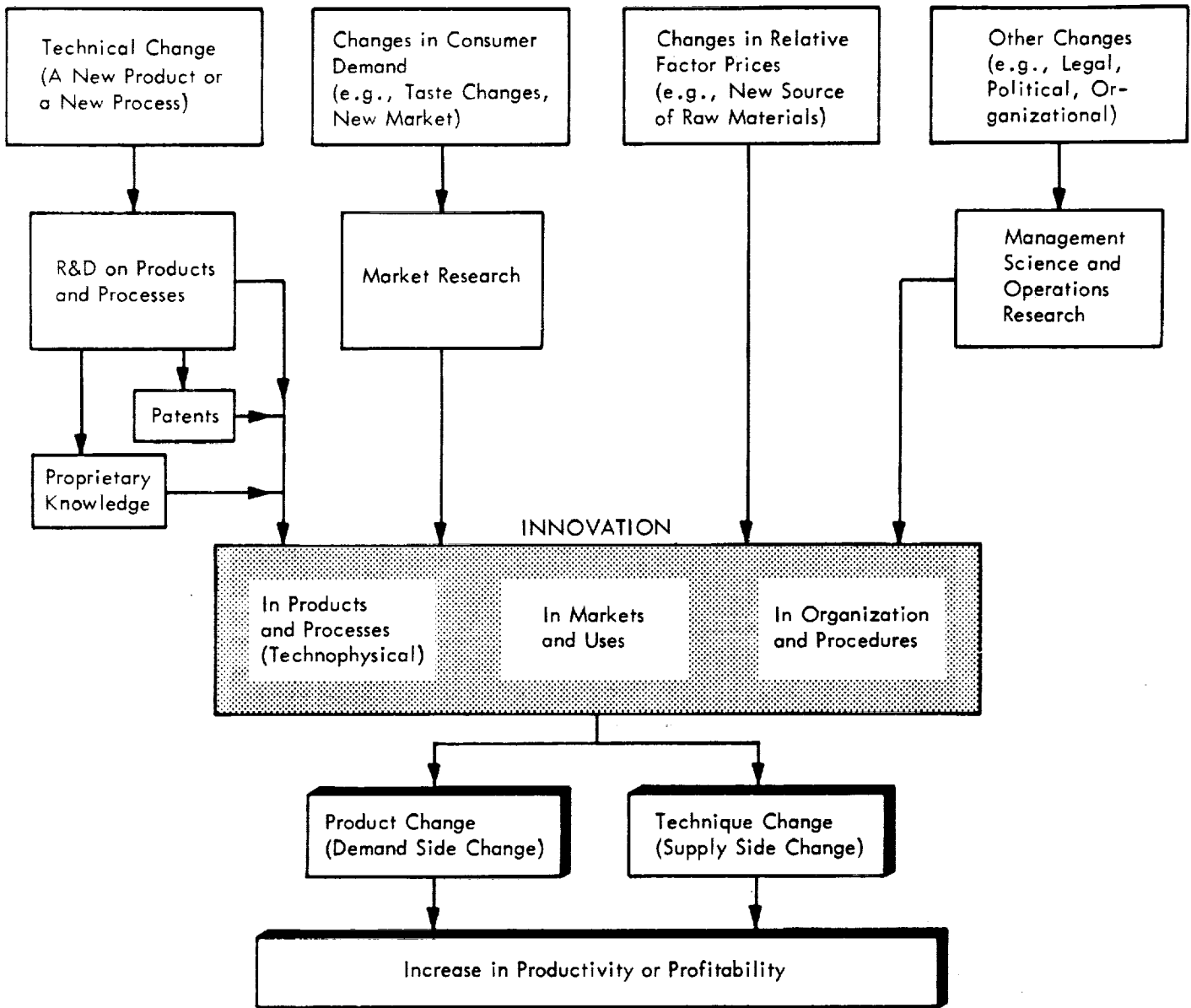


Figure 4

Participation in technically demanding and rapidly developing fields such as the early communication satellites and ground systems, can provide inputs, or act as "forcing functions" at several different points throughout this process as shown in Figure 4. Many of the firms interviewed in this study believed that their participation in space work had influenced one or more of these determinants of productivity or profitability.

Typical examples of how the various companies were affected can best illustrate the consequences of having worked on the communications satellite program. Undoubtedly, further investigation would have uncovered other interactions and, in fact, this list is far from complete, but it typifies the paths to economic gains within some of the firms.

Hughes Aircraft expanded its technological applications abilities into the commercial satellite area by becoming the principal spacecraft supplier to Comsat-Intelsat of the INTELSAT I, II, and IV devices. The old "Fire Control Department," has grown to a space division employing up to 4,000 people. Hughes further strengthened its position in commercial systems when it became the prime supplier of the ANIK satellites for the Canadian system. Hughes is one of the eight contenders for a domestic broadcast system. In a joint effort with General Telephone and Electronics, it proposes to supply the satellites for TV, telephone and other commercial communication links. Hughes also proposes to utilize these satellites as a means for distributing CATV signals to communities across the nation. The aggregate volume of Hughes commercial business springing from the SYNCOM success tops \$300 million.

Watkins-Johnson, a firm with outstanding capabilities in the conventional microwave tube field prior to their NASA involvement, applied technology gleaned from their experience with space qualified traveling wave tubes to their commercial line of devices. By successfully designing a tube compatible with the rigors of space, they were able to further expand their capability into ground based devices, and manufacture tubes with lifetimes far exceeding any prior units. Simultaneously, Watkins-Johnson improved their production expertise in other areas of tube manufacturing. As a further consequence of this NASA work, Watkins-Johnson became a recognized supplier of tubes for space use, and presently ranks as the number two supplier of space TWT amplifiers throughout the world.

Westinghouse Defense and Space Division does business almost entirely with government agencies. In theory, Westinghouse should experience only internal effects--no commercial products, no non-federal markets. Such is not the case, however. The division actively promotes commercial application of gravity-gradient boom devices and color enhancement techniques for TV. Their burn resistant S.E.C. Videcon tube has been an unqualified

commercial success. Among internal changes, Westinghouse management has adopted a program of planned employee rotation from other groups, into the space experiment packaging and integration group, for the explicit purpose of disseminating applicable technology.

Ampex provides a classic example of how a company met a NASA requirement for product standardization and extended the technique to their commercial manufacturing effort. After exploring and adopting methods of standardizing production, applying numerical controlled machining techniques, and modernizing their documentation and traceability in the manufacture of tape mechanisms for space, the practicality of transferring these solutions to commercial systems became apparent. The results were improved tape mechanisms for the many industrial and commercial users of their equipment, at prices substantially lower than had previously been possible. Higher performance standards at reduced cost, in turn, helped to further establish the Ampex position as a leader in sophisticated instrumentation recorders.

TRW Systems exemplifies how technology developed during a decade of satellite work can, with imaginative adaptation on the part of the practitioners, be transferred to commercial areas. Real-time data acquisition, processing and interpretation techniques, so vital for scientific satellites, are being adapted to the solution of problems of electric power distribution demand and control. The firm foresees that they will soon be profitably using similar techniques for the petroleum industry in areas of geophysical exploration, production optimization, and distribution.

The preceding examples clearly demonstrate how work in the space program has had definite--and identifiable--economic impact on the companies cited. Moreover, examples simultaneously illustrate the process by which knowledge--in the form of techniques, basic developments in materials and components and general business management skills--gained through NASA sponsored work has been applied in private sector economic endeavors. These forms of impact are included in the total economic impact of technological progress which was the subject of Part I of this report. The following brief examples are further manifestations of the indirect impacts from space program involvement.

Company Internal Changes

* Hughes Aircraft developed its own in-house components reliability program to such an enviable point that they are now documenting and selling this expertise as a separate marketable entity.

* Rantec has proceeded to develop sophisticated computer-aided antenna design routines, added electron beam welding equipment and skills, become proficient in electro-forming, and specialized in hybrid component

packaging--all technologies that help to secure technological leadership in the production and sale of antenna feeds for government and commercial markets.

* Watkins-Johnson has developed designs and techniques that make possible long-life and impact resistant TWI's. Proprietary arts that make high performance tubes practical have been responsible in part for W-J's growth and expansion from \$3 million to \$40 million sales since 1962.

* Westinghouse found that electromagnetic interference reduction techniques perfected in the packaging of scientific experiments aboard satellites were readily applied to the solution of underwater research problems. Management, recognizing the economic benefits of such technology transfer, subsequently formalized the process by publishing regular company bulletins called "Electromagnetic Design Notes."

* Ampex has altered the basis of their Management Information and Control System, patterning the new procedures after NASA's "fly-on-time" philosophy, and PERT-cost controls. Simpler reporting and tighter controls have resulted in substantial savings.

* General Electric has elected to continue developing its position in high-power, high-performance satellites, rather than compete against pioneering firms in low performance satellite markets. While developing technology needed to hold a commanding lead for this emerging multi-million dollar market, the research work itself has paid its own way. "The net-cash flow has remained positive," said the manager of G.E.'s communications satellite programs.

* Ampex was able to justify introduction of mass production tooling, numerical control drills, matched plate die casting, and other cost reducing technology to cut the cost of instrumentation grade recorders substantially.

* Three firms have contributed to, and been affected by the voluntary industry-wide code format and recording standards promulgated under NASA aegis, which in turn have upgraded instrumentation performance and helped insure compatibility of equipment.

Direct Commercialization of Satellites

* General Electric has established a primary position in supplying modems and other equipment to interface between satellite ground stations and terrestrial communication links. Nearly 8% of the more than \$300 million terminal equipment was produced by G.E.

* Hughes has designed and produced most of the commercial satellites for Comsat and for Intelsat--Early Bird, INTELSAT II, INTELSAT IV. Direct hardware sales of \$142 million are presented through INTELSAT IV-A.

* Sylvania Electronic Systems--formed a new division called General Telephone Electronics International to supply the commercial satellite market. This division, currently employing 100 people, has furnished major portions of over 40 earth terminals.

* Hughes Aircraft is now producing Canada's domestic satellite "ANIK." Together with Hughes' Canadian associate, Northern Electric, Ltd., this contract will generate \$32 million plus performance incentives.

* Rantec has become a standard supplier of cassegrain feed systems for earth stations in many countries. Costs of ground stations have become considerably lower over the years.

* TRW Systems (who in 1963 acquired the pioneering Space Technology Laboratories) became the second source for commercial satellites, as the spacecraft prime contractor to Comsat for the INTELSAT III series. The eight commercial satellites represented \$57.6 million in sales.

* ITT has produced 40 ft, 85 ft, and 30 meter diameter antennas for use with INTELSATS II and III. Worldwide sales of ITT satellite and ground station commercial equipment total \$75 million to \$100 million.

* Sylvania Electric has transferred directly to commercial sales for eight satellites of the INTELSAT III series, the technology of mechanically despun antennas developed by Sylvania for NASA's ATS III. The satellite customer directed TRW, the spacecraft contractor, to procure this technology and associated equipment from Sylvania.

* General Dynamics work in R&RR systems is considered a great asset in two out of three proposed Air Traffic Control satellite systems. This development scheduled for trial flight in 1974 represents a market of several hundred million dollars.

* Electronic Communications Incorporated has developed one-man transportable field terminals to work with satellites.

* ITT's solid state UHF amplifiers have formed the basis for several of the latest communications satellite transponders.

* ECI's pioneering work with circularly polarized loop-vee antennas has led to extensive commercial work with ocean buoy data relay systems using satellite data collection. When ERTS and other data collection systems are implemented, many thousands of small antenna systems will be required.

Transfer to Non-Satellite, Non-Space Markets

* Hughes Aircraft: Venture into CATV systems. The market for CATV is growing more than 35% per year; and 1971 operating revenues of \$375 million were up 21% over 1970.

* Watkins-Johnson: Tube reliability permitted offering a 1-year unqualified warranty on traveling wave tubes used in commercial test equipment.

* Martin Marietta: Five spin-off firms established by employees formerly working on NASA ATS-V. These small businesses employ 44 people selling exotic components and services to commercial markets.

* Martin Marietta: Currently applying millimeter wave technology to terrestrial computer links for dedicated and time-share services.

* General Dynamics: Two successful commercial companies spawned: RF Communications, and Scientific Products, Inc.

* TRW Systems: Presently applying space data handling and reduction techniques to electric power load distribution, demand and control to eliminate "brown-outs." TRW states that they hope to capture a fair share of this market, judged to average \$100 million per year over the next 6 years.

* Martin Orlando is applying satellite switching and systems techniques to the optimization of post office mail handling problems; and also to the improvement of airport design layout, efficient handling of baggage and passengers, as well as air traffic safety control.

* Watkins-Johnson has adapted techniques for rugged tube production to enter a new field--that of portable, lightweight (6 pounds total unit) industrial X-ray inspection equipment.

* Martin Marietta, having perfected techniques for producing large yttrium aluminum garnets for millimeter wave work, is seriously contemplating entry into the synthetic diamond market--which has already attracted other aerospace firms such as Litton Industries and General Electric. Synthetic diamonds currently enjoy annual sales of \$12 million and experts forecast growth at the rate of 15% per year for the next 5 years.

PART III

CASE STUDY--KNOWLEDGE ADDITIONS AND EARTH LINKS FROM SPACE CREW SYSTEMS

A continuing stream of scientific and technological knowledge is an essential part of the process of public and private "want satisfaction" through applied technology. The technology application process examined in Part II is dependent upon a continual replenishment, extension, and refinement of an underlying knowledge reservoir. Since knowledge is a necessary precondition to the achievement of any goal or the solution of any problem, it is appropriate to ask: What sort of knowledge have we obtained from our investment in the space program and what relevance does it have for us down here? Part III is addressed to these twin questions.

A. THE KNOWLEDGE BANK

What does the knowledge bank consist of? In simplest terms, it is everything known to man. The bank can be stratified in a number of ways, one of which is a spectrum ranging from knowledge on basic phenomena to manufacturing know-how. Also embodied in the knowledge bank are many grades of accuracy or precision. As the problems we address become more complex, additions and refinements to the knowledge bank are essential. Another characteristic of the knowledge bank is that the information in it usually contributes to the solution of problems beyond those visualized by the original developer. Thus, the ultimate utility of any piece of know-how cannot be assessed at the time of its generation.

What are the mechanisms by which we add to and refine the knowledge bank? There are many. At one extreme, we have basic research; at the other we have the individual innovator faced with a very specific problem. Somewhere in between the extremes is so-called mission-oriented research, of which the space program is an example. Since mission-oriented R&D programs typically stretch some aspect of the state of knowledge and ultimately culminate in hardware, they often make broad contributions to the knowledge bank--in the basic and applied sciences, in several engineering fields, in manufacturing processes, in analytical techniques, and so on.

We chose to examine the contributions expected of mission-oriented R&D by a case study of those aspects of the manned space program directly related to human life support and work performance in space.

B. WHY STUDY CREW SUPPORT

On the surface, about the last way one might expect to generate useful down-to-earth knowledge would be from putting man into space. It is obvious to all that about every characteristic of the space environment is different than its counterpart down here on earth. Space is a hostile, uninhabitable environment. Man must be encapsulated (spacecraft or space suit). The exterior of the capsule must protect against space hazards. The inside must provide an environment suitable for life. Performing the simplest earthly tasks and functions during space flight requires elaborate planning and provisioning.

Providing acceptable solutions to everyday human performance under the strict and unforgiving discipline imposed by space flight conditions posed a tough technical challenge. But, critically important from the rational viewpoint, the very process of reexamining man's needs in these new lights, required new inputs and provided a sharp stimulus to better understanding of ordinary functions--like breathing or sweating, or bending at the waist.

To design life support systems for space, the engineers must have comprehensive guidance on the interactions between man and his environment. Because man is complex, knowledge on these interactions was incomplete at the time that the space program was launched. It has been difficult, given our knowledge base, to specify and provide some form of optimal environment here on earth. Real difficulties begin, however, when the optimum environment is not attainable. At the present time, it just is not possible to take into space all of the things that man is used to here on earth. Thus, the task becomes one of deciding what to take along. This requires that physiologists and related medical specialists be able to state as clearly as possible the penalties associated with departing from the optimum environmental state.

Much of the information necessary to make the penalty assessments was not available. Therefore, scientists had to undertake research. Physiologists and others had to become much more precise in their understanding of human life requirements.

The research undertaken made it possible to specify the life support requirements for different space missions. These, in turn, provided guidance to the design engineers charged with the design of equipment and systems which would meet the requirements. In many instances, the knowledge available to engineers in their own fields was inadequate for the task at hand--in much the same way that physiologists' knowledge of requirements was lacking. Research was supported to develop data and extend the available engineering knowledge.

Given the design, it was then necessary to manufacture and test the equipment for the space flight. In many instances new knowledge was necessary in this area, too -- new materials were required, tolerances were smaller, reliability had to be higher, and so on.

Thus, a case study of knowledge contributions from the crew support aspect of the manned space program seemed in order.

C. RESEARCH PROCEDURE

The basic research technique employed in the study was personal interviews with NASA contractor and NASA laboratory personnel. Selection of interviewees was made following a series of computerized searches of the NASA RECON information system. These searches disclosed that in excess of 160 contracts and supporting studies had been performed within the crew support area. Clearly, all these participants could not be contacted within the resources allocated to this study.

Industrial contracts for system fabrication were given preference over academic grants and considerable weight was given those groups involved in the development of equipment for extravehicular activities. Nine company groups, the Air Force School of Aviation Medicine and two NASA laboratories were selected for personal interview.

The interview procedure was quite simple. Several participants in crew systems research and development at each firm or lab were asked:

- * What did you have to learn in order to do your part of the manned space program, i.e., what was known and unknown when you began?
- * What sort of solutions did you develop and apply?
- * How--if any way--does what you learned or what you did relate to earthly problems?

During the course of the interviews, several additional organizations that had made key contributions to the crew support effort were identified. The facts surrounding the contributions of 14 were subsequently obtained via telephone and literature review.

The final step in the research program was to synthesize the findings of the individual interviews and develop an organized presentation format.

D. THE FINDINGS

In the process of devising systems needed for space crew support and extravehicular activity, a surprisingly large amount of new and extended knowledge was acquired. These contributions to available knowledge span a wide range--from understanding of basic phenomena to specific processes and devices.

Even though this knowledge was derived from satisfying specific space mission requirements considerably removed from normal earthly problems, the knowledge gained appears relevant to many current domestic concerns. The ultimate impact, while impossible to specify at this time, may be widespread and significant.

Ten to twelve illustrations of new or improved knowledge were noted in each hour to hour and one-half interview, and most of the knowledge gained had some relationship to needs here on earth. In total, Part III of this report presents over 130 illustrations--identified during our limited number of interviews--wherein knowledge additions are traceable to the crew systems effort of the space program. Part III is arranged in terms of nine requirements which have to be met to maintain man alive and productive in space. Each space requirement and the work undertaken toward its satisfaction is briefly described. Then, capsule summaries of each knowledge contribution illustration--traceable to a requirement--are provided, and the actual and potential linkages to earthly problem satisfaction are indicated.

The nine space requirements, the number of knowledge addition illustrations attributable to each, and the number of knowledge contributions contained in the illustrations are:

<u>Space Requirement</u>	<u>Illustrations</u>	<u>Knowledge Contributions</u>
Supply Breathable ATMOSPHERE FOR SPACE	13	48
Metabolic CARBON DIOXIDE--REMOVAL	9	40
RECYCLING	13	40
CONTAMINANT CONTROL AND REMOVAL	15	54
Maintain THERMAL BALANCE	24	111
Space HAZARDS--DECOMPRESSION, RADIATION, METEORITES AND FIRE AND BLAST	17	75
Provide Adequate LIGHT AND VISION	17	70
Provide MOBILITY AND WORK CAPABILITY	23	79
Provide Adequate HABITABILITY	<u>6</u>	<u>14</u>
Total	137	531

The knowledge contributions contained in the illustrations span the full range of the knowledge bank: from better understanding of basic phenomena, through design and engineering, through materials and production processes to individual products and markets. Table 4 indicates the contributions in 11 categories.

Many illustrations embody more than one category of contribution. In fact, the average is about four per illustration. For example, a typical illustration might involve the intensive study of an incompletely understood phenomenon, together with an extension of our knowledge into a totally new regime, and the development of improved fabrication and processing techniques.

In general, the contributions occur most frequently in the design and engineering portion of the spectrum. Otherwise, there is a slight weighting toward the phenomenon end of the scale, with immediately applicable production and product contributions being slightly less frequently encountered. Overall the distribution of contributions follows the pattern which would be expected given the challenging nature of the space requirements.

Similarly, the significance of the contributions is representative of the nature of scientific and technological progress. About 10 percent represent step changes in our knowledge, i.e., those which effectively changed the state of the art or established a new standard in a field. Most of the contributions were incremental advances (44 percent) in either scientific understanding or technology, or were consolidation of technology (46 percent). The latter being instances where several existing concepts were consolidated and integrated to achieve the desired end.

The utility of the knowledge is not confined to space but is also relevant to a number of down-to-earth issues. Table 5 summarizes the linkage of the contributions to 13 categories of earth utility. In total almost 200 links were identified. All may not come to pass, instead other less obvious linkages may emerge. Predicting areas of greatest utility for given pieces of new knowledge has been subject to significant oversights throughout history. Thus, the linkages on Table 5 are those which seem most clear to the authors; they are offered only as indications of ultimate impact. But, the breadth of actual and potential impact is such that the linkage to earthly problem solution--of the space-induced knowledge additions--is apparent.

Ten typical illustrations are presented in the balance of this summary volume to provide a more concrete "feel" for the types of contributions and linkages encountered in our survey.

TABLE IV

CONTRIBUTION CATEGORIES	Space Requirements									
	Atmosphere	CO ₂ Removal	CO ₂ Recycle	Contaminants	Thermal Balance	Space Hazards	Light and Vision	Mobility	Habitability	
Newly Recognized Phenomena	2	1	2	1	4	1	1	1	1	
Little Understood Phenomena	9	8	5	9	9	7	13	4	2	
Baseline Data	3	6	2	5	6	3	4	1	1	
New Regimes	4	3	9	10	15	13	16	4	4	
Research and Measurement Techniques	1	6	5	10	10	13	15	4	4	
Materials	3	3	2	6	11	8	8	1	1	
Design Refinement	7	6	2	5	3	6	10	1	1	
Fabrication and Processing	8	1	4	8	5	6	8	8	-	
Manufacturing Operations Control	3	3	6	3	1	4	-	-	-	
Products	7	2	3	4	8	8	4	4	-	
Market	1	1	-	1	3	1	-	-	-	
Total	48	40	40	54	75	70	79	14		

TABLE V

EARTH LINKS	Space Requirements								
	Atmosphere	CO2 Removal	CO2 Recycle	Contaminants	Thermal Balance	Space Hazards	Light and Vision	Mobility	Habitability
Health and Medicine	1	2	1	4	4	1	6	1	1
Diagnosis	3	-	-	1	2	-	1	-	-
Treatment/Therapy	1	-	3	1	2	-	-	-	-
Surgery	1	-	-	1	2	-	-	-	-
Prevention	1	5	1	1	-	-	-	-	-
Food and Agriculture	2	-	-	-	-	1	-	-	1
Mining	-	-	-	-	3	-	2	-	-
Construction	-	-	-	-	-	5	-	-	-
Industry	5	4	3	2	3	1	1	-	-
Processes	2	1	1	3	1	4	7	1	-
Design and Engineering	1	1	4	8	1	4	1	-	-
Job Content and Safety	3	-	1	1	5	10	1	-	-
Transportation	2	-	-	5	-	-	-	-	-
Energy	2	-	11	-	-	-	-	-	-
Environment	1	-	-	-	-	2	2	-	-
Emergency Services	2	-	-	3	1	2	2	-	-
Leisure and Recreation	-	-	-	-	-	3	-	-	-
Education and Training	1	-	-	2	1	1	-	-	1
Households	-	-	-	-	-	-	-	-	-
Research	3	1	-	4	4	1	-	-	-
Total	30	13	25	35	26	29	23	3	3

FLOW
RESISTANCE
REDUCED

Capability to design and construct heat exchanger cores requiring minimum air flow across the fins and low flow resistance across the exchanger has been (greatly) extended.

Earth link--Achieving highly efficient transfer of heat requires that the air flowing over the fins be continuously mixed. The achievement of designs and equipments which induce precisely correct air turbulence while minimizing flow friction required several advances. The effect is the present existence of heat exchange units which are very efficient, minimize noise, and have lower blower power requirements, i.e., smaller, quieter air-conditioners.

THERMAL BALANCE

HEAT
PIPES

To maintain space suit thermal balance, heat pipes have been adapted to transmit metabolic heat through the pressure garment and into space. Several innovations were achieved: (a) A controllable heat pipe or "Thermal Switch" was created, permitting heat flow to be modulated by a throttling valve, or if desired, operated in an on-off fashion. (b) The first flexible heat pipes were developed. Flexible heat pipes maintain contact with the skin of the astronaut, yet permit normal body movement within space suits (both "hard" suits, and the more common fabric pressure suits). (c) Improved heat pipe materials, wicks, working fluids and construction techniques were developed and tested. Techniques were devised to prevent freeze-up, and to make heat pipes which were inherently capable of re-starting after solidification of the transfer fluid.

Earth link--TRW Systems Division, which developed heat pipes suitable for cooling space suits, has since granted licenses for use of this technology for industrial process furnaces. A major use of these furnaces will be the production of semi-conductors (which require extremely uniform heat treatment). Other heat pipe applications range from the processing of jet aircraft turbine blades to cooling nuclear reactions. A manufacturer in New Mexico has acquired rights to market a household "cooking-pin." This culinary aid uses the heat pipe principle to transfer oven heat to the center of a roast or turkey, reducing cooking time by one-half.

TRW Systems Division has also built an environmental test chamber at the Manned Spacecraft Center, which is possibly the world's largest heat pipe. This chamber automatically maintains completely uniform temperatures throughout the 45 ft long, 14 ft cylindrical room.

CONTAMINANT CONTROL AND REMOVAL

Compact distillation equipment has been developed that is capable of long term operation without loss of efficiency or need for maintenance. Two techniques, vapor compression distillation and vacuum flash distillation, each offer several advantages for processing heat-sensitive materials.

IMPROVED VACUUM EVAPORATORS

Fundamental studies in vacuum evaporation were required. Available knowledge on water jet injection theory and design data were judged inadequate to insure the achievement of the ultrafine, low velocity droplets necessary for highly efficient flash distillation units. Fuel injection theory developed for rocket engines was adapted to water atomization.

Earth link--Although developed by NASA to purify water, the knowledge adds to the technological base underlying a number of commercial processes which remove water from heat-sensitive products. Spray drying in vacuum chambers is the process employed in the production of "instant" food products, e.g., instant coffee and soups, dry nonfat milk, etc.

CONTAMINANT CONTROL AND REMOVAL

COORDIN- ATION TESTER

A compact coordination tester has been developed to determine the effect of atmospheric contaminants on astronaut performance. This device permits measurements of hand-eye coordination in several tracking and pursuit tasks, and the influence of toxic materials and fatigue can be determined.

Earth link--This Langley device has been demonstrated to Driver Education officials in California and was found to be suitable for testing driver coordination. The Environmental Protection Agency has found the tester useful for measuring effects of air pollutants, carbon dioxide and monoxide on driver performance. The degree to which alcohol degrades driver ability can also be tested.

LIGHT AND VISION

OPTICAL GRADE POLY- CARBONATE SHEET

Optical quality, premium grade polycarbonate sheet plastic was developed and produced initially for the Apollo helmet. Standards and quality control procedures plus contamination free processing facilities and techniques (clean room procedures) necessary to upgrade extruded Lexan sheet were developed. The improved plastic has closely predictable thermal processing characteristics and enhanced solvent resistance, together with superior optical properties. The manufacturer states that material of this quality would not have been developed without the helmet requirements.

Earth link--The improvements in production procedures and material properties have contributed to the production know-how applied to a variety of optical polycarbonate applications. Safety, riot control and motorcycle helmet faceplates, aircraft windows or canopies, plus screens around hockey rinks are examples.

LIGHT AND VISION

EYE MOTION MEASUREMENT

A NASA designed oculometer that measures eye movements in carrying out search and discrimination tasks makes it possible to determine the speed and efficiency with which the eyes process information within the visual field. Persons engaged in activities requiring vigilance and highly developed discrimination can be aided by training based on oculometer data.

Earth link--Conventional oculometers operate by shining points of light on the eyes which are photographed to provide eye movement tracks while the subject is performing visual tasks. The new oculometer is nonintrusive because it uses near infrared light. In addition, it provides real time eye movement tracings which are displayed on a screen. Thus, an instructor can coach the pupil in improving eye use. The extent to which the person under test can or cannot follow a particular eye movement procedure provides a means of testing concentration and alertness. The oculometer has utility in training air traffic controllers and quality control inspectors, in reading analysis and psychological testing, and for studying the early development of the oculometer system in children.

**FLURO-
ELASTOMERS**

NASA's search for elastomers that would not burn in oxygen prompted Minnesota Mining and Manufacturing Company to submit samples of several new experimental rubbers--all based on copolymers of hexafluoropropene vinylidene fluoride. All samples exhibited good physical properties, but burned under spacecraft conditions. The 3M Company modified their products to obtain an elastomer tailored to Apollo requirements. Fluorel rubbers resulted. Viton, another fluoro-substituted rubber was similarly modified to meet space requirements.

Earth link--These elastomers have the capability for use in a variety of oxygen-rich environments. Anesthesia hoses and masks from the material would reduce operating room flammability risks, for example. The material is being used in the interior decorative panels on commercial aircraft to reduce the possibility of fire spread and smoke production. They are also finding use as an upholstery coating in aircraft.

ATMOSPHERE FOR SPACE

**STABLE
OXYGEN
SENSORS**

New and improved types of oxygen measuring instruments were developed because of the importance of monitoring oxygen concentration in space.

The space requirement encouraged the development of miniature stable polarographic oxygen sensors that need only infrequent calibration, and are rugged and inexpensive enough for rather wide use.

Earth link--Measurement of oxygen content in air and liquids has traditionally been a cumbersome and sensitive operation. Winkler titration and gas chromatographic techniques have been the most common procedures. Both are laboratory procedures. Polarographic oxygen sensors have been employed but electrodes previously available were unstable and required recalibration for each use. The new membrane type polarographic sensors are extremely stable and permit direct readings of oxygen content. They are being used in water pollution and oceanographic studies, for measuring dissolved oxygen and as pocket size hypoxia warning devices for mine safety.

**ELECTROLYTIC
OXYGEN
SUPPLY**

Water electrolysis systems capable of furnishing crew oxygen have been developed and operated for more than 10,000 hours to demonstrate reliability. The vapor phase water feed system designed to permit zero gravity operation, while not needed for that purpose when operated on earth, is largely responsible for the long term, troublefree operation of these units. The operating life of previous electrolysis units was typically limited to 1,000 hours.

Earth link--At present there are a number of situations which require that oxygen be stored at high pressure. This is an inherently hazardous procedure. If impurities in minute quantities (dirt, metal chips, or organic contaminants) are present in the system during filling, an oxygen fire may occur, often resulting in rupture of the pressure system and rapid spread of the fire. In spite of elaborate safety procedures there have been several major commercial aircraft fires of this sort (all on the ground).

This electrolysis system is being tested for military aircraft, and is under consideration to replace high pressure oxygen for emergency use by commercial airline crews. The system provides oxygen on demand and does not require storage.

Water electrolysis is also being investigated as a source of oxygen for newborn infants. To prevent eye damage the amount of oxygen supplied to the incubator or isolette must be precisely controlled. Present practice is to measure flow rates of the oxygen being delivered from storage tanks. Greater precision can be obtained by water electrolysis generation of oxygen, because oxygen production is directly related to the supply of electrical current to the unit. A related instance in which electrolysis systems may prove apropos is in the supply of supplemental oxygen to persons suffering from chronic emphysema or asthmatic conditions.

DIRECT BODY
CALORIMETRY

Direct, whole body calorimetry can now be performed conveniently and accurately on a dynamic basis, by recording heat transmitted to liquid cooling garments. Previous techniques were indirect or restricted in the extent of human activity permitted, or had slow response rates which precluded study of thermal transients.

Earth link--Prior to the application of the liquid cooled garment to dynamic calorimetry studies, it was necessary to use secondary measures of metabolic heat production (e.g., oxygen consumption) or rigid calorimeter chambers. Now direct metabolic heat measurements are possible, the equipment has considerable flexibility and places few constraints on the study subject. Direct calorimetry is being employed on a number of research topics, including: physiological research on basic body homeothermic and metabolic processes; medical research on fever and antipyretic treatments, on diet--such as the specific dynamic actions of various classes of nutrients; on metabolic disorders--such as thyroid function; on the various types of shock and the physiological processes involved, and on heat exhaustion and sunstroke investigation; in industrial hygiene for the study of workers in hot and cold environments for the establishments of work standards and practices; and even in the study of athletic stamina and endurance.

* * * * *

The findings of this study indicate that the long-term economic benefits of the space program are much more profound than superficial examinations would indicate, and that the importance of technological progress to national well-being must not be ignored. However, much remains to be learned about the specifics of how technology interacts with the economy. The investigations reported upon in this five-volume work were performed within the current state of the art. There is a need to extend and refine our knowledge on many aspects of advancing technology and its economic and social impacts. The present researchers hope that this study will encourage others to seek better understanding of the processes involved and more precise answers to the questions we addressed.