ECONOMIC IMPACT OF STIMULATED TECHNOLOGICAL ACTIVITY

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

FINAL REPORT
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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.

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MIDWEST RESEARCH INSTITUTE

John McKelvey, Vice President
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22 November 1971

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF FIGURES

LIST OF FIGURES (Concluded)

LIST OF TABLES

PART II

CASE STUDY--TECHNOLOGICAL PROGRESS AND COMMERCIALIZATION OF COMMUNICATIONS SATELLITES

I. INTRODUCTION

Background and Purpose

Part I of this report answered affirmatively the question: How important is technological progress to the wealth of this nation? It also demonstrated that research and development (R&D) play important roles in generation of technological progress. It was further shown that mission-oriented R&D agencies of the government are particularly important actors in this complex process. 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.

In these examinations, the concern was with the aggregate economic effects of technological progress--with this progress being viewed abstractly as one of the principal growth inducing forces operating in the economic milieu. In this, the second part of the report, we turn to more concrete examinations of the processes whereby these effects are achieved. Questions of the how, why, what kind, and when variety are examined as they relate to the generation and economic application of technological progress.

The complexity of the interactions between technology and the economy almost defies an organized, comprehensive treatment. Technological progress is composed of a few major and countless small incremental advances which are constantly being combined and recombined to satisfy public and private demand. Technology also follows a variety of paths--direct and indirect--in its movement toward application. The mix of participants--public and private--and the roles each adopts also conditions the speed and direction of early and subsequent applications.

The application area selected for this case study was commercial communications via satellite, because it is clearly traceable to technological advances during the last decade and a half. Also, it is the first major direct commercialization of technology to result from the national space program.

Determining Technology's Impact

While Part I of this report took a holistic or overall view of the economic impact of technological progress, Part II examines how impacts of communications satellite technology occurred and how these impacts affect the firms involved. Having seen that the production function relates the three major inputs of a nation's economic output--capital, labor, and technology--we shall determine if any or all three have been activated as a result of NASA's original stimulus in this field.

Of particular importance will be the rapidity and manner of adoption of technology by user or potential user. If communications satellite technology, or for that matter any other technology, is developed and then lies dormant, its worth to a viable economy could never be realized. Conversely, a technology that is adopted could have an immediate and pronounced effect upon the economy.

However, any assessment of the economic impact of a new technology must still rely on its impetus to the production process. Does industry recognize the market potential of the technology? Is industry eager to invest capital in the commercial aspects of the technology? Are the existing and potential markets for the commercialized technology sufficient to involve a significant amount of labor as well as capital investment? Also, are the companies involved in the commercial application of the technology amenable to and capable of adding to the existing knowledge with internally funded R&D?

Other important questions concerning the economic impact of a new technology deal with the diffusion of the gained knowledge outside the immediate sphere of the initial program. Are other technologies affected in a positive manner? Are there residual or retained benefits from the processes or techniques involved that are generally applicable in other areas? Do any of these peripheral or indirect applications constitute an economic advantage that did not exist prior to the development?

And finally, we are concerned with the effect of the new technology upon people. What are the socio-economic implications? Were the people involved in the development of the new technology able to successfully pursue it further or were they able to transfer their acquired capabilities to solutions of other problems? How will the recipients of the commercialized technology benefit? What are some of the total effects on mankind not involved in the construction of the technology but only in the results? Will a few or many be affected in a positive manner?

A technological event, such as communications satellites, is never traceable to one specific breakthrough. Instead, many different and sometimes seemingly unrelated, incremental advances coupled with a few unique concepts are combined in the overall system. Some of these single occurences are quite naturally more easily traced than others. A few will almost surely defy any objective analysis.

Part I of this report viewed the technological event's impact in its entirety. All direct and indirect impacts were summed together. In tracing some of the "hows" of the total event in Part II, we will fractionate the total process. By demonstrating some of the individual aspects of the NASA supported program, we will show how an effort of this complexity was successfully managed or controlled. The implication of such an analysis is beneficial in that it provides a structural paradigm for managing the application of technology to other efforts, both large and small.

Research Procedure

Appendix A describes the research methodologies employed but the major steps can be summarized as follows:

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: 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 for air traffic control or accurate position fixing.

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 of a representative set of contractor companies that participated in the SYNCOM and ATS programs.

7. Interviews with these firms to identify the extent and ways in which they have participated in the commercialization of satellite communications, and indirect applications of technological capabilities accumulated during their participation in the space program.

Presentation Format

Figure 1 indicates the elements covered in the report, showing how participants in the technology development and application process relate to each other, and how these relationships interact to create economic impact. The chapter organization of the presentation is as follows:

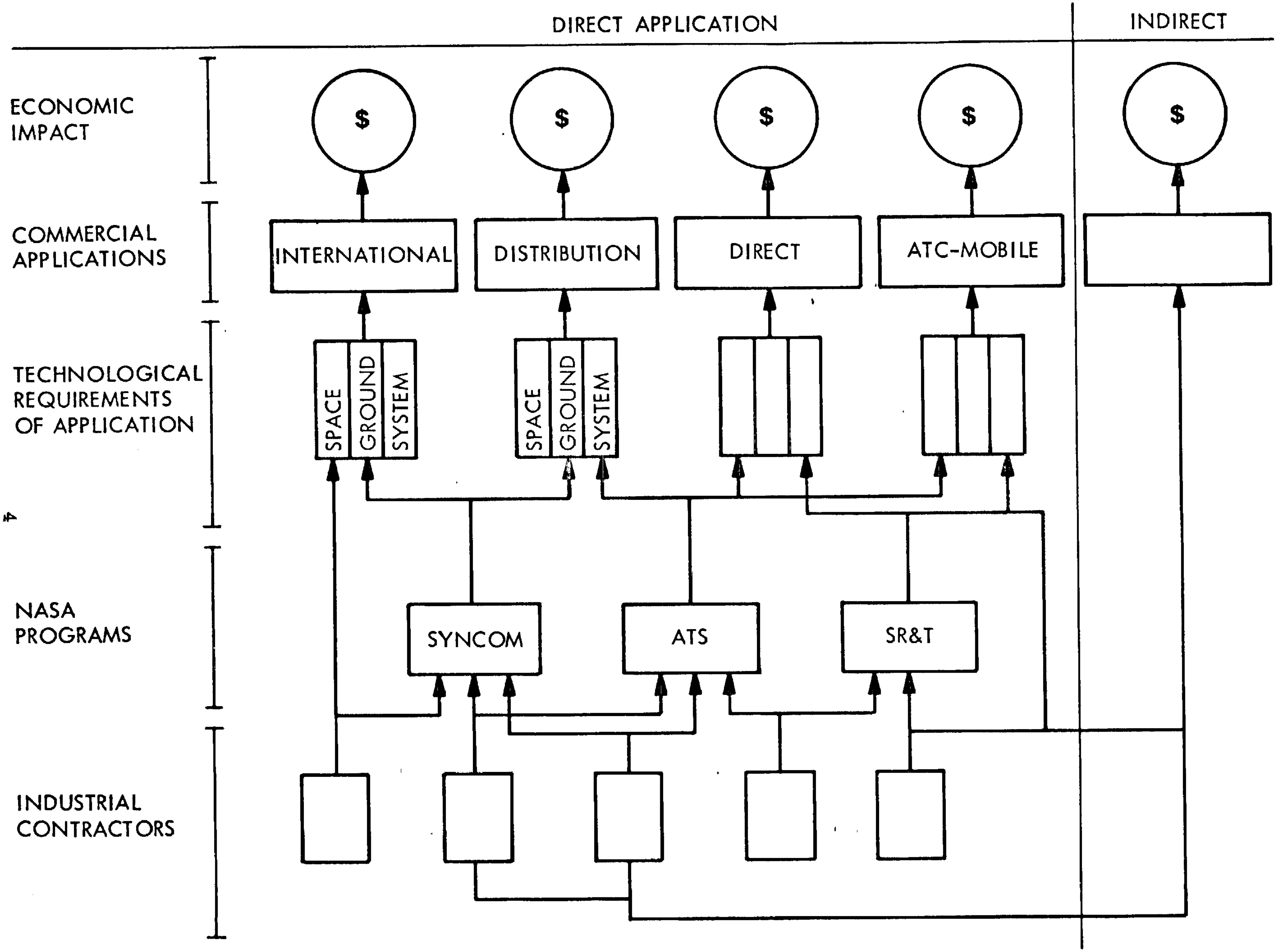

Figure 1 - Technology Application and Economic Impact

Chapter II - Technological History of Communications Satellite Research and Development: Describes significant programs which produced the necessary technology for communications satellites.

Chapter III - Commercial Applications and Technological Requirements: Describes the four general types of applications and the technological requirements which have to be satisfied before commercialization is achieved.

Chapter IV - Progress Inducing Roles of a Mission-Oriented R&D Agency: Describes specific solutions to selected technical requirements and the several ways that NASA interacted with the process.

Chapter V - Economic Impact of Commercial Communication Satellite Applications: Provides indicators of the present and future economic impact of communications satellite technology and its application in the commercial area.

Chapter VI - Technology Diffusion Through Participating Companies: Describes the effects on a sample of companies associated with NASA communications satellite programs. Particular emphasis is placed on their contributions to the technology of commercial communications satellites and on secondary or indirect diffusion of technology.

II. TECHNOLOGICAL HISTORY OF COMMUNICATIONS SATELLITE R&D

Only slightly more than 10 years ago, many experts had serious doubts that:

* Satellites could be placed in synchronous orbit before 1970.

* Satellites could survive in space, and operate long enough to pay out.

* The quality of satellite communications transmissions would be acceptable.

* The cost of satellite systems would be competitive with traditional earth-based communications.

Today, commercial communication satellites are a reality: an international system has been in operation for 6 years, domestic satellites will be in operation in a few years, and the first experimental mobile or navigation satellite is scheduled for 1973.

In this chapter we review the national R&D effort which led to commercial communications satellites. The purpose is to illuminate some of the key technical developments and decisions that led to the accumulation of our present knowledge and capability. Appendix B summarizes major milestones in the development of present technology, and presents chronologies for principal programs.

Early Satellite Communications Techniques Explored

When the first satellites orbited, the concept of using space for communication was clear. Since 1942, engineers and science fiction writers had speculated about satellite communications in general and the advantages of synchronous satellites in particular.[1/]

The earliest effort in satellite communication involved a passive reflector--using our natural satellite, the moon. The Navy Communication by Moon Relay (CMR) project reflected radar signals, and later voice communications, from Pearl Harbor to Washington, D.C., via the moon.

1/ See G. O. Smith, "O.R.M. Interplanetary," 1942; Arthur Clarke, "Extra-Terrestrial Relays," 1945; and J. Pierce, "Orbital Radio Relays," 1954.

NASA's first communications program, Project ECHO, did not start with communications as its objective. In January, 1956, William J. O'Sullivan at the Langley Research Center of NACA proposed balloon satellites to measure air density at 100 miles altitude.

During a communications conference at Woods Hole, in the summer of 1958, William Pickering, Director of Jet Propulsion Laboratory, with John Pierce and Rudolph Kompfner of the Bell Telephone Laboratory, agreed to support O'Sullivan's balloon proposal for use as a passive communications test satellite. By early 1959, NASA had decided that the ECHO program should include communications experiments. The cooperative effort was shared by Langley, NASA headquarters, JPL, and the Bell Telephone Laboratory. During the next 18 months inflatable satellites and ground station equipment were developed and tested.

ECHO I was successfully launched into a 1,000-mile orbit on 12 August 1960. Real-time voice communications were reflected off the 100-foot aluminum plastic balloon. The first TV transmission by ECHO I occurred on 24 April 1962.

ECHO left a substantial legacy. This program influenced ground station technology, radio propagation experience, and most of all, helped crystallize in the public mind the concept of satellite communications. The parabolic horn antenna at Holmdel, N. J., was built by AT&T as part of the cooperative effort with NASA. NASA's receiving station at Goldstone, Calif., was modified for communications via ECHO. Tracking facilities were improved, and the tracking beacon system developed. ECHO provided the first calibrated space target from which accurate radio propagation measurements could be conducted. ECHO proved that microwave transmissions through the ionosphere to and from satellites in space were adequately understood--there would be no surprises or unexpected phenomena. It demonstrated that large, narrow beam antennas could successfully track a moving satellite. The feasibility of new techniques in the design of sensitive ground receivers was proved. In a few short months ECHO dramatically demonstrated the promise of communications satellites.

NASA Active Satellite Work

In 1958, when the military and civilian space programs were separated, a policy had evolved that NASA was to work on passive communications devices, while the military would explore active repeater satellites. ARPA, the Advanced Research Projects Agency, was charged with combining the previously uncoordinated military programs.

The 1958 NASA/DoD arrangement remained in effect until August 1960, when it was agreed that NASA should now work on active communication spacecraft, but only at low and medium altitudes; synchronous satellites were to be the exclusive concern of the Department of Defense. This opened the way for NASA to cooperate with Bell Telephone Laboratories in the TELSTAR program and to undertake the important RELAY project.

TELSTAR I was built by AT&T and launched by NASA on 10 July 1962. It became the nation's first active repeater, medium altitude communications satellite.1/ The satellite had a capacity of 600 voice channels or one broadband TV channel. TELSTAR transmitted black and white TV, color TV, telephone conversations, photo facsimile and high and low speed data between Andover, Me., the British station at Goonhilly Downs, and the French station at Pleumeur-Bodou. Many of the technical advances of this era were shared between the concurrent TELSTAR and RELAY programs.

RELAY--An Internation Experiment

The RELAY program started in November 1960, when NASA awarded a contract to Space Technology Laboratories (STL) to determine the technical characteristics required for an experimental, low-altitude, active communications satellite system "capable of providing technology leading to a commercial communication satellite system".

In January of 1961 industry was briefed on the requirements of project RELAY, and seven bids were submitted. In May, a contract was awarded to Radio Corporation of America for the development of three flight spacecraft for project RELAY.

In the summer of 1961, President Kennedy added several new requirements for communications satellites. Kennedy requested a global network of satellites that would achieve worldwide communications "at the earliest practicable date". He invited all nations to participate in the system.

International interest and cooperation in this program contributed to its success. Eventually, organizations in the United Kingdom, France, West Germany, Italy, Brazil, and Japan developed ground stations for participating in the RELAY experiments.

1/ SCORE and COURIER, launched in 1958 and 1960, were delayed repeaters. This type of satellite was never flown again; delayed repeater concepts were abandoned in favor of real-time instantaneous transponders.

Part II

Case Study: Technological Progress and Commercialization of Communications Satellites

Prepared for:

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Briefly, the design objectives of RELAY were to:

(1) Provide as high an effective radiated power as possible for the satellite communications down-link. High power was essential to insure good reception by smaller earth stations.

(2) Provide orbits offering maximum visibility to many ground stations throughout the world.

(3) Insure a spacecraft life of one year--sufficient to conduct experiments and "demonstrations" with all participating nations.

The technical requirements for the RELAY satellites were conservative. Whenever possible, existing components were to be used to minimize development time. Further, reliability and a one-year life were to take precedence over technological innovation. Within these constraints, most of the work focused on providing maximum power transmission to the earth. This meant large and efficient solar power panels, high power output tubes, high antenna gain and keeping satellite size and weight within the capability of the launch vehicle.

These conservative requirements did not inhibit the technical progress made by the RELAY program. In addition to purely technical advances, RELAY made contributions at the conceptual and organizational level including:

* Stimulating efforts toward global telecommunication networks.

* Demonstrating the existence of a worldwide market for broadband communications. (Previous studies showed no "need" for TV transmission before 1980.)

* Significant scientific and engineering findings.

* Providing a framework for international technical cooperation.

* Advancing technical areas of satellite communication.

* Transferring U.S. satellite technology to those nations and organizations destined to become the INTELSAT Consortium.

The technical developments incorporated in RELAY influenced the systems, components, and operating methods that would be further developed in later programs. The significant contributions of RELAY are worth mention.

For Output Power:

--The first high-power active satellite repeater.

--Solar array experiments fixed future designs.

--Development of an efficient 11-watt TWT amplifier.

--Compact frequency multiplier communications repeater.

--A wide-band, low insertion loss, mast-antenna.

For Attitude Stabilization:

--Active attitude control systems.

--Vibration and nutation (wobble) dampers.

For System Reliability:

--First active satellite to survive into its third year.

For Earth Terminals:

--NASA stations at Nutley, N. J., and Mojave, Calif., pioneered techniques for smaller ground terminals.

--Use of the NASA PCM/PDM/AM/AM command format.

--New 10-kw wideband klystron tube design.

--Improvements in amplifiers for low noise receivers.

Synchronous Satellites--ADVENT and SYNCOM

NASA's advocacy of synchronous satellites derives from two parallel programs dating back to 1958: the Army's project ADVENT and Hughes Aircraft Company's Preliminary SYNCOM.

Shortly after ARPA was placed in charge of all satellite and space programs in October 1958, a panel on communications satellites was established. A plan was developed to test the feasibility of active synchronous communications satellites. A three-stage approach was to be used involving STEER, TACKLE, and the final program, DECREE, which was to be a 24-hour, broadband satellite.

During 1960 the program was modified by cancelling the three-stage development, and replacing it by project ADVENT which was intended to be an operational system rather than a feasibility test.

In the spring of 1961, Robert McNamara was informed that ADVENT was encountering serious problems. During the summer John Pierce reported that the ADVENT program was too advanced to be accomplished within the known state of the art.

One area that was progressing satisfactorily was that of earth stations for ADVENT. Early in 1962, the Army completed the 102-foot-diameter antenna at Fort Dix. Other stations were constructed at Camp Roberts, Calif., and aboard the U.S.N.S. Kingsport.

The ADVENT spacecraft was to be large, powerful and heavy. The communication system required the development of a high gain antenna, rigidly fixed to the craft, and pointed by adjusting attitude of the entire vehicle. Because travelling wave tube amplifiers had not yet demonstrated adequate reliability, low efficiency planar triodes were used to obtain the desired output signal. Much of the remaining electronics was transistorized to conserve weight. Thus, the craft was an enormously complex and sophisticated vehicle with many unsolved problems and many techniques to be developed.

In April of 1962, it became apparent that the needed launch vehicle would not be available on schedule. The first launch could not occur before the second quarter of 1963; and an additional $50 million would be required for the first phase of the program.

Ironically, the swift progress in technology provided the final blow. ADVENT management ultimately concluded: "The steady progression of the state of the art, since the original satellite design had been detailed, now permitted the same basic operational functions to be performed in a satellite vehicle weighing approximately one-half of the existing design."

Dr. Harold Brown, Director, Defense Research and Engineering, and his deputy, Dr. Eugene Fubini, summarized the problems of ADVENT: "There was an attempt to go operational before the system was designed." . . . "We tried to jump the technological barrier too fast." . . . "We found ourselves constantly trying to solve technical problems that nobody had anticipated. . ."

On 26 May 1962, Robert McNamara cancelled the ADVENT program. In the four years since the project was conceived something in excess of $159 million had been spent, much of it unrecoverable. However, three new earth stations had been constructed; and this $40-50 million asset could be used by NASA on project SNYCOM.

Spin-Stabilized SYNCOM

Much of the conceptual development of SYNCOM dates back to a period before NASA had any contractual relationship with Hughes Aircraft Company. Indeed, until 23 June 1961, NASA was explicitly excluded from working on spacecraft using the synchronous orbit.

The two parallel and contemporary programs SYNCOM and ADVENT present an interesting contrast in technological development. Both projects originated in October of 1958, and both were designed to place active communication repeaters in a 24-hour equatorial orbit. The design of both spacecraft reflected the technology available during 1960-1961. But the technical approaches and the hardware developed to meet the objectives of each program were strikingly different.

In the fall of 1958, the Fire Control Systems Division of Hughes Aircraft Company was completing its work on aircraft radar systems. A company task group was formed to explore new research and development opportunities. This group included Dr. Harold Rosen, Donald Williams and Thomas Hudspeth, each destined to make major contributions to the technical development of SYNCOM.

Dr. Rosen was familiar with the speculation about synchronous communications satellites as described in papers by Arthur Clark and John Pierce. However, he disputed one of Pierce's major premises--that it would be extremely difficult to establish a heavy satellite in a 24-hour orbit, and that the satellite would have to point at the earth at all times. The group believed that the job could be accomplished with a simple, light-weight spin stabilized spacecraft. This was the key concept which essentially dictated the pacing technology over the next five years (1958-1963).

The group developed their ideas into a specific engineering plan during the next year. Rosen and Williams worked out the orbital mechanics and stabilization of the spacecraft; Hudspeth designed the transponder, spacecraft antenna and the ground stations; while J. T. Mendel concentrated on the microwave power tubes.

The basic concept involved was that of placing a simple spin-stabilized satellite in the synchronous-equatorial or stationary orbit. By aligning the spin axis perpendicular to the orbital plane, the spin axis would always have the same orientation relative to the earth's surface; therefore, the antenna pattern would always intersect the earth. Orbital control would be achieved by using two simple jet thrusters to adjust the orientation and to change the velocity of the satellite to make the orbital period exactly 24 hours.

Rosen's group concluded that the development, construction of facilities, and launching of three satellites would cost $5 million and take one year. The first informal presentation to NASA came in November 1959, followed three months later by formal presentation of the proposal, "Commercial Communications Satellite."

The system envisioned in the spring of 1960 was a 25 pound spacecraft, orbited by a SCOUT (an inexpensive, four-stage, solid propellant rocket under development by NASA). Placing the satellite in an equatorial orbit using this vehicle required launching from a site near the equator, and Jarvis Island in the Pacific was suggested.

The achievement of such an orbit has been described as more difficult than hitting the moon, and in 1960 the attainment of synchronized orbit was categorized as a relatively high-risk mission. While the fundamental concept appeared sound to NASA, its marginal character and the agreement to not duplicate DoD efforts prevented further consideration.

Hughes next presented their plan to the Department of Defense, which expressed enough interest to request a more formal proposal, but indicated that it believed the idea had little real promise.

A private, commercial venture, as originally proposed by Rosen, appeared impossible. Hughes had considered joining with General Telephone or with ITT and other carriers to build a communication system, but these plans were abandoned. Costs might run from $5 million to $50 million, and the risks and obstacles were formidable.

Unable to obtain outside support, Hughes continued with the development of the long lead-time items, such as the traveling wave tube and a prototype satellite. A satisfactory phase modulator had been constructed. Improved traveling wave tube heaters and permanent magnets were constructed and it now appeared possible to obtain 2 watts output without exceeding a weight of 1 pound.

This preliminary prototype satellite was demonstrated to NASA and the Department of Defense during August 1960. Once again both agencies rejected the proposal. But NASA's interest was growing. During that same month, a new agreement on satellite activities permitted NASA to work on active devices, and the Department of Defense to go ahead with Project West Ford, the use of passive dipole reflectors. However, NASA still had no authority to work on the synchronous system.

Leonard Jaffe, Chief of the NASA Communications Satellite Programs, had followed Hughes' work, and supported using the synchronous orbit. But he favored a larger satellite and a more reliable launch vehicle.

On 15 May 1961, President Kennedy instructed NASA Administrator Webb to accelerate work on communications. Webb asked Congress for a supplemental appropriation of $50 million and Jaffe argued that the logical way to spend the money was on a synchronous system.

Technical progress during the previous year permitted Hughes to revise its proposal to NASA, but Hughes clearly indicated it would not justify spending more company funds without NASA support. A more conservative project with a larger spacecraft designed to use the Thor-Delta booster was proposed. Although the three stage Thor-Delta could not place a satellite in the synchronous orbit by itself, it could launch 150 pounds into an elliptical orbit with an apogee at the synchronous altitude of 22,300 miles. By the use of an apogee-kick motor, the orbit could be circularized for a 24-hour equatorial position. It was around this capability that the SYNCOM mission was designed.

Within a month NASA and the Department of Defense worked out a new memorandum of understanding, agreeing that NASA could now work on synchronous satellites. On 11 August 1961, NASA announced award of a contract to Hughes for three experimental satellites.

With construction of the spacecraft proceeding, NASA turned to the matter of earth terminals. When ADVENT was cancelled, the possibility of using the terminals with SYNCOM was suggested. An agreement was worked out whereby the Department of Defense would support the NASA SYNCOM operations.

The Technology and Impact of SYNCOM[1/]

The first SYNCOM launch in February 1963, achieved one milestone--it was inserted into a nearly perfect synchronous orbit. But all communications contact was lost.

Changes were made to improve the chances of a successful launching. The nitrogen tanks were repositioned and the pressure reduced. Critical electronics were rewired to provide redundancy, thus minimizing the risk of open circuits. Standby batteries were installed to provide 40 minutes of telemetry and communications in the event of a power failure.

SYNCOM II was successfully placed in high-altitude transfer orbit on 26 July 1963. Six hours later the apogee motor was fired to insert the spacecraft into a nearly circular orbit. A series of maneuvers were carried out and the spacecraft was brought to its intended position over Brazil. After attaining near-zero drift, the axis was aligned so that the antenna beam always contacted the earth.

1/ Table 1 shows the technical characteristics of this and subsequent satellites.

TABLE 1

TECHNICAL CHARACTERISTICS OF MAJOR COMMUNICATIONS SPACECRAFT

Spacecraft Launch Date:	SYNCOM II July 1963	SYNCOM III August 1964	"Advanced SYNCOM" Designed 1963 Never Flew	ATS-I December 1966	ATS-III November 1967	ATS-F/G 1972	Intelsat I "Early Bird" April 1965	Intelsat II January 1967	Intelsat III December 1968	Intelsat IV January 1971	IDCSP 1966-1968	LES-6 September 1968	TACSAT February 1969
Initial weight in orbit (pounds)	85	86	760	775	350		85	192	334	1,544	100	360	1,600
Primary solar power (watts)	28	32.5	147	187	185	~ 400	33	75	125	470	42	130	775
Number of repeaters	2	2	4	2	2	1	2	1 (4 tubes)	2	12		8	
Type of transponder	freq. trans.	freq. trans.	dual mode	3-mode	mult. mode	mult. mode	--	freq. trans.	freq. trans.	mult. mode		solid state	
TWT output (watts)	2	2	4	4	12	80	6	6	6	80	3	120	
ERP watts/repeater	5	5	--	80			10	32	158	200-20			
ERP all repeaters (watts)	--	--	--	160		60,000	20	50	300	4,000 - 4.5		600	6,000
Efficiency DC-RF (percent)	7	6	--	4.3	13	20	18	24	10	16	7.5		
No. of two-way voice channels	1		2,400	600			240	240	1,200	3,000 - 9,000	5	--	10,000
No. of TV channels	None	1	4				1	1	4	12			
Channels per watt	0.036	0.030	16.3	3.2			7.3	3.2	9.6	12.8	0.125		12.9
Bandwidth (MHz)	0.5	10	--	25	25	40-500	25	130	225	36 x 12	--		
Antenna type	co-ax. array	co-ax. array	elect. phased	elect. phased	mech. despun	30-ft dish	squinted	omni bi-cone	mech. despun	despun-multiple	bi-cone	elect. phased	despun array
Pattern of coverage (degrees)	360 x 20	360 x 20	20 x 20	20 x 20	12	3	360 x 11	360 x 12	19.3 x 19.3	20 x 20 4.5 x 4.5	--		
Antenna gain (decibels)	6	6	18	16	17.4	50	9	14	20.3		--		
Design lifetime (months)	--	18	--	36	36	60	18	36	60	84	72	--	--

Since a direct launch from the Florida Cape was used, the orbit was inclined 33 degrees to the equator. Therefore, SYNCOM II was not in true stationary orbit, but moved in an elongated figure-8 pattern 33 degrees north and south of the equator.

From the technical standpoint, the systems used for the SYNCOM spacecraft stand in stark contrast to the approaches planned for ADVENT. SYNCOM was basically a simple, small, spin-stabilized, drum-shaped satellite, with modest power, and a repeater system designed to handle one two-way telephone channel. The project objectives were modest and straightforward:

(1) To achieve synchronous orbit using the spinning injection concept.

(2) To demonstrate precision control of spin-axis, attitude and orbital parameters using the pulsed-jet control system.

(3) To obtain engineering measurements of communication system performance at the synchronous altitude.

Thus, SYNCOM was designed to test the feasibility of somewhat radical concepts of achieving synchronous orbit, and to determine the characteristics of communications at that altitude. It was not primarily targeted at developing new hardware systems. Nevertheless, the innovations pioneered and the communication achievements that were demonstrated in the SYNCOM program, have affected every subsequent communications spacecraft design. The impact on ground station design and overall system operation was equally important.

Some of the areas of improvement include:

Orbital Positioning:

Apogee-kick stage engine

First use of JPL-540 "Starfinder" metallized fuel

First satellite having spin-axis perpendicular to orbital path

Communications Repeaters:

Dual Frequency translation transmitters for FM with feedback

Both narrow- (0.5 MHz) and wide-bandwidth (5.0 MHz) repeaters

Long life, 2-watt TWT amplifier

Circuit Improvements:

Multipliers, filters, diplexers

Spacecraft Antenna:

Pancake pattern, 6-decibel gain, skirted collinear array

Station Keeping System:

High pressure nitrogen jets

Hydrogen peroxide jets

Pulse-valve system and controls

Solar attitude sensor

Nutation damper

Telemetry:

Simple, sequential command format

Thermal Control:

All passive system for spinning spacecraft

Earth Terminals:

First synchronous range and range-rate system (low-orbital rates)

Experimental use of low-power earth stations (down to 40 watts)

Fifteen-foot-diameter portable antennas

Most of SYNCOM's significance, however, lay in its communications performance. Many engineers had misgivings concerning the quality of transmissions that could be obtained over this 45,000-mile path. As a communications transponder, SYNCOM II performed superbly. Measurements were made by the U.S. Army Satellite Communications Agency using voice, teletype, facsimile and data transmission. Signal-to-noise ratios up to 40 db were obtained. More than 7,000 hours of "on" time were accumulated during which all types of communications were transmitted via SYNCOM II.

Two demonstrations conducted using SYNCOM II had major impacts on the future. In the fall of 1963, the delegates to an extraordinary conference of the International Telecommunications Union (ITU) were given the opportunity of placing telephone calls made via SYNCOM from the conference site in Geneva, Switzerland, to the United States. NASA arranged land lines from Geneva to Rota, Spain, where the U.S.N.S. Kingsport was anchored, and from the Kingsport via SYNCOM II to Washington, D. C., and the United Nations building in New York. Conference delegates could talk with their United Nations representative or with embassy officials in Washington. It was an appropriate and timely demonstration, for the conference was at that time considering frequency allocations for space communications.

A controversy had developed concerning the problems of intelligibility that might result from the half-second delay inherent in synchronous transmissions. The Geneva demonstration provided an opportunity to judge this factor. To be sure, the time delay was there, but the users adjusted to it with little difficulty.

The second demonstration dealt with television transmission. Although SYNCOM II was not designed to transmit television, a last minute transponder modification provided one 5 MHz channel. The desire to transmit the 1964 Olympic games from Japan to the United States suggested a serious look at SYNCOM's capability. The most sensitive ground station, the AT&T horn antenna at Andover, Maine, was equipped with a special maser receiver, and a test was conducted in early 1964. Television pictures were sent from Fort Dix, New Jersey, via SYNCOM II to Andover. NBC officials viewing the transmission in New York found them good enough to start making arrangements to televise the Olympic games using SYNCOM III.

An unexpected contribution from SYNCOM II affected the station keeping characteristics of nearly all subsequent satellites. Analysis of SYNCOM's movements provided the first accurate measurements of the earth's triaxiality. The earth's bulge at the equator was measured as 213 feet, and the location of major and minor axes of the elliptical equator were determined to within a few degrees. The results of these orbital determinations showed that the impulse required to keep a synchronous satellite on station is only 5.36 feet per second per year, considerably smaller than had been predicted. This finding made it far more practical to consider onboard station keeping systems designed to hold satellites at a truly geostationary point for years.

SYNCOM III--Precision Station Keeping

The final craft in the SYNCOM series was the up-rated SYNCOM III. Although launched just one year after the first flight, incremental improvement made this SYNCOM perform like an accomplished professional. One major change was the use of the thrust-augmented Delta that was capable of making the "dogleg" maneuver needed to align the orbit around the earth's equator. Solar cells were changed to minimize radiation damage. Solar cell power had increased from 28 to 32.5 watts, and from an array yielding 6 watts per pound compared to 4.7 watts per pound a year earlier. The broadband experiments on SYNCOM II were so successful, that the bandwidth for SYNCOM III was raised to 10 MHz to permit full television capabilities.

The major objective of the SYNCOM III launch was that of demonstrating a stationary orbit through precision station keeping. Because the 19th Olympiad was to be held at Tokyo in October 1964, a second objective became that of getting the satellite on station and tested in time to present live television coverage.

SYNCOM III was launched on 19 August 1964; the dogleg maneuver to reorient the third stage for firing at the equator crossing was nearly perfect. At the third apogee, SYNCOM III was inserted into synchronous equatorial orbit over Borneo. From here it was maneuvered along the equator to the international date line on 10 September. When the Point Mugu earth station in Calif. was completed on 1 October, international transmissions began. Syncom III was to make history as the world's first geostationary satellite and would be used 24 hours a day seven days a week for trans-Pacific communications.

This seemingly straightforward demonstration required close cooperation among 16 organizations, including NASA, the Department of Defense, Hughes Aircraft Company, the newly formed Comsat Corporation which operated the Point Mugu Station, and the television broadcast networks in the United States, Canada, Europe, and Japan.

The problem of locking the first geostationary satellite into perfect orbit and attitude, gave rise to a series of innovations in ground station systems. Initial ground station measurements of position and orbital period were slightly in error. Later it was discovered that the station keeping capability of SYNCOM III exceeded the ability of existing range and range-rate systems to measure it.1/

1/ SYNCOM III had a period of 1,436.04 minutes, close to the length of the siderial day: 1,436.068 minutes. Initial telemetry showed a period of 1,436.28 minutes, and inclination errors of 0.4 degree.

Tight station keeping was significant in that no readjustment of antenna pointing was needed during the whole period of the Olympics. The measurement problems for stationary satellites would dictate the need for three new generations of improved range and range-rate equipment.

From Advanced SYNCOM to the ATS Program

As soon as the synchronous concept appeared feasible, it became clear that increased power and channel capacity would be needed. Substantial progress toward these goals was made on a NASA satellite which never flew. However, all of the important developments of Advanced SYNCOM were later incorporated in NASA's Advanced Technology Satellite program--a project for testing and developing the technology needed to support future applications.

As early as July 1961, Harold Rosen proposed a phased-array antenna on SYNCOM II and III. Development work had been done to increase channel capacity and user convenience, and extended life on station. These developments included the electronically phased-array antenna, a multiple access communications transponder, and a bi-propellant spacecraft control system.

Advanced SYNCOM was formally proposed to NASA in February 1962, and the development of long lead-time components was started in June. The Advanced SYNCOM feasibility study was extended to 31 August 1963, to include the development of a prototype spacecraft and associated ground equipment. It was felt that Advanced SYNCOM would be launched only in the event that SYNCOM would not be successful. The program associated with this improved spacecraft was primarily intended to advance certain basic technologies and develop new components and subsystems. With the subsequent success of SYNCOM II in July 1963, NASA, viewing its role as broader than that of supporting commercial development, cancelled Advanced SYNCOM in early September.

Although abandoned as a flight project, all the basic technologies of Advanced SYNCOM were retained as experiments in the ATS series. The key developments of antennas, attitude and station keeping, and electronics represented the core of experimentation over the next five years (1963-1968).

NASA Stimulus of Advanced Technology

By 1964, the technical issues regarding communications satellites were quite well defined. Feasibility or desirability of such systems was no longer in question. For point-to-point trunking of international com munications, careful trade-off studies and systems optimization became the order of the day. Engineers and scientists now realized that it was rash to assert that we could, quickly and without mishap, do anything concerned with space.

Successful demonstrations were a prerequisite for future systems. For NASA to support and develop technology required for advanced satellite application meant undertaking high-risk experimental programs. Realizing this, the Space Agency intensified its development of advanced technology and returned to exploring and demonstrating the feasibility of satellite applications far beyond point-to-point transmissions.

Advanced Technology Satellites I Through V

A study to define the technological needs for advanced satellite missions was initiated at Goddard Space Flight Center in November 1963. A decision was made to investigate three kinds of spacecraft--(a) spin-stabilized, synchronous altitude; (b) gravity-gradient-stabilized, medium altitude; and (c) gravity-gradient, synchronous.

Five spacecraft, designated ATS-I through ATS-V, were initially planned. In addition to the spacecraft, three NASA ground complexes were required: The Rosman, N. C., facility with an 85-foot antenna; the smaller Mojave, Calif., site with a 40-foot antenna; and a transportable station with a 40-foot antenna, to be located at Cooby Creek, Australia. These earth stations were to have communications receivers and transmitters, tracking receivers, real-time experimental data displays, and equipment for measuring range and range-rate, spin speed, sun angle, and polarization angle. They would also have the capability for receiving meteorological, gravity gradient and other scientific information.

The ATS project was approved in February 1964. Beginning in May, contracts were let to the agencies and contractors as shown in Table 2. This table shows the wide range of equipment developed, concepts explored, and demonstrated operating techniques.

NASA contacted scientists soliciting suggested experiments that would augment the predominantly engineering and technical missions of these spacecraft. Some 15 experiments were integrated into the ATS program, while other investigations that could be conducted from the ground were added.

The launch schedule and primary mission objectives for ATS-I through ATS-V are shown in Table 3.

TABLE 2

MAJOR TECHNICAL ELEMENTS DEVELOPED FOR ATS-I THROUGH -V

Element	Contractor or Agency
Spacecraft Prime Contractor	Hughes Aircraft Company
Apogee motor	Jet Propulsion Laboratory
Shroud	Douglas Aircraft Company
Ion engine	Lewis Research Center
Experiments	
Communications	Hughes Aircraft Company
Environmental measurement	Various contractors
Earth sensor	Space Technology Laboratories
Meteorological	Various contractors
Advanced Vidicon camera system	Radio Corporation of America
Cloudcover camera	University of Wisconsin
Gravity gradient	General Electric Company
Technological	Various contractors
VHF	Hughes Aircraft Company
Mechanically despun antenna	Sylvania
Nutation sensor	Geophysics Corporation of America
Electronically despun antenna	Hughes Aircraft Company
Albedo	Department of Defense
Image orthicon camera	Hazeltine Laboratories
Millimeter wave propagation	Various contractors
Resistojet microthruster	Avco Corporation
Image dissector camera	IT&T
Advanced gravity-gradient boom system	Westinghouse
Solar cell damage	Hughes Aircraft Company
L-band air traffic control	Hughes Aircraft Company
Reflectometer	Electro Optical Systems
Navigation experiment	General Dynamics Corporation
Ground Communications	
SSB/FM transmitters	Raytheon
PM/FM receivers	RCA, Montreal
Phase-lock loop demodulator	General Instrument Company
Multiplex equipment	General Electric
Video tape recorder	Ampex
Audio tape recorder	Ampex
Communications integration	Westinghouse
Test equipment	Various contractors
Command transmitters	Hughes Aircraft Company
Telephone receivers	General Dynamics Corporation
Pulse code modulation/data handling equipment	Radiation Incorporated
Range and range-rate equipment	General Dynamics Corporation
Mojave	
Antenna retrofit	Philco
Feed system	Sylvania
Communications integration, master control console, communications test and evaluation console	Westinghouse
Rosman II	
Feed system	Rantec
Antenna	Blaw Knox
Antenna control system	Collins Radio
Communications integration, master control console, communications test and evaluation console, spin-scan cloud camera equipment	Westinghouse
Transportation Station	Sylvania
Data Analysis	
Experiment correlation study	Franklin Institute
Communications experiment data reduction and analysis	Westinghouse

TABLE 3

ATS-I THROUGH -V - MISSION OBJECTIVES

Designation	Launch Date	Primary Mission Objectives
ATS-I	7 December 1966	Multiple access; phased-array antenna; aircraft communication; spin-scan camera, station keeping, small terminals
ATS-II	5 April 1967	Gravity-gradient stabilization, SHF multiple access frequency translation aspect sensors and active dampers
ATS-III	5 November 1967	Mechanically despun antenna, color spin-scan camera; OPLE; APT; aircraft comm.; range and range-rate
ATS-IV	10 August 1968	Gravity-gradient stabilization, cesium ion-engine thrustor, microwave SHF and UHF communications
ATS-V	12 August 1969	ATC on L-band; G.G. stabilization; active and passive dampers; multiple spiral antenna arrays; heat pipes, 10 and 31 GHz mm wave propagation; multiple access C-band

The ATS project was aimed primarily at developing and testing new technology for future satellite applications. Many elements of advanced systems now in the planning stage were conceived, developed, and tested during the first five years of the ATS program.

Some ATS experiments have had major impacts on the design and operation of subsequent satellites. Ground station work has influenced the design of earth terminals; and research on advanced applications has accelerated planning for new modes of operation. Among the most significant accomplishments of ATS were demonstration of multiple access traffic; mechanically despun spacecraft antennas; millimeter wave experiments; ground station feed systems; communication with aircraft; long-term station keeping with bipropellant pulse-jet systems; navigation and position location work; low noise receivers; electronically despun phased-array antennas; precision-range and range-rate techniques: high-gain directional antennas; stabilization and attitude control of spinning spacecraft; improvements in modulation and coding; and studies of radio frequency interference problems.

Just as the SYNCOM program showed the feasibility of commercial telecommunications systems and demonstrated their operating characteristics, the ATS program helped establish the pacing technologies needed for applications in air traffic control, domestic communications, data transmission, regional and instructional television. In addition, supporting research conducted for the ATS program provided a strong technological base for the development of future high performance spacecraft.

ATS-F and -G; High Performance Satellites

Geostationary satellites able to radiate signals to selected portions of the earth, rather than viewing the whole earth disc, can yield significant advances in communication, meteorology and earth resources survey capability. Such satellites would offer improved TV distribution and community education, safer travel, more accurate weather forecasts and more effective management of our environment and natural resources.

To accomplish these goals a relatively large antenna would be required, as well as much greater stabilization accuracy than possessed by spacecraft of the previous ATS series. Thirty feet represented the largest practicable antenna size; 0.1 degree stabilization would provide precise geographic coverage at the higher frequencies of interest for communications.

This narrow beam antenna will improve efficiency by a factor of some 300 over the whole-earth coverage patterns of the ATS-I and -III satellites. The erection of a 30-foot antenna in space was identified as the principal technological difficulty.

In June of 1966, three aerospace companies received contracts for six-month feasibility studies. Goddard Space Flight Center conducted its own parallel study. All results indicated that the missions could be accomplished with a 2,000-pound satellite launched by a Titan IIIC.

The ATS-F and -G experimental satellites, scheduled for launch in 1973 and 1975 will prove out technologies which can be ultimately applied to provide a number of benefits: mass instruction through TV transmission to inexpensive ground receivers; improved safety, economy, and convenience in air travel; continuous contact with satellites in orbit; improved use of the crowded frequency spectrum; and finally, improved weather prediction.

After gathering the data from the initial experiments, NASA will move ATS-F to a position over India, and conduct--in conjunction with the Indian government--the instructional television experiment.

India is particularly suited for an experiment of the type planned for ATS-F. The population is distributed fairly evenly throughout the country, rather than being concentrated in a few large cities which could be reached easily by terrestrial television distribution methods. There is no existing TV distribution network, and the Indian subcontinent is of a convenient size relative to the antenna pattern of the ATS-F satellite. A ground station suitable for transmission to the ATS-F satellite is already available in Ahmedabad.

Three conceptual designs resulted from TV broadcast satellite studies conducted in 1969. They are shown in the table below. The direct broadcast satellite would not be technically feasible until the mid-1980's. If the required technology is pursued, the others would be technically feasible to launch by the late 1970's.

Type of Service	Direct Broadcast	Community	Community
Frequency	UHF	2.5 GHz	12 GHz
Number of TV channels	1	7	6
Coverage, square miles	1,000,000	2,200,000	2,200,000
Weight, pounds	3,500	1,600	1,600
Spacecraft power, kilowatts	12	4	2.5
Booster	Titan III-C	Atlas-Centaur	Atlas-Centaur

The principal technologies still requiring additional research include: multikilowatt RF power tubes and associated high-power components for TV transmission; thermal control subsystems; high-power feeds; low-sidelobe, multiple-beam antennas with beam shaping; and solutions to the problems of high voltage breakdown and multipacting.

III. COMMERCIAL APPLICATIONS AND TECHNOLOGICAL REQUIREMENTS

Periodically, technology introduces a new capability that makes possible vast improvements in man's ability to live and work in his environment. On rare occasions, this same technology gives man the opportunity to perform functions not previously within his capability. In some cases, the magnitude of the social and economic impact of these advances affects millions of persons in scores of nations and changes their concepts of established practices. Communications satellites are a result of such technological progress.

The options opened by communications satellite are difficult to conceive in a world more familiar with telephone lines linking one user with another, or TV broadcasting from 1,000 foot towers to viewers within 100 miles of the station. The technology underlying communications satellites advanced in an evolutionary fashion; the communication options made available are revolutionary. The new communications mode also changes the operational procedures of our regulatory bodies and commercial operators, geared as they are to the characteristics of link-to-link land bound communications.

Many different services and types of information can be transmitted on satellite links. The most common include: television, voice, facsimile, and data of various types. New communications services and benefits are provided to a wide range of users or customers served by any one satellite system. A total of over 50 different applications for communications satellites have been proposed. Satellite links can be combined with existing terrestrial facilities in many advantageous ways.

Functionally, all satellite communications systems contain several basic elements (Figure 2): the earth-based up-link facility; the spacecraft with its transponder; the earth-based receiver; and the tracking, telemetry and command system--portions of which are located on the ground and in the spacecraft. Within these functional constraints, the particular system for each application will differ to best achieve the desired purpose. Factors such as: frequency, bandwidth, modulation, power or signal levels, access, traffic load, antenna beam angles and pointing accuracy and signal distortion become key parameters. These define the technical characteristics which must be satisfied for each general application.

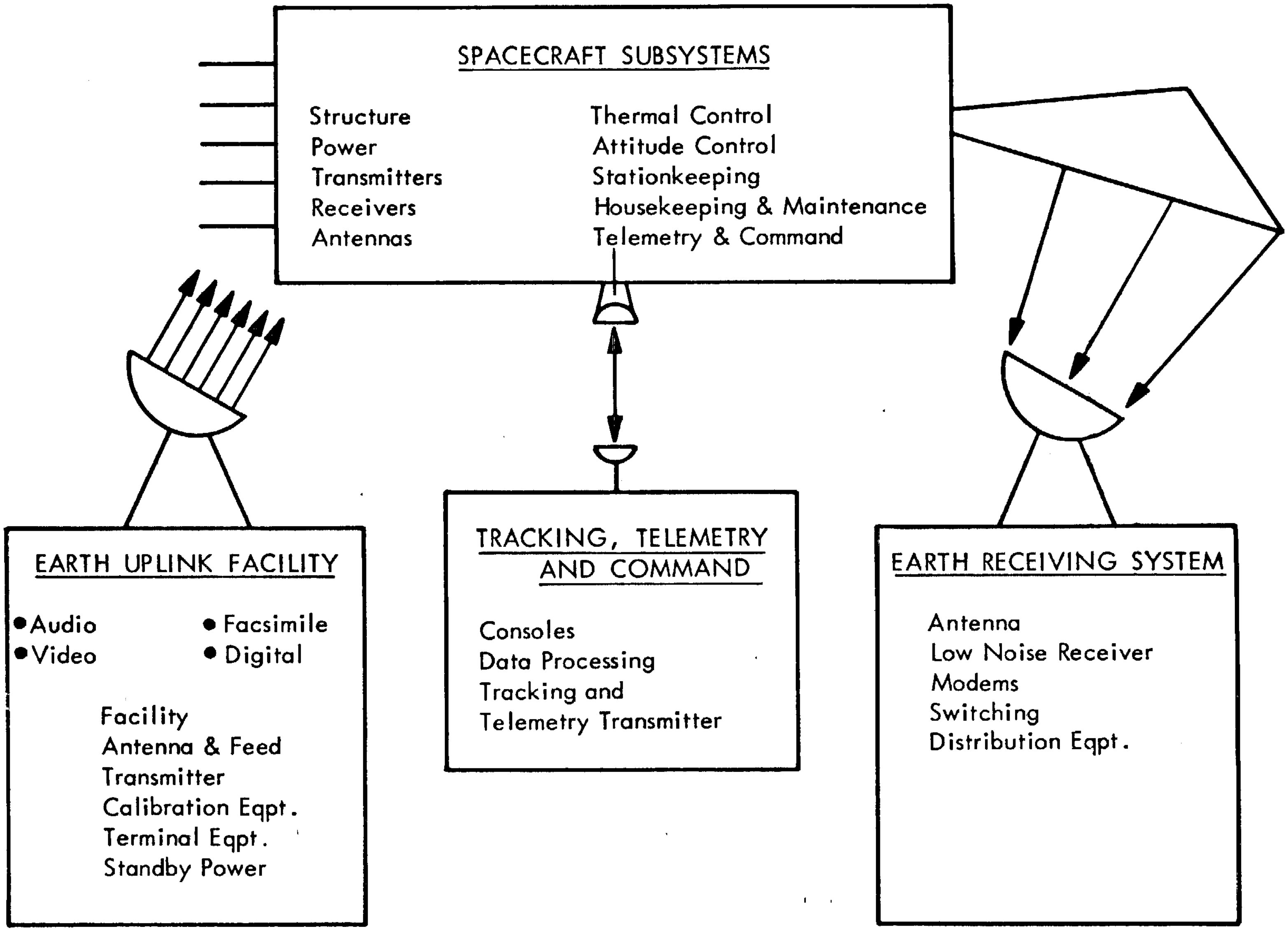


Figure 2 - Elements Basic to All Communications Satellite Systems

Four Types of Commercial Applications

Four broad categories of applications, each with an immediate market or user potential, are fairly representative of the presently achievable services (Table 4). Other groups of uses could have been chosen, but these four are compatible with the objectives of this study--i.e., to illustrate the differing technological characteristics of various commercial applications, and how these technical requirements are being satisfied. The basis of the somewhat arbitrary division of services among the four classes of systems is twofold: (a) the extent to which the transmission is handled within the satellite system, from point of origin to final destination, and (b) the number of users or direct recipients of the satellite signals. Brief descriptions follow:

International. The International or point-to-point service (Table 4 and page 31) provides all communications capabilities, TV, voice, data, teletype, facsimile, between many separate points in many different nations (see Figure 3). These points or ground stations in turn interface with other domestic and international communications services in the television, telephone, data handling and record traffic areas and the satellite becomes analogous to a very long-range microwave link. Many different terrestrial stations use the same satellite at the same time to carry out independent and noninterfering communications and the stations are usually connected via the satellite in communications pairs. Thus, the system is commonly referred to as "point-to-point." Intelsat, presently operating to provide transoceanic communications, typifies such service. The Intelsat system serves the common carriers and government sanctioned national communications networks where channel time is sold to the end users or subscribers.

The operating characteristics shown for International Satellite Systems in the chart are significantly different from other categories of service. System access requirements for this application are unique. Certain pairs of points in the International System will be terminations of high traffic telephone circuit routes and these channels may be preassigned through the satellite. Other point pairs on the earth will require infrequent interconnection, and such channels as are necessary for their use may be assigned only on demand. A television signal requires the same bandwidth as 300 to 800 telephone channels, and realizing that such TV service is needed on only a part-time basis, the system must be designed for flexible reallocation of the channels. As TV programming is often delayed for retransmission during prime time, it is conceivable that some TV signals would not be transmitted in real time, but would be sent during minimum traffic periods.

TABLE 4

DEMAND CATEGORIES FOR MAJOR SYSTEMS

APPLICATION TYPES

International Satellite System (Point-to-Point)	Broadcast Distribution (Point-to-Multipoint)	Direct Broadcast Satellites (Point-to-Wide Area)	Air Traffic Control Surveillance, Communications and Positioning
International telephone trunking	Network TV to local rebroadcast stations	Remote village TV Direct to home TV	Aircraft communications
			Aircraft surveillance
Trans-oceanic television	School district ETV Rebroadcast ETV	Instructional TV Schoolhouse TV	Traffic control
Global multiple access switching network	Larger CATV systems Cable TV systems		Position location
			Geodosy
Commercial teletype, facsimile, data	Regional telecommunications		Data collection and relay
	High quality, high speed facsimile		Satellite-to-satellite relay
	One-way digital data distribution; financial		
	Time sharing services Meeting and polling Information networks Law and justice Medical and scientific		

IUR TYPES OF COMMERCIAL COMMUNICATIONS SATELLITES

PACE SEGMENT				EARTH SEGMENT			
	SATELLITE TRANSPONDER	CHANNEL CAPACITY	DOWN-LINK FREQUENCY	GROUND STATION TRANSMIT ANTENNA	UP-LINK FREQUENCY	GROUND STATION RECEIVE ANTENNA	GROUND STATION RECEIVER
for but tes ree . .	Multiple access. Non-return to baseband. Separate transponders ensure against total failure and reduce interference and inter-modulation.	Multiple channels (3,000-9,000) for best utilization of satellite. 10-20 TV channels are possible. (300-800 voice channels per transponder.)	3.700-4.200 GHz used at present. Higher frequency gets more gain from same area of antenna. (Millimeter waves future possibility.)	Large high gain directional 80-100 ft dish. Minimum side-lobes reduce interference to other satellites and terrestrial systems.	5.925-6.425 GHz used by Intelsat but others available. Orbit control and telemetry may use lower frequencies. Millimeter waves future possibility.	Same as transmit.	High gain, high technology with wide band-width capability. Weak satellite signals require low noise design. Cooled parametric amp.
egion ountain ountry m). r mul- s.	Limited or assigned access from earth stations. Multiple transponders for mixed users (i.e., broadcast networks, law enforcement, data).	10 or more channels of TV. These may be traded for teletype, voice, data, domestic common carriers, or other. 10,000 or more narrow channels.	Special frequency allocations or present microwave assignments.	Large high gain directional dish. Minimum side-lobes.	Any available microwave frequency. (Possible future use of millimeter waves.)	May be high gain, high technology or small 10-30 ft antenna (latter for CATV or ETV/ITV systems).	High gain, high technology for rebroadcast. Unattended converters to feed cable systems for CATV.
one lawaii, gain to s. le .	Limited or assigned access. High transponder power, high output power final stage.	Possibly one to three channels of high power utilizing most of DC primary solar cell output.	Some proposed frequencies are 0.8, 8.4, 12.2, 2.5 GHz. (These are converted down to standard TV channels at the receivers.)	Large high gain directional dish. Minimum side-lobes.	Available microwave frequency. (Possibly millimeter wavelength in future.)	Low priced, serviceable, unattended with converter. Priced from $100-$2,000 (wire mesh dish on wood frame).	Low priced, mass produced, converters for individual TV receivers. State of art TV components. Low as $100 with antenna.
or to Cir- ed	Multiple access from aircraft (time-sharing), assigned access from earth controllers. High power to antenna. Sensitive receiver.	As few as two channels of data, four of voice. Some proposals for 300 channels 4 KHz wide.	In 1.6 GHz (L-band) range for link to plane. Satellite to master station link could be in microwave region.	Large dish for master station to satellite.	In 1.6 GHz for plane to satellite link. Microwaves for master control to satellite.	Aircraft send-receive antenna is low profile, circularly polarized. Gain may be 4.0 db Broadbeam, omnidirectional.	Aircraft receiver using solid state circuits. Redundancy may increase system reliability. Display or warn devices.

REQUIREMENTS FOR FOUR TYPES OF COMMER

TYPE OF SERVICE	TOTAL SYSTEM		SPACE SEGMENT				
	SYSTEM CAPABILITY (TV, Voice Data, Etc.)	OPERATING CHARACTERISTICS	ORBIT, STABILIZATION, STATION KEEPING	SATELLITE POWER	SATELLITE ANTENNA	SATELLITE TRANSPONDER	[illegible]
INTERNATIONAL SATELLITE SYSTEM (Point-to-Point)	All types of service sold by international carrier (TV, voice, record data)	Multiple mode, multiple access. System wide interconnectivity. Channel preassignment plus demand assignment, eventual diversity. Traffic switching, automatic accounting.	Spin stabilized, geostationary or despun platform 7-10 years of station keeping 1-2 degrees of stabilization sufficient.	Relatively low power on each down-link channel. 100-600 w DC. Has been power limited in past. Future may be bandwidth limited.	May be beamed for global coverage but high density routes could use 4-degree beams to ground. Polarization diversity in future.	Multiple access. Non-return to baseband. Separate transponders ensure against total failure and reduce interference and intermodulation.	[illegible]
BROADCAST DISTRIBUTION (Point-to-Multi-Point)	Primarily voice and TV but data and telephone possible in joint venture. Domestic system. Canadian Telesat is example. Eight U.S. applications for consideration.	Several dedicated broadband channels (network TV). Multiple tariffs for real-time or delayed transmission. Variable capacity data-links.	Stable platform on a dual spin body. Stabilized to 0.5 degree. May be desirable to remove from orbit at end of life.	Medium power 1-2 kw DC. Relatively high power per down-link. Solar-array paddles, power converters, slip rings.	Directional to region (i.e., Rocky Mountain States) or one country (Canadian system). Beam shaping or multiple spot beams.	Limited or assigned access from earth stations. Multiple transponders for mixed users (i.e., broadcast networks, law enforcement, data).	[illegible]
DIRECT BROADCAST SATELLITES (Point-to-Wide Area)	TV and voice direct to home or community. ETV, ITV, news, weather, culture. May be part of another hybrid system.	Mixed system, real-time or delayed. Fascimile "news." Many modes may be used. Human interfaces.	Control over stabilization to 0.2 degree. Low thrust station keeping. Control over flexible body interactions.	High power in few channels. 5-12 kw DC. Large solar cell arrays. Slip rings. Power converters, distribution. Fuel cells possible for power.	Regional, covers one country or state (i.e., India, Hawaii, Alaska). High gain to simple receivers. Large deployable 30-60 ft arrays.	Limited or assigned access. High transponder power, high output power final stage.	[illegible]
MOBILE Air Traffic Control (Surveillance Communication and Positioning)	Air traffic control, surveillance, data, position location, communications, warning and display. Remote sensor and weather data.	Diversity or signal redundancy. Digital multiple access. Interrogation and response, on-board processing, discrete address.	Accurate range and range-rate could be desirable in determining position. Platform stabilized to < 0.1 degree.	Moderately high power in narrow channel. Solar paddle arrays with 2-axis drive. Must provide strong signal to small antennas and receivers.	Global pattern or to major ocean. Circularly polarized antenna.	Multiple access from aircraft (time-sharing), assigned access from earth controllers. High power to antenna. Sensitive receiver.	[illegible]

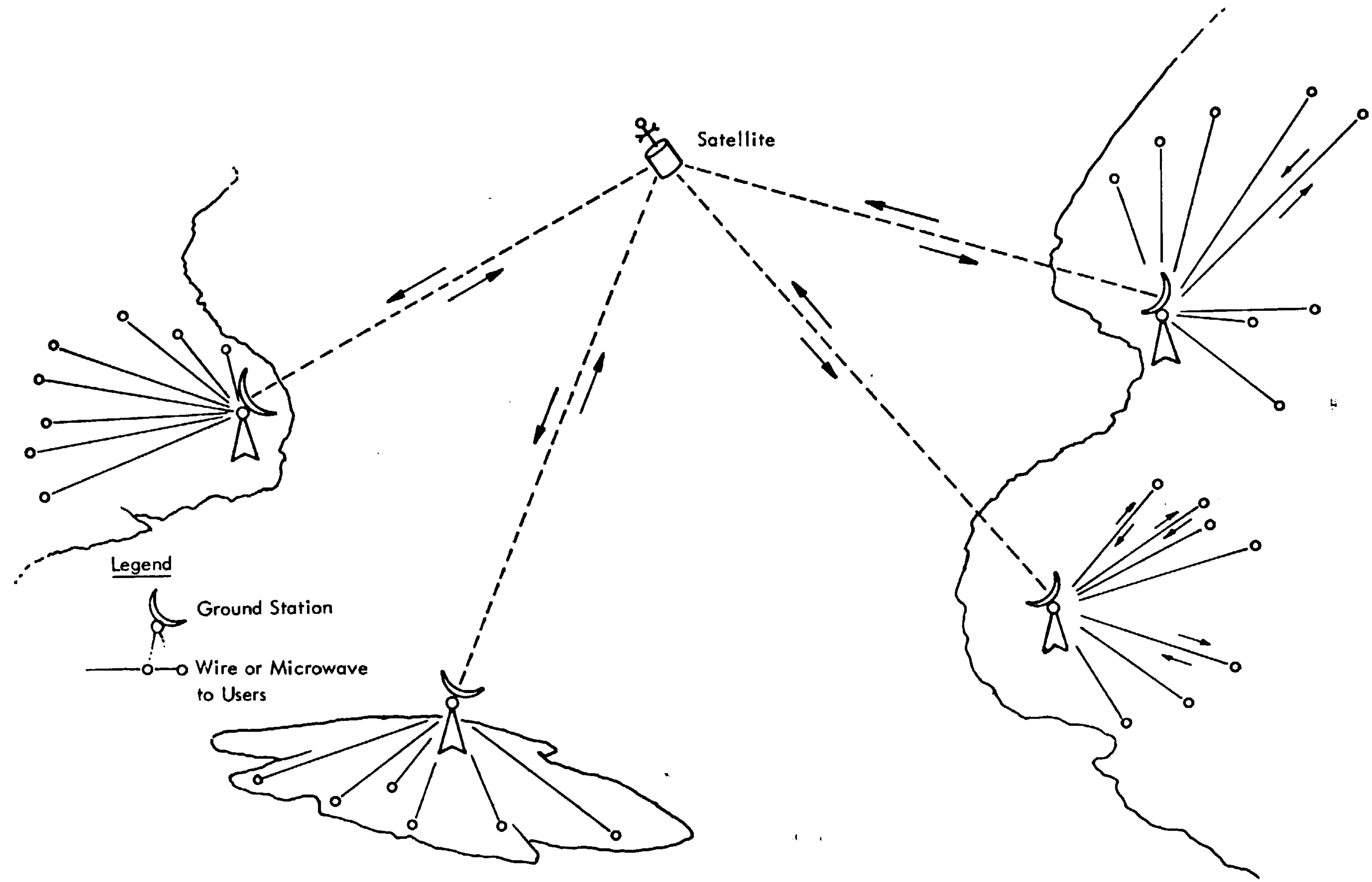


Figure 3 - International Satellite Systems Serve Many Points in Many Nations

Broadcast Distribution. Broadcast distribution or point-to-multipoint service, could also handle all modes of transmission, but as it is now conceived, TV and voice, one-way channels would be of primary importance. Eight organizations have applied to provide such service in the United States. Some of these applications stress hybridized operation of the system wherein some circuits in the satellite would be used for telephone or data service. However, network television distribution of programs to local stations for rebroadcast seems to be the greatest application of such a system. The Canadian Telesat system is a typical example of broadcast distribution.

Another possible use of such a system is educational television broadcasting to receivers feeding signals to school districts or to local TV stations for rebroadcast by conventional methods. Larger community antenna or cable TV systems could also use the broadcast distribution satellite. In such an application, ground-receive-only stations would convert the signals from the satellite to standard TV channels and then feed these signals to coaxial cables leading to the homes of the individual subscribers (see Figure 4).

The operating characteristics of the broadcast distribution system differ from those of the point-to-point or International System. The distribution satellite would have several dedicated, full-time, wide-band channels carrying network TV on a real-time basis. Programming from the continental United States could thus be relayed to Alaska or Hawaii for rebroadcasting at the same time, or for videotaping for later rebroadcast. Another use would be as a program source for stations in the Western U.S. not connected to microwave repeaters or coaxial cable.

Other proposed applications for broadcast distribution service are in the transmission of high-quality, high-speed facsimile to provide recorded news or other information to all areas of the nation, dissemination of information to the medical or scientific community, and information broadcasting necessary to law enforcement and crime prevention.

Direct Broadcast. The third system of our illustration directly involves the end user. The signal from a direct broadcast satellite will be so strong that an antenna and converter costing about $100 can receive the transmissions and convert them for use by a standard TV set. This direct broadcast could be utilized for facsimile, entertainment, health services, agricultural bulletins, national weather forecasts, and other functional programs aimed to the general population. With NASA assistance, a system of this type will be demonstrated in India where small isolated communities will use centrally located receivers for group viewing. Feasibility studies have also been performed for a system for Alaska and all U.S. schools (see Figure 5).

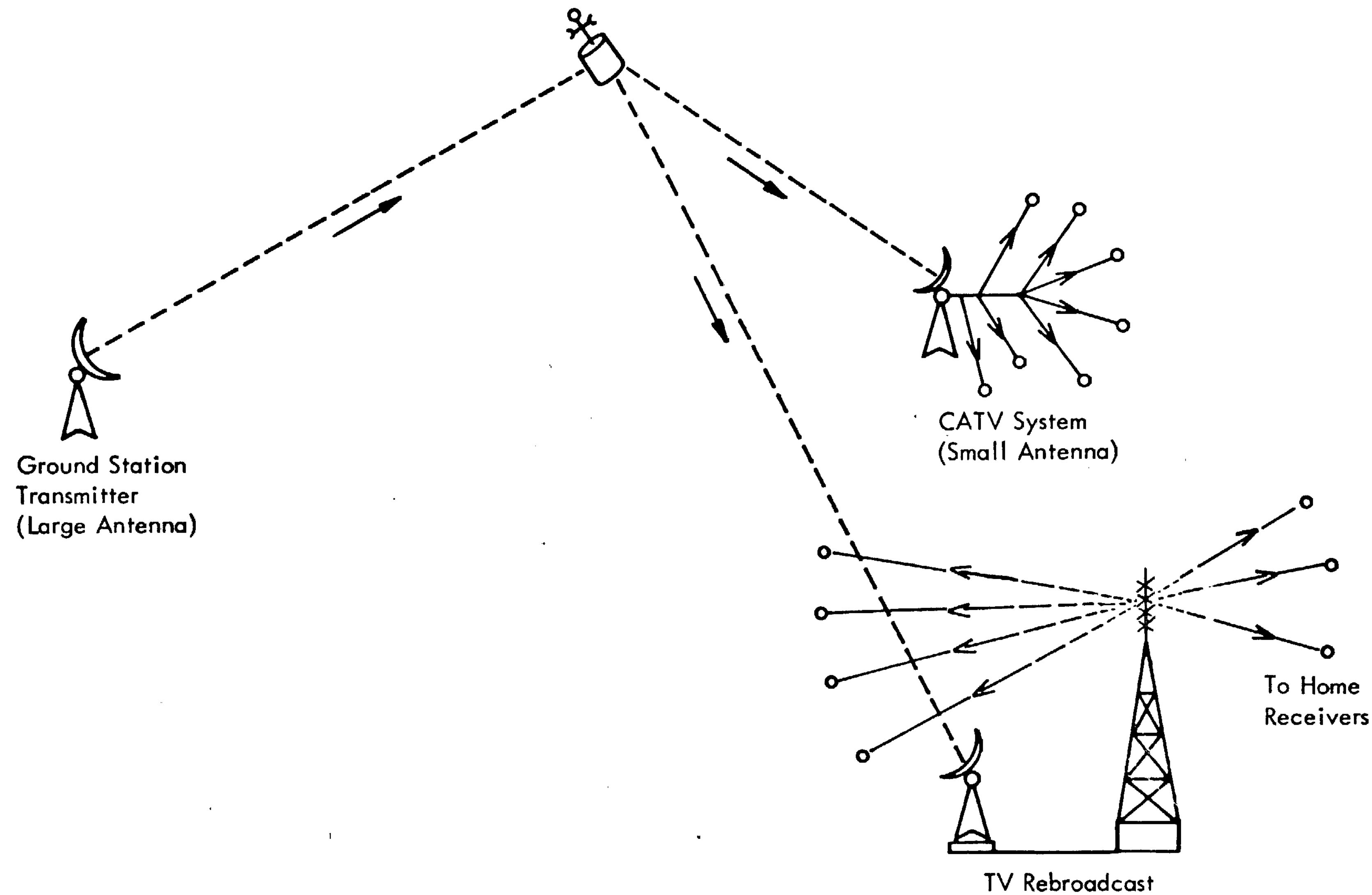


Figure 4 - Broadcast Distribution Via Satellite

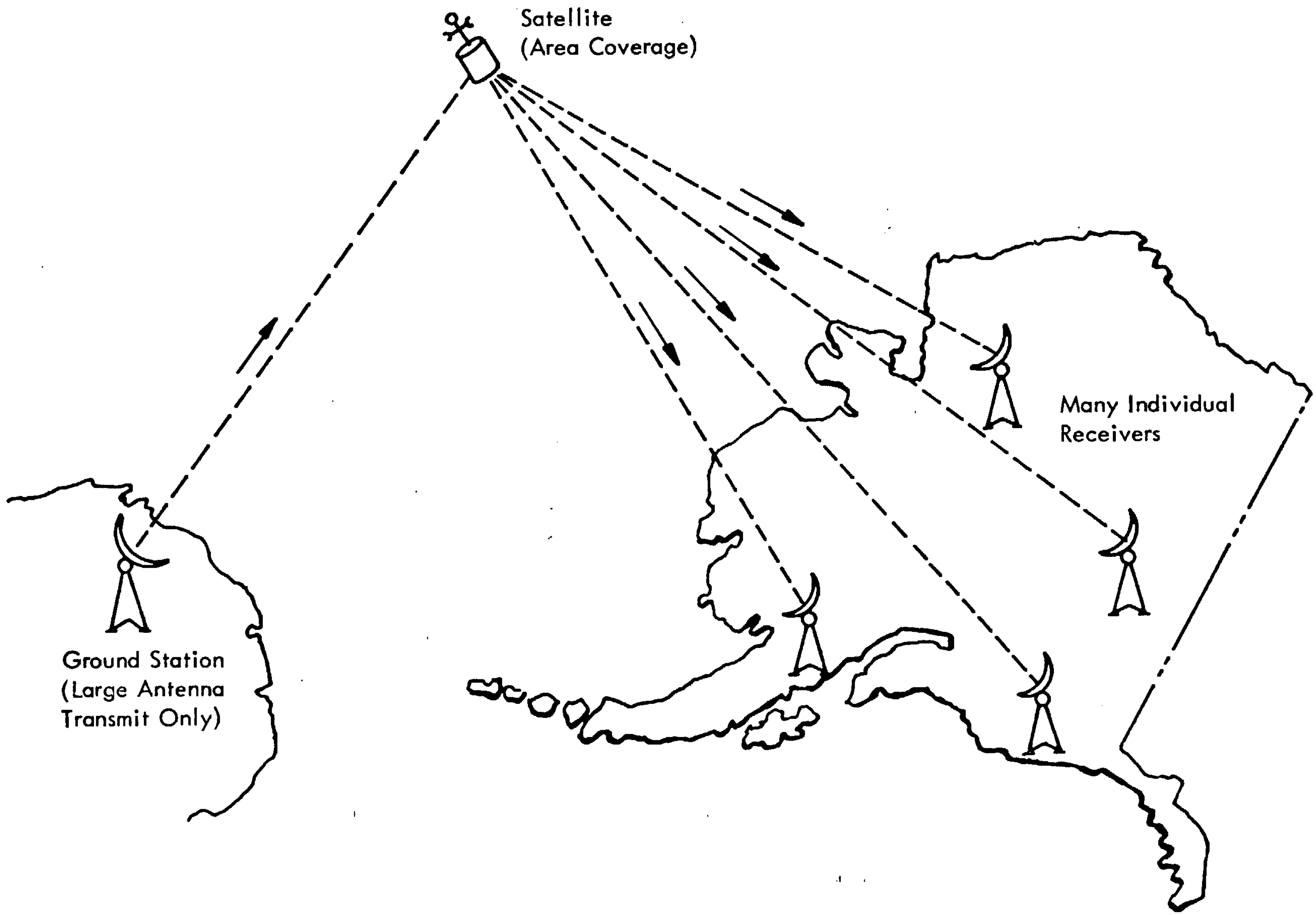


Figure 5 - Direct Broadcast to Small Receivers Via Satellite

Mobile and Navigation. The navigation or air traffic control satellite (Figure 6) is the fourth system. Aircraft communications, traffic control, precision location, geodesy, data collection and relay, and ship navigation are major functions of the system. In-orbit spares and channel diversity will minimize equipment outages and increase reliability. The transponders on such satellites will handle multiple interrogations on a time-shared basis. Independent surveillance of all aircraft in the coverage of the satellite could provide a visual display at major ground control centers without the necessity of pilot interaction with the system.

With on-board instrument data monitoring, flight route information could be automatically sent to the satellite. This information would be correlated with weather information and data from other aircraft to prescribe the ideal route. Collision avoidance information could also be handled by the system, and the aircraft's pilot would receive visual or aural warning of danger.

Technical Requirements

When determining the best type and design of a communications satellite, one must think in terms of tradeoffs. For example, more solar cells can be added to the spacecraft to increase transmitted power at the expense of eliminating one of the extra repeaters originally intended for greater reliability or extra capability. Ideally, the designer wishes to optimize the utility of the entire communications system from ground station to satellite back to ground station. As communications capability is a salable commodity, optimization usually means transmitting the most information for the least cost in terms of satellite, ground facilities and operations.

User needs, therefore, dictate the technology appropriate for the various elements and sub-systems. The performance characteristics and operational requirements describe how each major section within the earth and space segments must function. Needless to say, the required technical parameters have been defined to fractions of feet, watts, degrees, decibels, and cycles. The technical requirements for different categories of communications do not affect all characteristics of the system equally. A general comparison of the requirements of the four types of service follows. Six major parameters of the space segment will be treated first, in the same order as shown on page 31 and four parameters of the earth segment will then be considered.

Orbit, Stabilization, Station Keeping. All four applications are predicated upon the achievement and maintenance of geostationary orbits (i.e., orbits at 22,300 miles, synchronized with the earth's rotation and placed over the earth's equator). Satisfaction of this technical requirement is fundamental to all others.

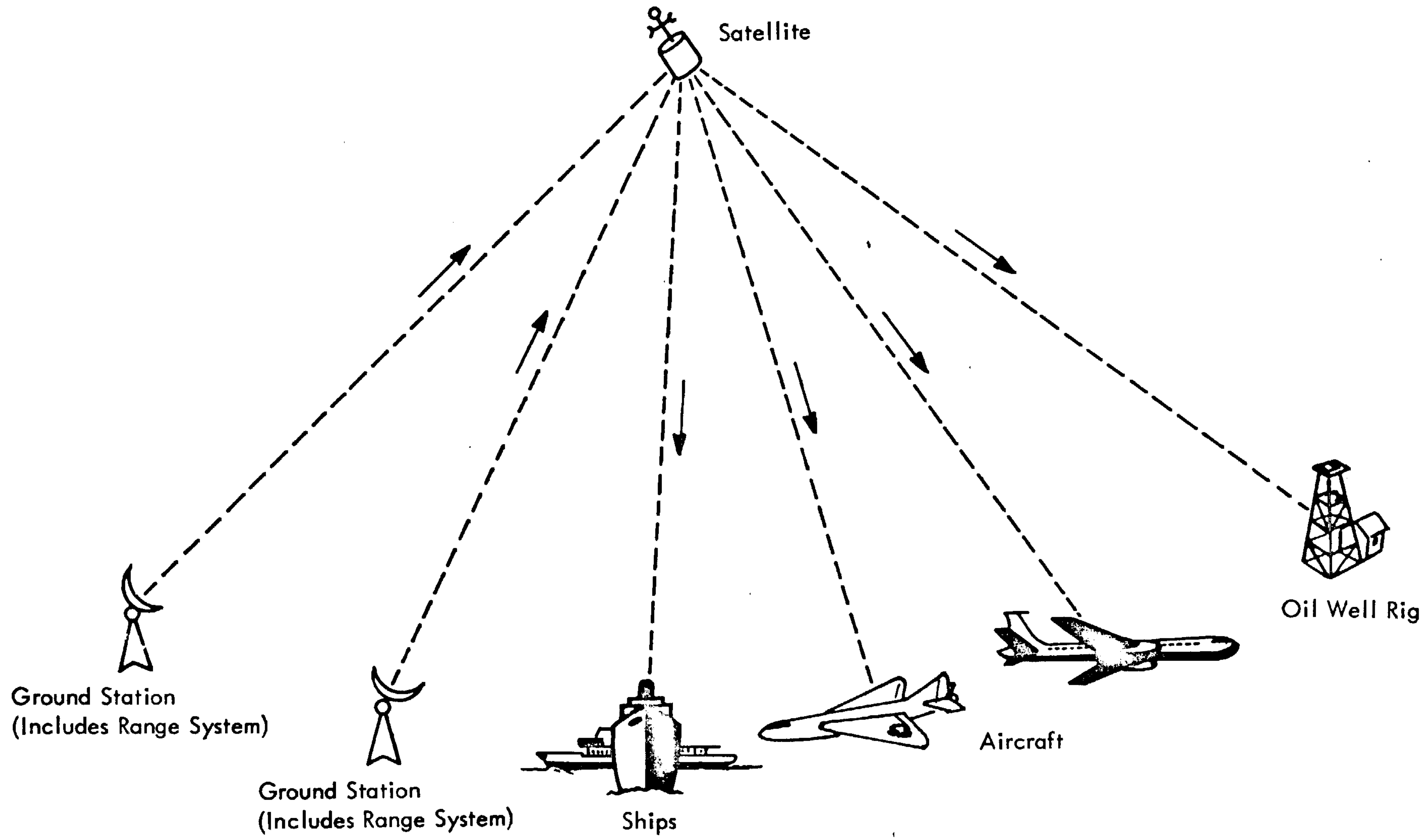


Figure 6 - Mobile and Navigation Satellite

The nature and degree of spacecraft stabilization, attitude control and station keeping required for the four classes of systems vary considerably. Both the accuracy of attitude measurement and the extent of stabilization required for International service are less than that demanded by the other applications. Most International satellites use antennas providing earth coverage and therefore can tolerate perturbations of 1 to 2 degrees about the spacecraft axis.

At the other extreme, spacecraft for Direct Broadcast and Air Traffic Control require a stable platform for accurate antenna pointing. Spacecraft must, therefore, be stabilized to 0.1 to 0.2 degree. Requirements for broadcast distribution fall between the 2.0 to 0.1 degree extremes.

Requirements for measuring the orientation of the spacecraft attitude (from the earth station) also differ for the same reason--accuracy of antenna pointing. To permit precise alignment of the spacecraft, attitude determination must be accurate to about one-tenth of the stabilization angle requirement. International and Broadcast satellites can use one or two attitude sensors of moderate precision; Direct Broadcast and Mobile applications necessitate multiple, independent attitude sensing systems.

Some form of on-board station keeping is required for each type of system, but the needs of each application dictate differences in the station keeping techniques used, and the duration the spacecraft can be held on station. International and Broadcast Distribution satellites can be made compact and structurally rigid. Thus, they can utilize high thrust systems for orbital and altitude control. High specific impulse, and maximum total impulse are desired, with little requirement for low-force vernier adjustments. Direct Broadcast and Mobile satellites have extended solar arrays or large antennas--structures that are fairly flexible. Special, low-thrust or low-torque control systems must be used to minimize disturbance of these flexible elements.

Satellite Power. In any application, the satellite signal must be sufficiently strong to be received by the systems ground terminals. The effective radiated power for this down-link is dictated by the sensitivity and noise characteristics of the earth receiver. Achieving the required signal strength involves selected trade-offs among the spacecraft primary power, transponder and antenna characteristics. Because many satellites are primary-power limited, special attention must be given to optimizing the sub-systems for power supply, storage, conditioning and handling.

International satellites, capable of thousands of low-power voice channels, require 100 to 600 watts of primary power. This power can be supplied from solar cells mounted rigidly on the surface of the spacecraft. Storage batteries power the electronics during eclipse, and few problems are encountered in power conditioning and distribution. Low voltage DC slip-rings are needed for the latest INTELSAT IV series, because the repeater electronics are mounted on the de-spun portion of the dual-spin-body spacecraft.

The higher effective radiated power needed for Broadcast Distribution, and especially for Direct Broadcast or Mobile applications, can be achieved only partly by the use of high-gain, spot-beam antennas on the satellites. Considerably higher levels of primary DC power are also needed, together with higher RF output from the communications repeaters. This requires power sources of several kilowatts and deployable solar arrays or other power supplies must be used. High power levels also require complex power conditioning, and the difficult problems of handling high power in the space environment.

Satellite Antenna. Antenna designs for the four applications are determined by the required signal strength and area coverage. As previously noted, antenna capability can be traded off against satellite power or earth station size and sensitivity. The main characteristics of spacecraft antennas are physical size, beam width (which determines the earth area covered) and accuracy of pointing.

International applications, with global service from only three satellites, require substantially earth disc coverage (12 to 20 degrees beam width). High traffic-density links, for example, New York to Paris, can best be handled, and satellite power conserved by also having secondary spot-beam antennas pointed directly at these cities.

The other three applications require (to minimize ground station cost and satellite power level) antennas that focus the signal on the specific area to be served. For irregular areas, and where signal intrusion beyond geographic boundaries is undesirable, beam shaping is required.

For Direct Broadcast and Mobile applications where the effective down-link power must be high to serve small earth receivers, large antennas (30 feet to 60 feet in diameter) are required. These antennas must be deployable in order to fit within available launch vehicles. Large antennas which require accurate pointing also present difficult problems in mechanical control, RF feed design and stabilization.

Satellite Transponder. Multiple access, multiple channel transponders are required in the International satellite to handle the high flow of traffic and high degree of interconnectivity demanded by the system. Multiple access allows any ground station to contact any other ground station through the satellite without having to be "wait listed."

Direct Broadcast needs a limited number of dedicated, high power transponders capable of one-way TV relaying. Each transponder is assigned to a particular user and is not shared with other services.

Transponders in the Broadcast Distribution system must be both (a) medium power, limited access and (b) low power multiple access. The limited access transponders are one-way devices that distribute the network TV programming to regional stations for rebroadcast, while the multiple access units provide domestic two-way communications.

The air traffic control transponders are hybrid devices that provide two-way communications between small mobile stations and large fixed ground control stations. The transponders in the ground station to mobile unit link must be assigned access. Those transponders in the mobile unit to ground or control station path must be multiple access allowing the various aircraft to use the system.

Channel Capacity. Requirements for International systems stipulate multiple TV and voice channels to handle traffic between the various nations utilizing the service. The lower power signals complementary to this form of communications place 10 or more TV channels, or the equivalent 3,000 to 9,000 voice channels, well within the capacity of the spacecraft. The splitting of this channel capacity among 10 or more transponders is desirable to prevent interference and enhance reliability.

The Direct Broadcast satellite needs fewer TV channels to fulfill its mission. All the satellite power is concentrated in these few channels to provide, in conjunction with the large transmit antenna, the necessary signal on the ground.

Broadcast Distribution systems require channel and power capacities that offer a compromise between the International and Direct Broadcast systems. The medium power requirements of the distribution satellites allow tradeoffs between various combinations of power and channel capacity. The demand for flexibility of such a system allows the various combinations to be offered to the user without penalizing the entire system.

Channel demands for the air traffic control systems are less stringent than the others, as each user needs only intermittent contact through the satellite to acquire the necessary information and direction. A single ocean system providing 300 narrow band, high power channels fulfills the requirements of this service and allows for increases in air traffic.

Down-Link Frequency. Down-link frequencies for any of the sytems must be in a portion of the microwave spectrum that contains sufficient channels. For the International and Broadcast Distribution systems, assignments in the 4 GHz range presently suffice. As satellite usage increases, other portions of the spectrum will have to be utilized.

Direct Broadcast places different requirements on the down-link frequency. The UHF area is desirable for this service because channels in this range are compatible with existing receiver and antenna technology in the mass production TV market. The low cost of producing equipment at these frequencies also makes this a more attractive range for the high use system.

Compatibility with existing systems and low mobile equipment cost are controlling factors in the selection of UHF L-band for the air traffic control system. Installation and service procedures for electronics in this range are within the capability of most airport service centers, as present DME (Distance Measuring Equipment) is in this range.

Ground Station Transmit Antenna. Ground station transmit or uplink antennas are similar for all satellite services. The antenna must provide high signal gain to assure that an undistorted, noise free signal is received by the spacecraft. A narrow beam assures that only the satellite of interest receives the signal from the earth. Off-side signal radiation must be minimized to prevent interference with other services using microwave frequencies or other satellite systems. Mechanical drives are necessary to point the antenna to the satellite.

These requirements are met in the international system by large parabolic antennas with diameters from 90 to 100 feet and gearmotor drives. Some compromises are achievable if only a limited number of channels are needed. Thus, stations in the international system with lower traffic loads, broadcast satellite system stations carrying only a few TV channels, or air traffic control antennas with a capacity of a few hundred narrow-band channels can be scaled down in size with no degradation of quality.

Up-Link Frequency. Up-link frequencies, like the down-link frequencies, must be in a portion of the microwave spectrum that can accommodate all the needed channels. International, Broadcast Distribution, Direct Broadcast, and the ground station up-link for air traffic control service can be accommodated in the present 6 GHz assignment. As terrestrial stations are not limited by primary power or weight, up-link frequency is not critical.

The up-link frequency for the aircraft to satellite path in air traffic control service is the same UHF L-band assignment of the satellite-to-aircraft link. Selection of these frequencies is determined by factors of availability, compatibility, cost, and technological capability.

Ground Station Receive Antenna. Ground station receive antennas for the four different systems are unique to each service. The antenna used with the International system is the same as the transmitting antenna; high gain and directivity are prerequisites for receiving the low-level, multichannel down-link signal from the low power satellite.

Broadcast Distribution system stations designed to receive only a few channels of TV are smaller than the multichannel International antennas. Parabolas of 10 to 30 foot diameter fulfill the requirements of these systems. A multichannel broadcast distribution receiver requires the larger of these, while a single channel receiver functions with the smaller antenna. As the antenna is always aimed toward a single stable satellite, its position is fixed and simple orienting mechanisms suffice.

Direct Broadcast receiving antennas are low priced, mass produced, small structures that can be easily assembled and manually aimed at the satellite for best signal reception. The antennas for home or school room use must be small; a 10 foot diameter or less is sufficient.

Aircraft antennas for the air traffic control system are mounted in the fuselage and have to be omnidirectional to pick up the satellite as the aircraft is maneuvered. The strong down-link signal eliminates the need for high gain, but the antenna must be designed to prevent blackout or signal loss under various conditions of turning or tilt.

Ground Station Receiver. A high gain, high technology receiver with wide-band capabilities is needed with the International Satellites. The numerous signals from such a satellite place rigid requirements on the bandwidth and the low signal levels demand high gain and minimum noise within the receiver. Such design requirements are fulfilled by cooled parametric amplifiers.

The number of received channels and size of the antenna directly affect the characteristics of the Broadcast Distribution system. High-gain, wide-band receivers operate with ground stations handling many channels while lesser gains and lower bandwidths suffice under single channel reception conditions. Simple parametric amplifiers, masers, and solid state devices fulfill these requirements.

Converters for operation in the Direct Broadcast system are provided with higher satellite signals and only one channel is received at a time. These parameters lower the required receiver gain and reduce its complexity, resulting in lower cost. A converter and antenna for direct broadcast reception should sell for about $100.

Receivers for positioning or ATC systems must be high gain devices capable of operating with associated systems and voltage levels. Solid state circuits meet the reliability and operating criteria of aircraft electronics. Such circuits are also compatible with other electronics used in navigational aids.

IV. PROGRESS INDUCING ROLES OF A MISSION-ORIENTED R&D AGENCY

The two preceding chapters described the technological requirements of four classes of commercial communication satellite systems and the national R&D effort which has been directed toward the satisfaction of the requirements. The technological accomplishments of the effort have been such that the International class of commercial telecommunications satellites is already in its fourth generation of spacecraft and its third generation of ground stations. The first Domestic commercial system will soon be deployed in Canada. At least eight applications for U.S. domestic satellite systems are under consideration by the Federal Communication Commission. One or more will doubtlessly be installed in the near future. Similar regional systems are under active consideration for continental Europe. In addition, a Direct broadcast experiment is scheduled in India and the first Mobile application will be a prototype aeronautical satellite communication system.

Thus, technological progress in the communications satellite field has proceeded at a remarkable rate. The technical feasibility of all proposed systems is widely conceded. Given technical feasibility, emphasis has proceeded to resolution of the economic, regulatory, and organizational details. This is the natural progression characterizing the technology application process.

The question addressed in this chapter is: to what extent and in what ways have the synchronous communications satellite programs of the civilian space agency stimulated progress toward these commercial systems and supported the pacing technologies required for their accomplishment?

The presentation format adopted has four parts: First, examples of specific NASA contributions toward the satisfaction of the technical requirements of each of the four classes of commercial application are indicated. Second, several types of roles played by the space agency in nurturing the technology and the demand for the resulting new communications capabilities are described. Third, a brief assessment is made of the extent of technological progress which has occurred in the field of communications by satellite in the past decade. Finally, an assessment is included of the U.S. strategy toward technological progress and its commercial application--a strategy which has been highly successful and widely envied by other nations.

Requirement Satisfaction--R&D Leading to Commercial Use

Science and technological progress are essentially cumulative processes. Each successive advance stands on the shoulders of preceding discoveries and accomplishments. Fully acknowledging the debts owed to earlier satellite programs, and to radio communications and electronics in general, we have attempted to summarize and illustrate some of NASA's contributions stemming specifically from the synchronous programs--SYNCOM, Advanced SYNCOM, ATS plus Supporting Research and Technology (SR&T) undertaken during the same period. Selected technical developments identified within the SYNCOM, ATS, and SR&T programs surveyed during this project are indicated on page 47. The blocks in this chart are keyed directly to the technical requirements necessary to support various aspects of the four commercial systems. The nature of significant developments, and the programs with which they are associated provides some indication of the breadth and variety of impacts which research and feasibility demonstrations can have on the synthesis of operational systems.

No attempt is made in this chart to be comprehensive in coverage or exhaustive in detail. The developments selected for inclusion here are those identified during interviews with NASA personnel and major space contractors as representing a cross section of technical advances and accomplishments directly supporting and contributing to commercial systems. Certain technical advances and contributions were also included on the chart because they illustrate the variety, complexity, and interactive nature of the support and impetus provided by experimental programs. This form of presentation does not imply that the impact of a particular advance is confined to one system characteristic; such interpretation underestimates the range of effects. An essential purpose of this summary presentation is to convey some of the "flavor" of the process by which mission-oriented research undergirds, and enables the achievement of economic goals.

Federal Roles in Technological Progress

The Space Act of 1958 requires as one of its objectives, that space activities materially contribute to:

> "The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere."

...AM CONTRIBUTION TO REQUIREMENT SATISFACTION

...ACE SEGMENT				EARTH SEGMENT			
	SATELLITE TRANSPONDER	CHANNEL CAPACITY	DOWN-LINK FREQUENCY	GROUND-STATION TRANSMIT ANTENNA	UP-LINK FREQUENCY	GROUND-STATION RECEIVE ANTENNA	GROUND-STATION RECEIVER
Phased lly y)	SYNCOM III (Broadband 25 MHz) ATS-I ATS-III (Dual Mode)	SYNCOM II & III ATS-I (Building Block) (Channelization)	SYNCOM II & III ATS-V (Millimeter Waves)	(Cassegrain Feeds) ATS-I ATS-III (Pseudo Monopulse) SR&T	SYNCOM II	SYNCOM II (Margins) ATS-I SR&T	SYNCOM II ATS-I SR&T (Threshold Demodulars) (LN_2 Cooled Paramps) (Wideband I-F)
a	SR&T (High Output TWTs)			ATS-III (12 KW Multi-Cavity Klystrons)	SYNCOM III	ATS-I ATS-III ATS-F (Small Stations)	ATS-III ATS-V (Paramps 30 GHz)
oyable	SR&T ATS-V (200 Watt TWT 12 GHz) (Multipacting High Power RF Components)	ATS-F	ATS-V ATS-III (SHF and Millimeter Wave Propagation)	SR&T ATS-F (Small and Transportable)	ATS-V	ATS-F SR&T (Small, Low Cost)	SR&T ATS-III ATS-F ($100 Converters)
	SYNCOM III ATS-I ATS-III (On Board Processing) (40 Watt L Band)	ATS-I ATS-III ATS-F	SYNCOM (VHF) ATS-III (UHF) ATS-F (L-Band)	SYNCOM III ATS-I (ARINC) ATS-III (OPLE)	ATS-III ATS-F (Modems)	ATS-F ATS-I SR&T (Low Drag Designs)	ATS-F SR&T (Low Noise Detectors)

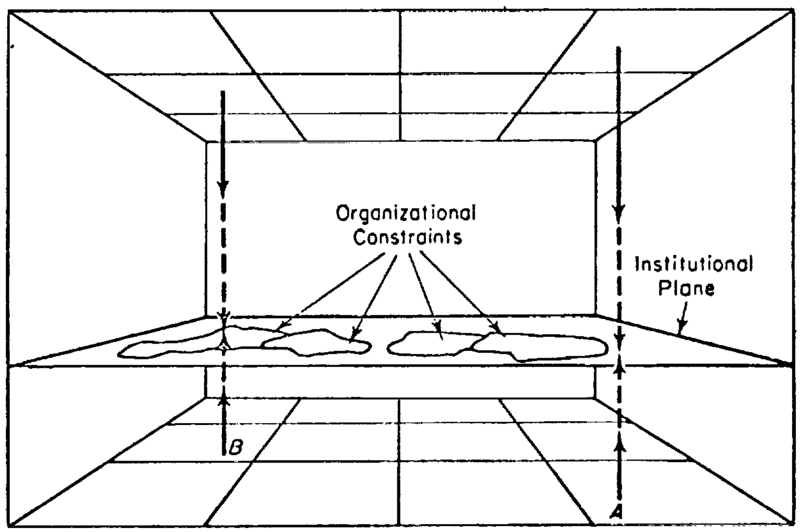
NASA'S PROGRAM CONTRIBUTION TO R

TYPE OF SERVICE	TOTAL SYSTEM		SPACE SEGMENT					
	SYSTEM CAPABILITY (TV, Voice, Data, Etc.)	OPERATING CHARACTERISTICS	ORBIT, STABILIZATION, STATION-KEEPING	SATELLITE POWER	SATELLITE ANTENNA	SATELLITE TRANSPONDER	C C
INTERNATIONAL SATELLITE SYSTEM	SYNCOM First Synchronous Transoceanic TV	ADVANCED SYNCOM ATS-I (Multiple Access) SR&T (Coding and Modulation) (PCM-FM)	SYNCOM II (Altitude Sensors) ATS-I (Spin Stabilization) (Pulse Jet Control) (Polang Attitude)	ATS-I (Low Energy Proton Damage)	ATS-I (Electronic Phased Array) ATS-III (Mechanically Despun Array)	SYNCOM III (Broadband 25 MHz) ATS-I ATS-III (Dual Mode)	SY AT (B (C
BROADCAST DISTRIBUTION (Point-to-Multi-Point)		SR&T (Multi-Path Protection)	SYNCOM III (Triaxiallity and Gravity Potential)	SR&T (RF Power Handling) (RFI Problems) (Heat Pipe Cooling)	ATS-III SR&T (Shaped Area Coverage)	SR&T (High Output TWTs)	
DIRECT BROADCAST SATELLITES (Point-to-Wide Area)	ATS-F	SR&T (Digital Multiple Access)	ATS-F&G (Low Thrust Jets) SR&T (Flexible Body Effects)	ATS-F (High Power Arrays) (Slip Rings)	ATS-F&G (30 Ft Deployable Array)	SR&T ATS-V (200 Watt TWT 12 GHz) (Multipacting High Power RF Components)	ATS-
MOBILE Air Traffic Control (Surveillance Communication and Positioning)	Aircraft VHF SYNCOM III ATS-III (ARINC) ATS-F (Place)	ATS-III (Address Codes) ATS-IV SR&T (Coding and Modulation) (Error Correcting Codes)	ATS-F (Reaction Wheel) (Dual Spin) (0.1 Degree)	ATS-F (Two Axis Array Drive)	ATS-III ATS-F	SYNCOM III ATS-I ATS-III (On Board Processing) (40 Watt L Band)	AT AT AT

How did the technical content of the SYNCOM and ATS programs satisfy this requirement? What roles and functions does a mission-oriented research and development agency play in supporting the technology needed for commercial applications?

Technological change does not just happen; it is managed by organizations, both private and governmental. Technical progress occurs as the result of attempts by many organizations to find ways to match scientific and technical capabilities with societal needs. To support and promote technical accomplishment, institutions often direct their efforts to both the supply side (or technology), and to the demand side (operational needs). (See Figure 7.)

Science and Technology Plane (Supply)



Societal Needs Plane (Demand)

Source: Buttner and Cheaney: "An Integrated Model of Technological Change."

Figure 7 - Organizational Roles: Matching Technology With Needs

The different roles and functions played by NASA in promoting the application of advanced technology to communication needs can be observed using examples from the SYNCOM and ATS programs.

<u>Transfer of Total System</u>. When a new techrology is developed for a specific purpose, and in a particular form, the whole system--concept, configuration and operating confidence--can be transferred to commercial enterprise.

Examples of this very important type of technical support and technology transfer are found in INTELSAT I and INTELSAT III. For each generation of international communication satellites, the Intelsat ICSC committee was able to procure the performance desired with minimum risk, by adopting without major change the space qualified and flight proven systems demonstrated on SYNCOM III and ATS III. The overall system configuration, major subsystems, functions and components of these spacecraft are substantially similar.

Research and Development Leading to Commercial Use. In-house government research has been carried through the subsequent phases of development, fabrication, test and qualification, and operation in space, and has ultimately been transferred to commercial operations.

A good example of this channel of technological support is seen in the evolution of spacecraft antennas; and in particular the concept of mechanically despun antennas. The initial idea behind the motor driven reflector element came from a laboratory group at Goddard under Abe Kampinsky. In the initial stages of planning for ATS III, only the feasibility of mechanically driven elements was to be tested--reliability would have to be proved before basing the main communication antenna on a mechanical system. However, as the development of ATS III continued, the antenna contractor, Sylvania Laboratories, together with Kampinsky and his associates, became convinced that the mechanical antenna offered such an enormous improvement in satellite power that it was worth the risk. The project development plan was modified to include the mechanically despun antenna for the spacecraft down-link. Sylvania designed and fabricated the antenna--with key technical assistance from Ball Brothers Research on the bearing and lubrication system; Kearfott for the drive motor, and Mechanical Technology Incorporated, who performed the all important thermal-vacuum space simulations of mechanical reliability.

The performance of the mechanically despun antenna on ATS III more than justified the faith of those who championed the idea. By concentrating all of the transponder output into a 19 degree conical beam to cover the earth's disk, the effective satellite communication handling capacity was increased by a factor of 15-fold over the pancake antenna patterns previously employed. Much additional laboratory work, and many thousand hours of simulation and actual space experience would be required before the ideas were perfected. But in 1963 when Intelsat selected TRW Systems as spacecraft contractor for INTELSAT III, the contractor was specifically instructed to work with Sylvania and incorporate the mechanically despun antenna as the key feature of this third generation of international satellites.

Scientific Findings Influence Subsequent Technology. In many cases technical progress depends upon discoveries stemming from basic investigations of natural phenomena. New knowledge and understanding gained from scientific experiments often provide the clues needed to improve the performance of subsequent systems. Typical examples are found in the areas of station keeping, and in solar power systems.

The SYNCOM program provided the first detailed information on gravitational potentials at the synchronous altitude. The findings of the earth's tri-axiality, and the mapping and location of "gravitational graveyards" made it possible to select positions for locating geostationary satellites where they could be kept on station much longer than their station keeping expendable supplies would otherwise permit.

Solar cell performance on ATS I provided the first evidence of a new type of solar cell damage attributed to low energy proton effects. This phenomenon--important for all satellites in the synchronous environment--was the subject of several NASA investigations which elucidated the mechanism and indicated ways that damage could be minimized. An interim "quick-fix" to avoid low energy proton damage was first implemented on INTELSAT II-F5. More effective and elegant protection methods were designed into the solar arrays for subsequent communication spacecraft.

Defining Technological Requirements for Advanced Systems Procurement Specifications Which Stretch the State of the Art. These two classical ways by which mission-oriented government agencies stimulate and support advanced technology are essential parts of the "feedback process" of working with aerospace industries. Continuous surveillance of relevant technologies, and the appraisal of alternative technical approaches, are important functions of all mission-oriented R&D groups. Technical planning to define the requirements needed to support future missions and projects, followed by making these needs known to research organizations and the industrial community, is a traditional way of motivating innovations which may advance the state of the art. The procurement process involving RFP's and specifications at or beyond present technical limitations, has been a principal vehicle for developing advanced capabilities.

In the field of satellite transponders, steady evolution of improved microwave transmitter tubes provides a typical example. Space qualified output tubes experience significantly different problems than their terrestrial counterparts. The two-watt traveling wave tube of SYNCOM was based on a slimmed down design from SURVEYOR. The Watkins-Johnson backup tube for SYNCOM never flew, but has had a profound effect on subsequent design. Today the Watkins-Johnson model 395 is the only space qualified tube providing 100 watts of output power. During the interim, NASA programs have been instrumental in exploring alternatives. Space qualified crossed-field amplifiers were developed by Litton and by SFD laboratories. Magnetic and electrostatically focused klystrons have been developed by General Electric and Litton. The new "super efficiency" traveling wave tube developed by NASA Lewis Research Center is more efficient and powerful than any in space today. Operating at 12 GHz with 200 watts of RF output, this tube is scheduled to fly in 1974.

Similar patterns are found in Earth Terminal development. When SYNCOM range and range-rate measurements showed that better systems would be needed to control the orbits of advanced geostationary satellites, having precision station keeping abilities, Goddard Space Flight Center wrote new specifications calling for an order of magnitude improvement. By using substantially different technical approaches, the contractor was able to achieve this 10-fold improvement which for four years defined the limits of the art. Still greater precision will be required for direct broadcast satellites which require stabilization and antenna pointing accuracy of 0.10 degree, and a new cycle of development is currently under way.

Initial Users of Innovations. Early adopters of new technology play an important role in developing applications and markets for innovations. Incorporation of independent advances into technical programs has been a vital way of promoting progress and encouraging commercial utilization.

The ATS programs provide many examples of this mode of technical development--in ground station antennas, spacecraft amplifiers, and signal enhancement. Modification of the Rosman, North Carolina, terminal to take advantage of the improvements promised by cassegrain feed provided early impetus to this now standard approach. Initial use of an advanced solid state amplifier for L-band communication, developed by ITT laboratories, has influenced subsequent transponder designs both by ITT, and by other spacecraft contractors. NASA's use of the "Loop-Vee" antenna design for OPLE uplinks has stimulated similar applications on data buoys and small earth transmissions stations.

Early experiments with the signal improvement using gray-scale color enhancement techniques have led to other applications in meteorology, military uses, and airborne environmental studies.

Critical Evaluation of Technical Alternatives. Realistic tests and long term evaluation are often required before the comparative advantages or trade-offs of competing technologies can be assessed. Demonstration of the capabilities and advantages of alternative approaches markedly influence the direction of further development.

One basic goal of SYNCOM was to explore the performance of satellites in synchronous orbit as compared with medium altitude spacecraft such as RELAY and TELSTAR. Similarly, the ATS program has systematically demonstrated both the advantages, and the problems associated with gravity-gradient stabilization, spin stabilization and reaction wheel or dual-spin stabilization.

In improving the capabilities of ground station receivers, ATS-I performed an important side-by-side comparison of the most advanced cryogenic maser and the newer cooled parametric amplifier. Both types of low-noise receiver front ends are still in use for special purposes, but the advantages provided by the paramp have made this detector the predominant first choice for today's earth terminals.

On ATS-F, the aircraft communications performance of both VHF and L-band frequencies will be explored.

Demonstrations to Acquire Operating Confidence. Unlike demonstrations which evaluate alternative technologies, government projects often contribute to technical progress through the accumulation of operating confidence and predictability. An important aspect of technical change is the reduction of uncertainty.

Throughout the development of communication satellites--in almost every aspect of the systems--early designs were made ultra-conservative due to uncertainty or lack of experience. Later designs frequently offered improved performance as system constraints were progressively relaxed to reflect growing confidence--the kind of technical progress which economists call "learning by doing."

An example from the station keeping area involves the performance of the pulse jet control system--especially the valves. For SYNCOM there was no basis for believing that hydrogen peroxide valves would continue to work for long times in space. Therefore, primary reliance was placed on cold pressurized nitrogen. On ATS both nitrogen and hydrogen peroxide systems were phased out and replaced by the hydrazine system. Progress toward the higher performance system depended mainly upon acquiring confidence that poppet-valve control systems could be designed to operate trouble-free for 5 to 7 years.

Growing confidence and predictability have greatly influenced the way communications links are scheduled and used. An engineer concerned with Air Traffic Control via satellite expressed it thus: "Over the past two years we have really learned to trust the space communications path. We know that we can predict the quality of signal reception, anywhere in the Pacific Ocean Basin, within ± 2 db--and for a year in the future. That's more than can be said for other communications systems."

A current experiment with millimeter wave propagation using ATS-V illustrates this aspect of confidence building demonstration. Prior to ATS-V the ability to transmit and receive signals at 12 and 31 GHz through the earth's atmosphere, under all types of weather conditions, was not well known. Some 13 organizations--commercial and governmental--are now studying millimeter wave propagation in order to determine the margins that must be allowed, and whether space diversity or other redundancy will be needed to insure error-free signal reception.

A further compelling reason for conducting long term demonstrations of the capabilities of satellite systems is that the experience gained influences not only the technologies used, but--often more important--the perception by potential users of the needs, benefits and markets that are involved. Demonstrations such as the India ETV experiment, or Alaskan regional domestic service, help to move societal needs closer to technological solutions.

Experts agreed in 1962 that there would be no foreseeable demand for transoceanic television transmission before 1980. TELSTAR and RELAY showed that a viable market demand existed--once the technical capability had been proved. In a similar way, present experiments aboard ATS are exploring the desirability of, and benefits associated with, a variety of new types of service. Medical communications, library networks, criminal justice information, commercial and financial data, and the collection of environmental information from widely scattered unattended sensor stations are under study. Both the technology required and the uses first implemented will depend in part upon these demonstration projects.

How Much Progress Has Occurred?

Simply enumerating the problems solved or the number of fields of technology that have been advanced by the NASA communications satellite program since 1960 fails to address the proper question. To state that technology has changed at a rapid pace ignores the implications of economics involved in the change.

The overall effect of the applications of improved or advanced technology in some measurable area of commercialization provides an objective analysis of progress. Consider first the magnitude of the effect of change on our capability to use space for communication. This can best be done at present for the commercial satellite systems that have a five year record spanning four generations of development. Similar rates of improvement can be anticipated for applications such as air traffic communications, position location or domestic satellite use.

For the space segment of long-haul telephone service the most important parameter has been cost per channel per year. This one "figure of merit" combines the three key factors: power-bandwidth, cost in orbit, and design lifetime.

INTELSAT performance characteristics and costs are shown in Table 5. The parameter of dollars per channel per year is plotted versus date of first launch in Figure 8. An estimate is included for INTELSAT V--an advanced generation of spacecraft planned for 1976 to 1980.

The 30-fold reduction in cost per channel per year is attributable to dozens of changes over the six-year period. The main factors of course are size, launch cost per pound, power, bandwidth, antenna gain and reliability. Selected parameters to gage the effects of change include:

Performance Parameter		Change 1965-1971
Weight in orbit	up	20x
Cost per pound in orbit	down	4x
Orbit weight/launch weight	up	30%
Solar power, watts	up	12x
Power watts/pound	up	40%
Decline in power over lifetime	down	3x
Batteries watt-hour/pound	up	3x
Depth of discharge	up	3x
Power conditioning losses	down	40%
RF output, watts	up	12x
DC to RF efficiency	up	30%
Bandwidth used	up	40x
Antenna gain	up	3x
Design life	up	4x
Channel capacity	up	25x
Dollars/channel/year	down	30x

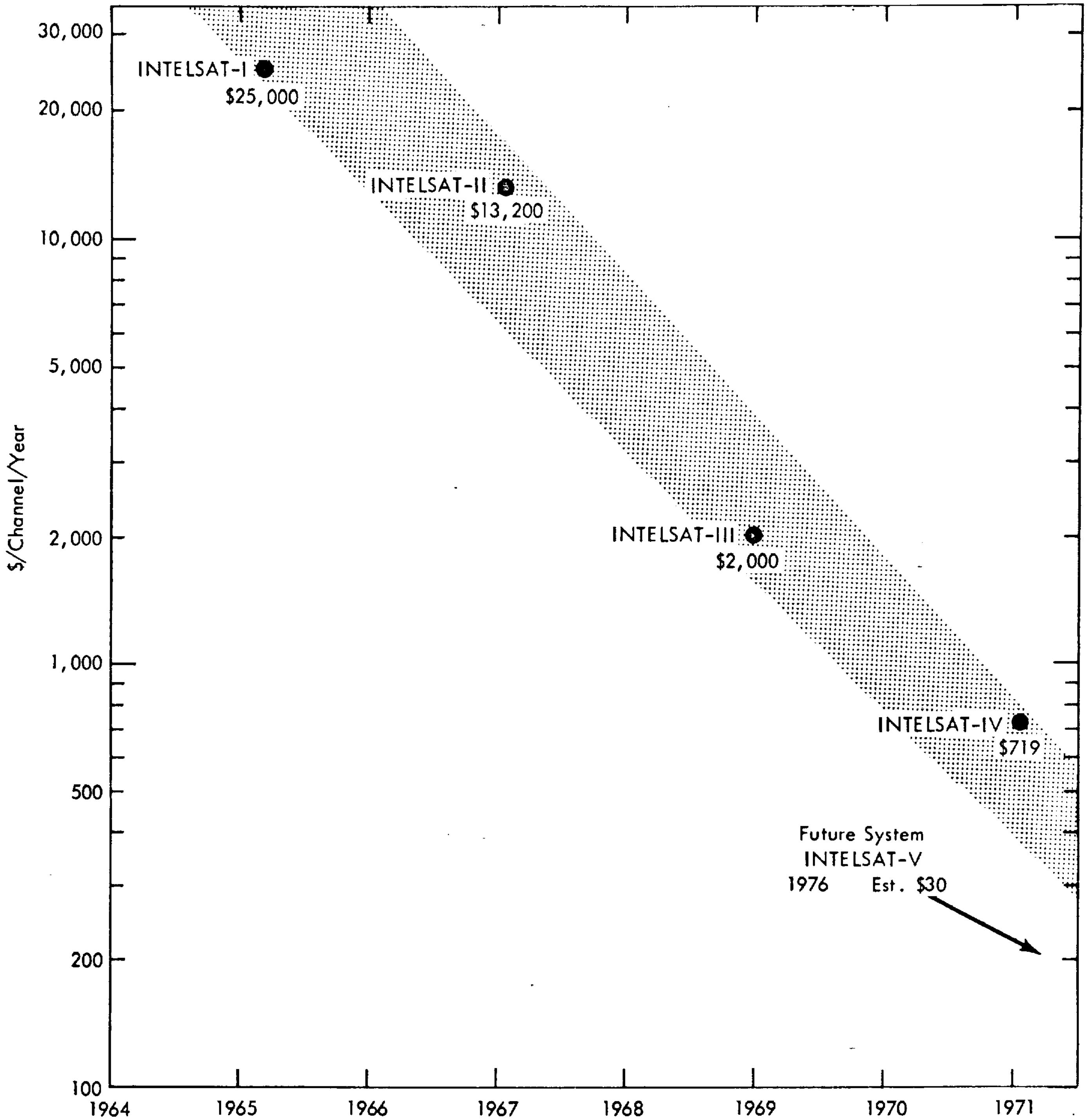
Each change can be traced to many smaller improvements. Spacecraft power provides a typical example. There have been no revolutionary changes in the power systems. Silicon solar cells provided 1/4 watt for VANGUARD in 1958; they will provide 1 killowatt for SKYLAB in 1972. Solar cell

TABLE 5

COMMUNICATION SATELLITE PROGRAM COSTS

	INTELSAT I	INTELSAT II	INTELSAT III	INTELSAT IV	INTELSAT V 2/
Date of launch	April 1965	January 1967	December 1968	January 1971	Estimated 1976
Cost/satellite 1/	5.2	4.4	7.2	13.7	--
Number of satellites	2	5	8	8	--
Total satellite cost	10.4	22.0	57.6	109.6	--
Cost/launch	3.8	5.1	5.0	16.5	--
Number of launches	1	4	8	8	--
Successful launches	1	3	7	1 so far	--
Total launch cost	3.8	20.4	40.0	132.0	--
Total program cost	14.2	42.4	97.6	241.6	--
Cost/launched satellite	9.0	9.5	12.2	30.2	--
CCIR voice channels	240	240	1,200	6,000 avg.	--
Design life (years)	1.5	3	5	7	10
Cost/channel/year	$25,000	$13,000	$2,000	$719	$30 est.

1/ Costs include allocated R&D and minimum performance incentives.
2/ Comsat Corporation Planning Document, January 1971.
Source: Jack Eldred Cole, International Telecommunications Policy, Planning and Regulation. Doctoral Thesis, George Washington University, February 1971.
Comsat Corporation, Pocket Guide to the Global Satellites System, December 1969.



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 8 - Dollars Per Channel Year Vs. Date of First Launch

conversion efficiency has only increased from about 9 percent to 11 percent. Gradual improvements, however, have made possible solar arrays that are lighter, less expensive, have higher output per pound and per square foot, exhibit less damage from radiation, have better cover slips, eliminate soldering, give higher voltages, avoid low-energy proton damage, and have better thermal conductivity. Batteries now provide over twice as many watt-hours per pound. This improvement derives from better separators, terminal feed-throughs, seals and cases. Battery reliability is up. Depth of battery discharge has been doubled without sacrifice in life. Power conditioning losses have also been reduced substantially. The overall progress in utilization of solar power is shown in Figure 9.

The cumulative effect of power system improvements can be seen in the stagewise increase in power-density (watts per pound, power) shown in Table 6. An indication of the value of progressing from 2.0 watts/pound to 2.5 watts per pound can be obtained by calculating the potential extra revenue from using the next generation of power system technology. Table 6 shows that for INTELSAT III the 55-pound power system would have provided 137 watts and 1,320 channels, if a power system of 2.5 rather than 2.3 watts per pound could have been used. Over the five-year design life these extra 120 channels would have generated $9 million in additional revenues. This hypothetical exercise shows the economic consequences of a slight (in this case, 9 percent) advance in technology.

Earth terminal performance and costs also show the consequence of many technical changes. INTELSAT established the standard ground station performance parameter of 40.7 db G/T, gain over system noise temperature. In terms of effect on channel capacity, improvement of a terminal from 40 db to 41 db was roughly equivalent to 12 channels and worth nearly $1 million per year.

The capacity of typical earth terminals has also increased since 1962. Figure 10 shows this effect in terms of kilowatts of power times megahertz bandwidth. These improvements result from low noise receivers, threshold extension demodulators, cassegrain feed systems, larger antennas, high power-wideband tubes, more efficient antenna figures, side-lobe suppression--and many other technical improvements.

As performance improved, costs have tumbled. The first generation of U.S. earth stations, built around 1962-1963, cost about $9 to $10 million each. An improved 1972 terminal costs about $3 million. Figure 11 shows the range of costs for several generations of earth terminals.

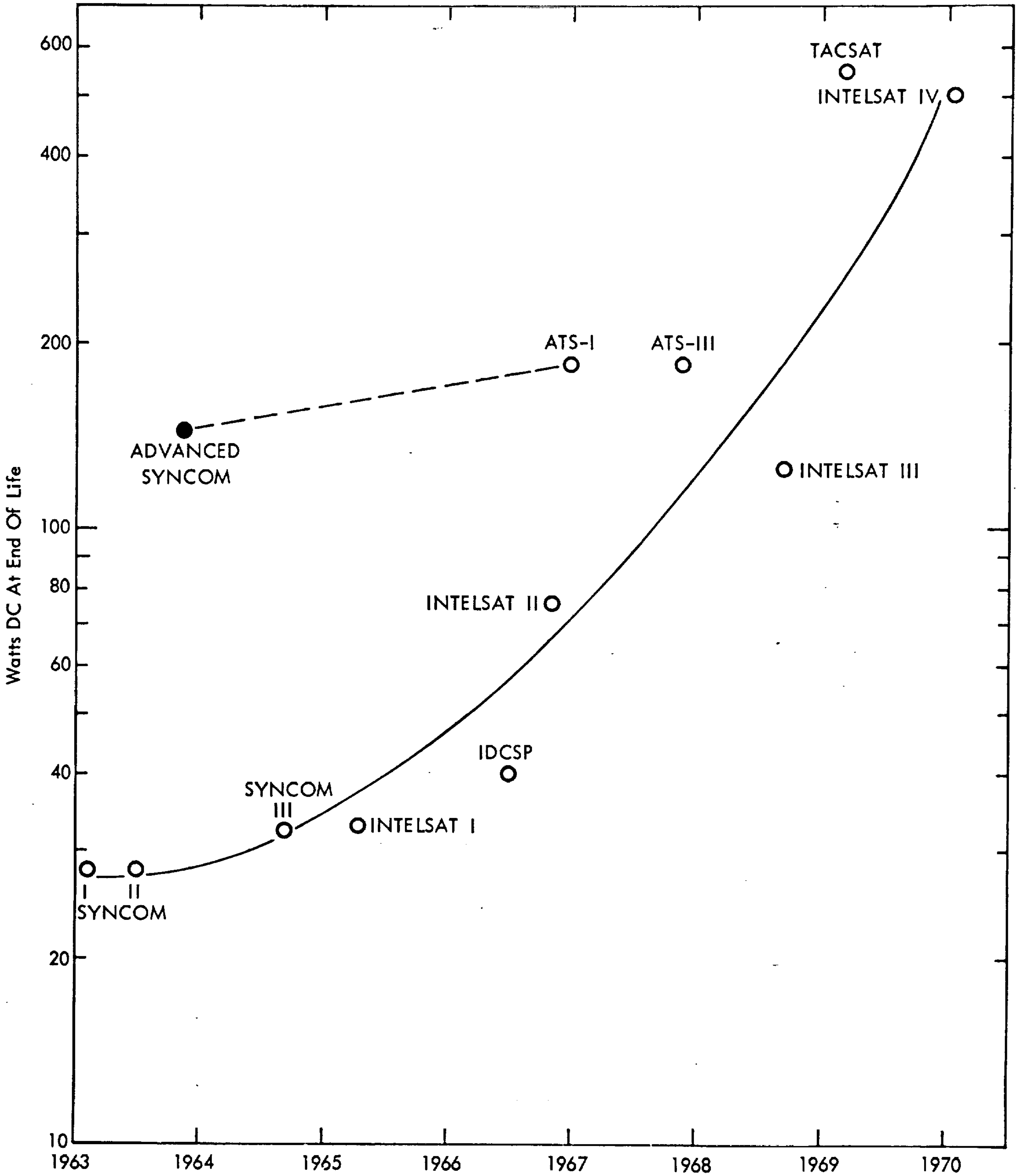


Figure 9 - Progress in Solar Cell Supplies for Communications Satellites

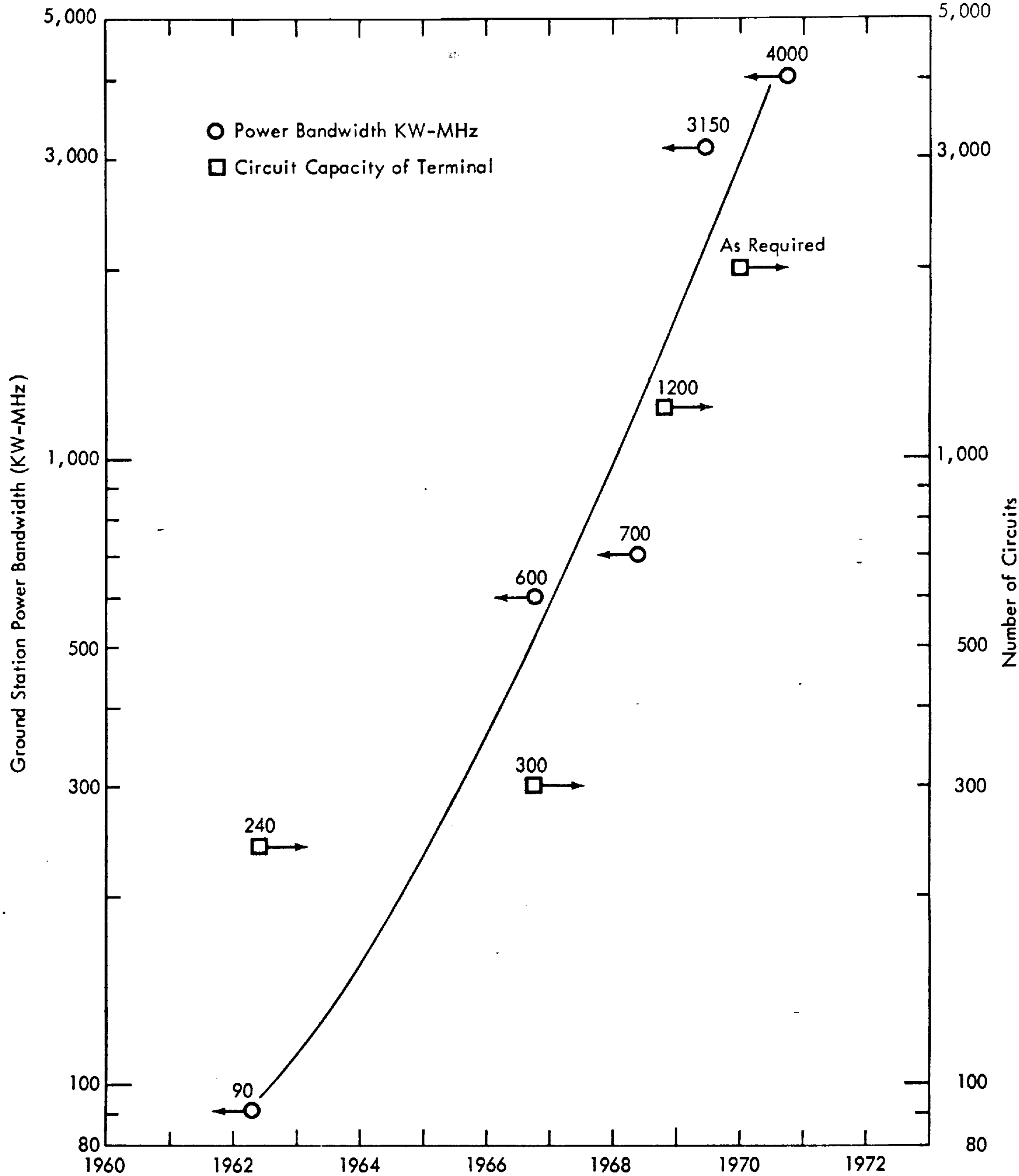
TABLE 6

HYPOTHETICAL REVENUE VALUE OF USING ADVANCED POWER SYSTEMS

	INTELSAT II	INTELSAT III	INTELSAT IV
Weight of power system (pounds)	38	55	185
Watts power	75	125	470
Power density (watts/pound)	2.0	2.3	2.5
Channel	240	1,200	6,000 avg.
Channels/watt	3.2	9.6	12.8
Design life (years)	3	5	7

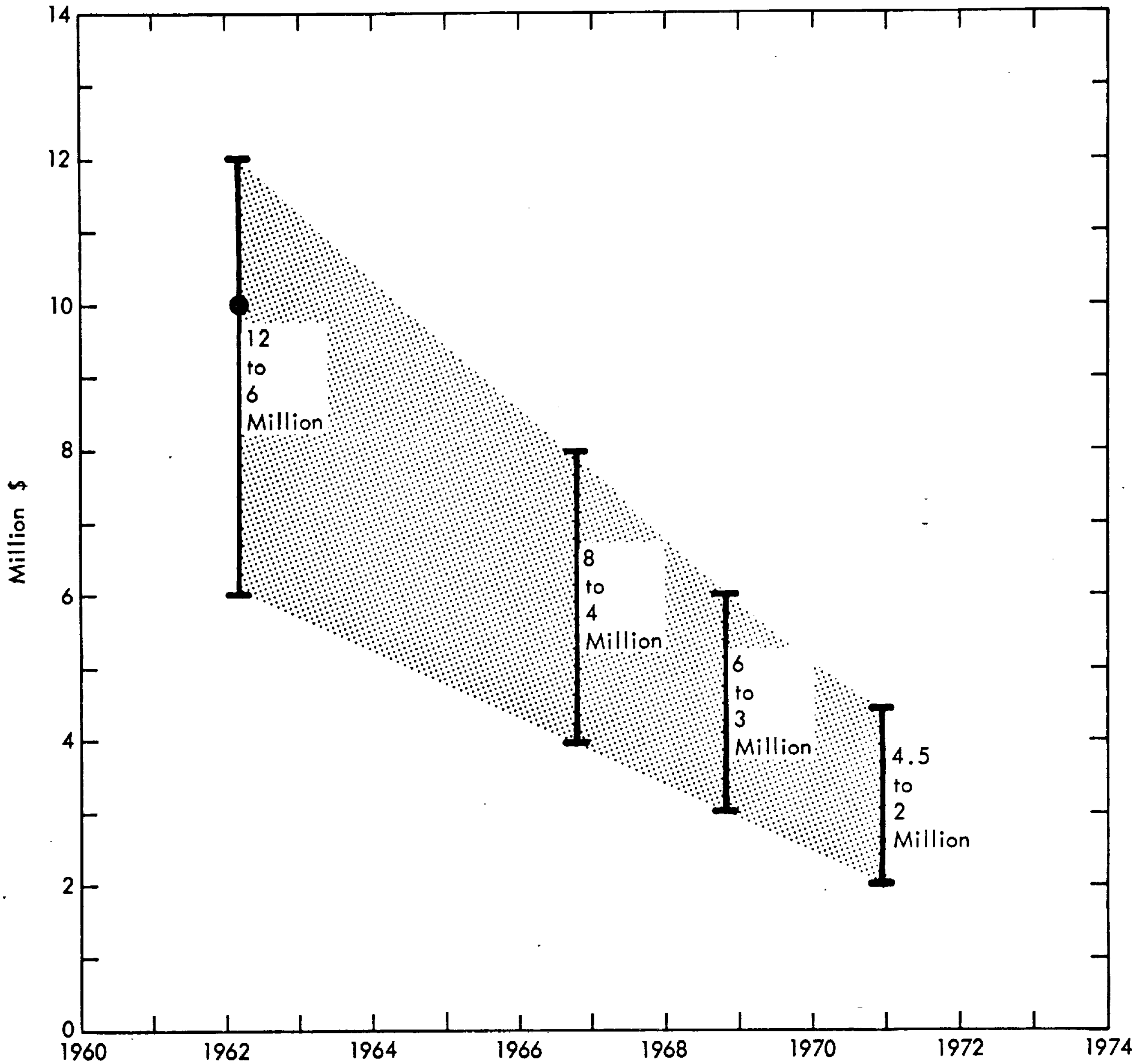
Additional revenue contributions assuming earlier achievement of "next generation" power density as designated by the broken arrows:

Watts of power	87.4	137.5
Total channels	280	1,320
Extra channels	40	100
Extra revenues over design life at $15,000/channel/year	$1.8 million	$9.0 million



Source: Comsat Corp; (Potts 1970)

Figure 10 - Capability of Typical Ground Station in Communications Satellite System



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 11 - Basic Earth Station Costs

The effect of technological progress on the cost of practical satellite systems has been observed and quantified. In almost every instance, technological advances have been a major stimulus in the improvement of efficiency, expansion of systems capability, and subsequent lowering of communications unit costs.

By lowering the cost of the communications capability of the satellite system, such service is made appealing to more potential users. As these potential users become actual users, demand for further expanded service goes up. Thus, facilities must be enlarged, more technical personnel are required to design, assemble, install and operate the hardware, and the total value of the technology increases.

One example of the stimulus of technology to economic worth is seen in satellite ground station development. If terrestrial terminals still cost $10 million, as they did in 1962, a relatively few stations would be constructed each year at only major population centers. Such an effort would require the services of a somewhat fixed number of personnel. But, terminals of even greater capability can now be constructed for $3 million. Large secondary population centers, formerly utilizing satellite communications in a rather peripheral way, can now afford direct involvement in the system. A relatively greater labor force is required to meet the demands of these added installations.

This phenomenon of growth occurs as science progresses to technology, and technology becomes a service. Experimental communications satellites are of rather undefinable worth when confined to the laboratory or a study program. Practical, commercial satellites resulting from such research are of definable worth when their services are offered for dollars to those capable of purchasing and using them. The total transition for science to practical application occurs only when high risk, logically planned, far-sighted stimulus is applied through technology.

Strategy for Technological Progress

The extent of technological progress and some of the principal ways by which a mission-oriented government agency supports and promotes technical progress have been illustrated by means of NASA's work on synchronous communications satellites for current and future commercial uses. Taken together, the roles and functions played by such an agency, active at the interface between technological possibility, and national needs, neatly fits the present pattern of U.S. strategy for maintaining technological leadership.

A perceptive analysis of the strategies adopted by foreign nations and the United States to insure the economic benefits of advanced technology was recently made by Robert Gilpin.1/

After comparing the strategies and policies used for technological development in other countries, Gilpin indicates the pattern of practices and objectives which amounts to the American strategy for the advancement of technology:

> "First, one must note the frequent initiation by the U.S. government of technological projects considered to be of public interest but neglected by private enterprise for one reason or another. Developments in which the scale of investment or of risk is too great for private enterprise--for instance, atomic power and supersonic transport. Other developments with potential military or political significance--for instance, computers and space technology. Still other areas are hampered by the absence of profit incentive--for instance, pollution control technology, housing technology, mass transportation, ship building, and the electric automobile.
>
> "The second common practice is a maximization of the involvement of private enterprise in technological advance, especially through the extensive employment of the contract mechanism. Perhaps of even greater importance in stimulating private enterprise in its research efforts, however, is the role of government as the primary consumer of advanced technology and the consequent creation of an immense public market and strong demand. These policies maximize the commercial spin-off of government programs and stimulate American industry across a broad front of technological advance.
>
> "The third common practice in the United States is the functioning of the government to bring a new technology to the point of commercial exploitation and then turning it over to private enterprise to reap the profits."

This strategy has been particularly successful in advancing the high technology areas of our national economy. The strong involvement of private industry insures that resources are channeled into the most productive sectors of the economy, and also promotes early application of technology for commercial purposes.

1/ "Technological Strategies and National Purpose." Robert Gilpin. Science, 31 July, 1970. pp. 441-448, 31 July 1970.

V. ECONOMIC IMPACT OF COMMERCIAL COMMUNICATIONS SATELLITE APPLICATIONS

Brief reflection on the four types of satellites, and the services offered by each, helps to visualize the associated economic impacts. However, measurement of the full impact of the commercial applications of any technology is a formidable task. Four fundamental problems are involved.

First, any new application has both direct and indirect impacts. If only the direct impacts are considered, the full effects will be understated. For example, the primary impact of the gasoline powered vehicle might be measured as the output of the auto and truck industry. This would exclude secondary economic impacts in the oil industry, highway and street construction, garages, service stations, etc. It would also exclude indirect impacts in the form of motels, and drive-in theaters and restaurants. Perhaps more important, it would exclude the numerous changes in our way of life which are traceable to the mobility provided by the automobile; recreation patterns, commuting, population relocation trends, and so on. The advent of new communications options will have similar impacts on our economy and way of life.

Second, the economic effect of any major new application is traceable to the particular combination of labor, capital, and technology embodied in the commercialization process. Given the existing state of the econometric art and the statistical data available, it is not possible to assign precise shares of an application's economic impact to the three factors of production. Moreover, when indirect impacts are considered, the assignment task becomes almost unending because each area of impact has its own special combination of labor, capital and technology.

Third, any new application initiates economic impacts which occur over time. The total result is impossible to predict. In 1910, many of the most profound impacts of the automobile were unforeseeable.

Fourth, even if all the direct and indirect impacts of a new application were identifiable and measurable, we would still fail to include the effects of the "fall-out" or "spin-off" variety. The adoption of mass production techniques by all segments of the manufacturing industry followed Mr. Ford's demonstration of their efficacy. Attributing the share of the impact of a new technology is even more complex, because it almost always results from the combination of the new technology, labor, and capital with preexisting technology, labor and capital.

The primary purpose of Part II of this study is to illustrate the processes at work in the attainment of the economic impacts identified and measured in Part I. The case study is employed because it is well suited to an illustration of processes involved in the movement of technology to application. The econometric methodology employed in Part I is most suitable for assessing the overall economic effect attributable to technological progress.

Thus, Part II makes no attempt to specify the full economic impact of commercial communications satellites. Neither does it attempt to precisely quantify the contribution of technology alone to the total process. Instead, benchmarks are provided to generally illustrate how applied technology can stimulate economic growth--in the present and future.

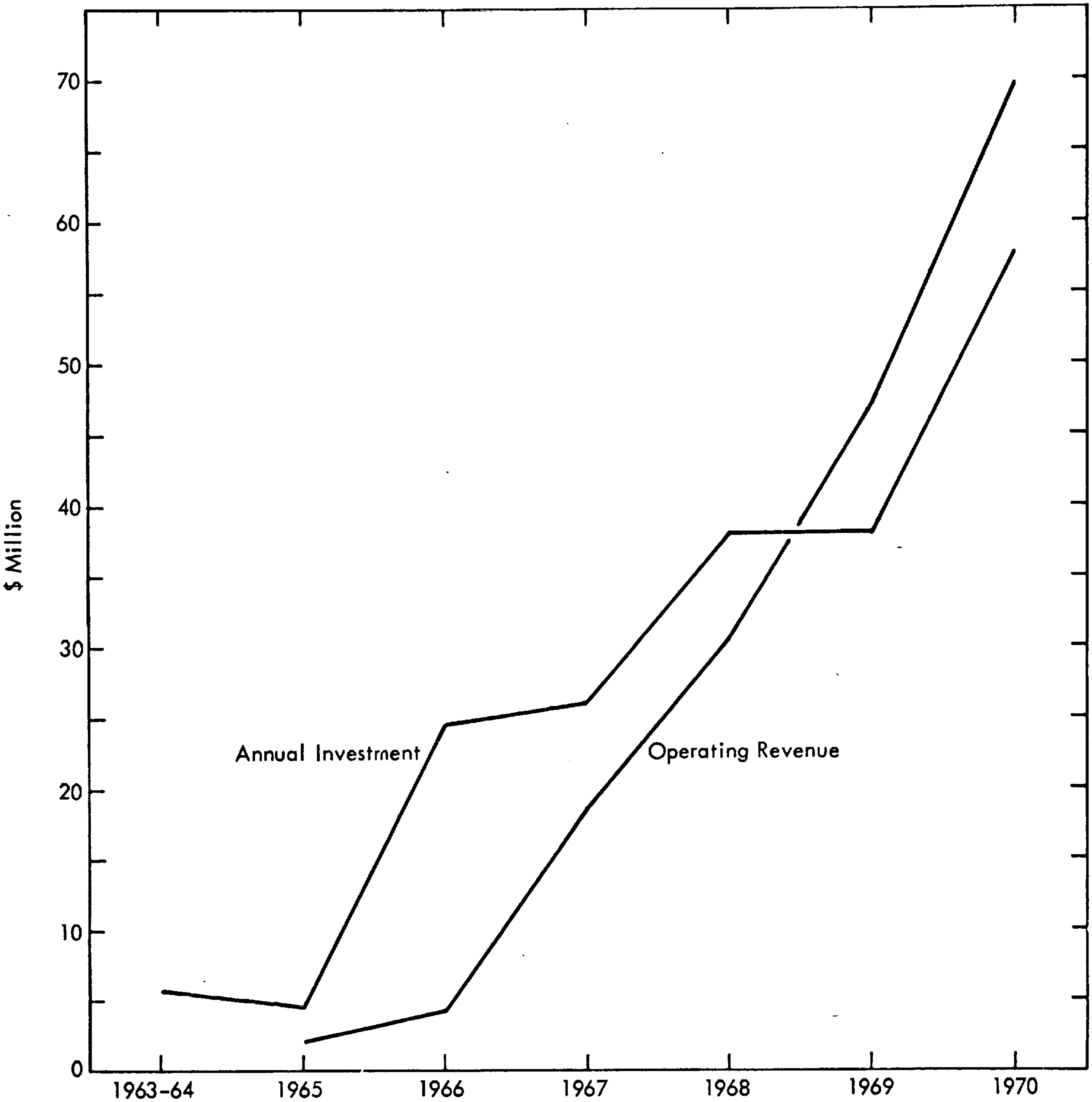
These benchmarks or demonstrations, are provided for each of the four types of commercial applications considered throughout the case study. Given the findings of Part I, the full economic impact of technological progress in the communications satellite field can be expected to be significantly greater.

International

International satellite communications is the first application area to reach commercialization. The application is in the form of the INTELSAT Consortium in which Comsat Corporation is the U.S. partner. The reasons for the early application are straightforward: satellites can provide TV service while existing undersea cables cannot, there were few regulatory barriers to the establishment of international communications, and there was a definite cost advantage. As a consequence, we have had international service via satellite since 1965.

Two measures of direct economic impact of international communications via satellite are: the investment made and the revenue generated. In the eight years prior to 1971, Comsat invested almost $200 million in equipment and facilities. As with any new enterprise, the annual rate of investment has increased rapidly. It exceeded $57 million in 1970 and the upward trend is expected to continue (Figure 12). Thus, an entirely new commercial market has been established for the technology produced during the R&D phase of communications satellites.

Comsat revenues have exhibited continual growth. The first commercial satellite was placed in orbit in June, 1965. Operating revenue for the remainder of that year totaled just over $2.1 million. In just five years operating revenue had grown to nearly $70 million (Figure 12). The revenue growth is a function of the expansion of the global ground



Source: Comsat Corp. Annual Reports 1965 - 1970

Figure 12 - Annual Investment and Operating Revenue for Comsat Corporation (1963-1970)

station network as well as the increase in the number of satellites and channel capacity. In 1965 just five ground stations in five nations were operating. By 1970, 51 antennas were operating at 43 ground stations located in 30 countries. Projections for 1974 call for over 90 antennas at over 70 ground stations to provide direct communication service via satellite to nearly 60 nations (Figure 13).

Ground station construction for INTELSAT is now at a rate of $100 million annually and is expected to continue at that level for three or four years. In addition, as the technology evolves, the cost per station has declined dramatically. At one time, the construction cost was in the $6 to $10 million range; now the figure is $3 to $6 million.

Some perspective of the R&D pay-off from just this commercial application can be obtained by examining NASA expenditures. The ECHO, RELAY, and SYNCOM programs cost $70 million. The communications and navigation experiments associated with ATS-I through -V were $27 million. An additional $40 million was devoted to supporting research and technology. Thus, total NASA spending on communications satellites prior to ATS-F and -G (which are continuing the chain of technological progress in the communications and other fields) was $137 million.

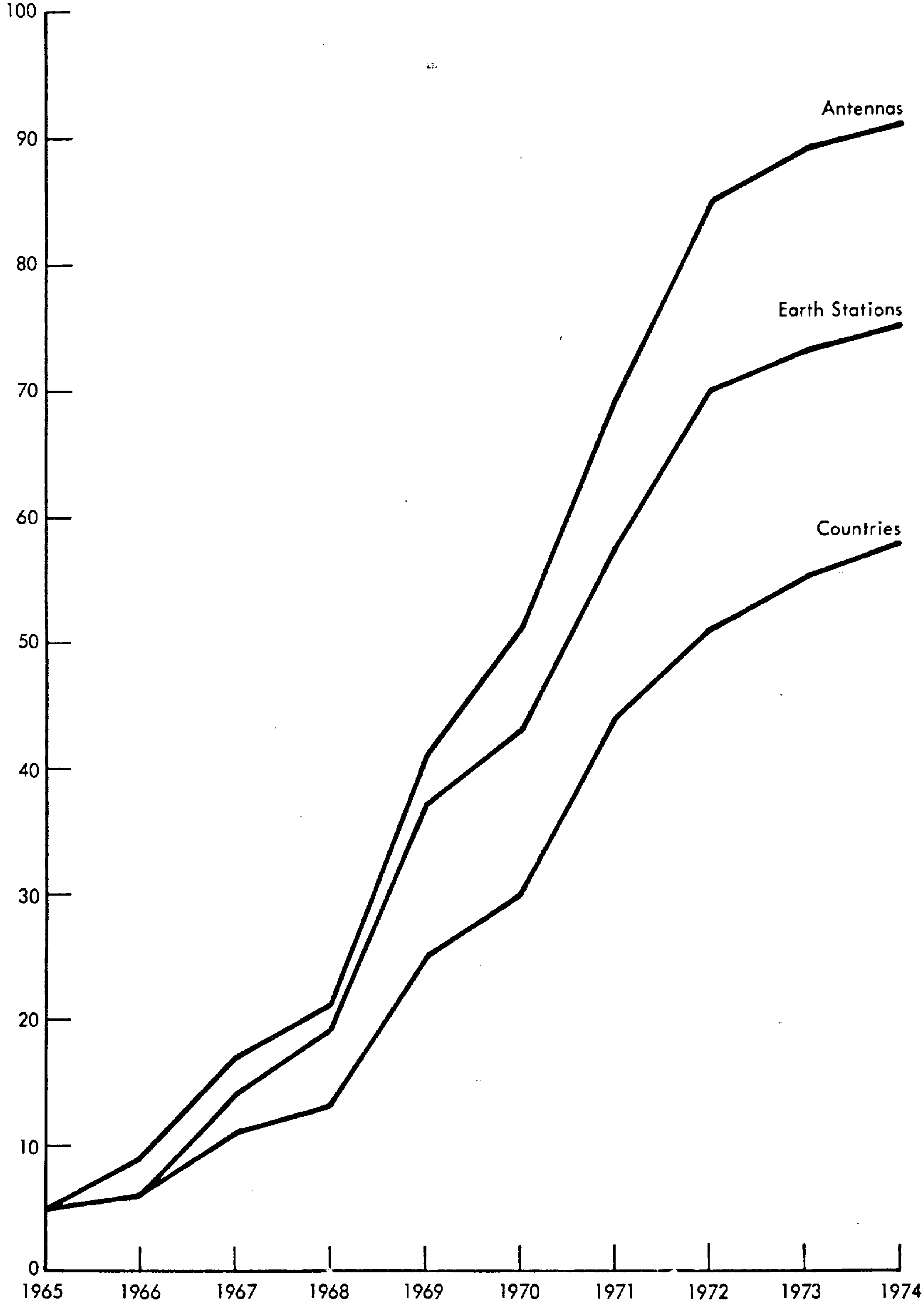
Another characteristic of the impact of technological progress is that costs decline as the technology is refined and proven. In 1960, the Rand Corporation examined the economic potential of communications by satellite. The investment cost per voice circuit per year was placed at $30,000 for a 3,500-mile cable using next generation of cable technology.1/ The most optimistic estimate for a voice circuit via synchronous satellite was just over $6,000; and the most pessimistic estimate was about $27,000 (Figure 14). Eleven years later, Cole examined the actual costs associated with the INTELSAT satellites.

Figure 14 shows the decline in cost which had been achieved by the commercial vehicles in six years. The channel cost of INTELSAT I was $25,000 per year; INTELSAT IV was $700 per year.2/ Thus, there have been compelling economic reasons for the rapid expansion of international communications by satellite. Even so, the potential for satellite communication has barely been touched.

Table 7 shows the traffic volume of U.S. telephone and telegraph companies in 1968. The operating revenue of Comsat is also indicated for comparative purposes, and it was only slightly over 10 percent of total overseas traffic. Clearly, there is much room for growth of international telecommunications by satellite.

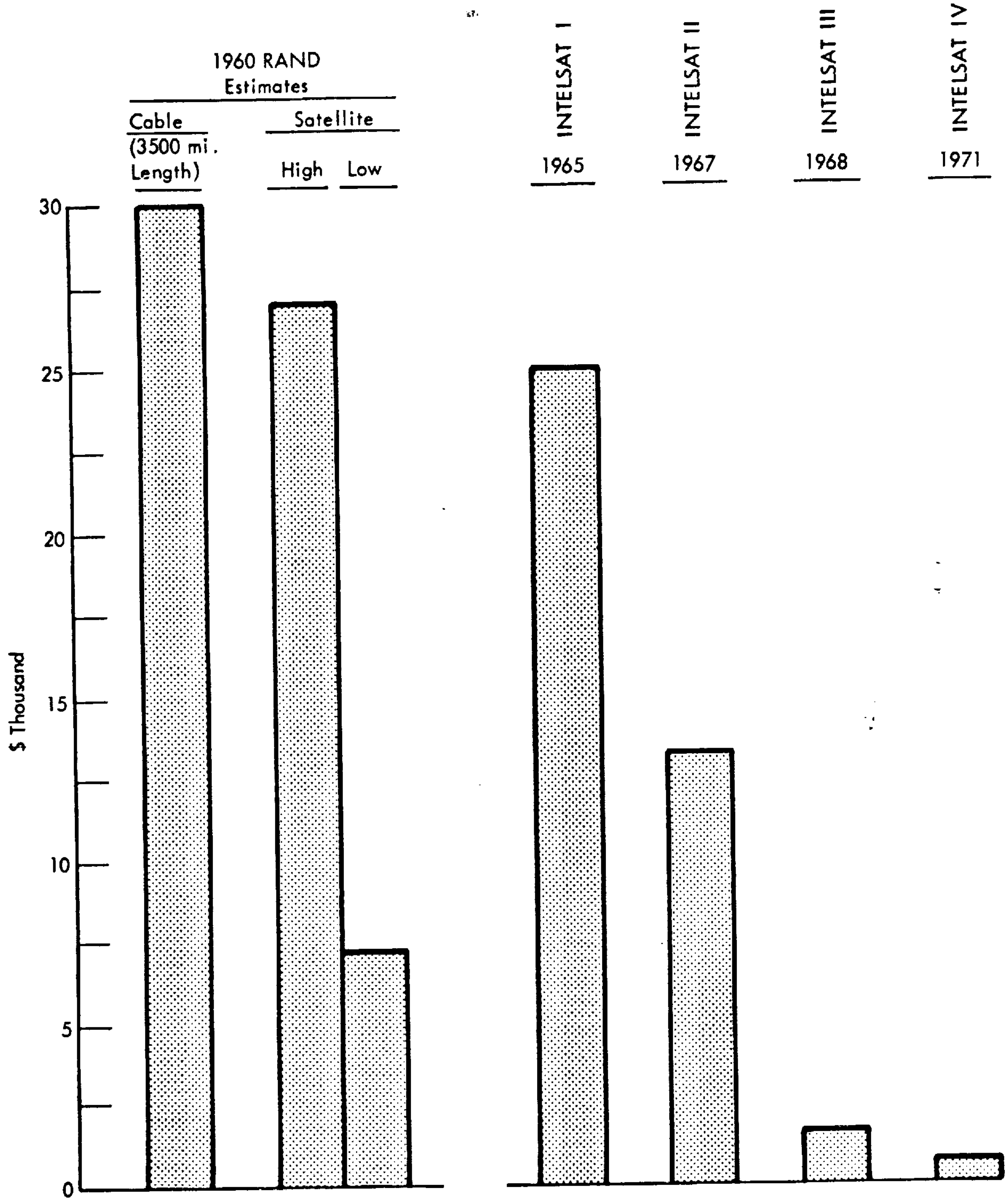
1/ During same period the price per year of a voice circuit for the then existing cables was $240,000.

2/ Both studies assumed 24-hour utilization of the available circuits. In practice, circuit utilization has been 30 to 75 percent.



Source: 1970 Comsat Annual Report

Figure 13 - Growth of the Intelsat System (1971-1974 Projected)



Sources: Figures III and IV, William Meckling and Sigfried Reiger, Communications Satellites: An Introductory Survey of Technology and Economic Promise, RM-2709, NASA, THE RAND CORPORATION, September 15, 1960.

Table 14, Jack Eldred Cole, International Telecommunications Policy, Planning, and Regulations, (Thesis, The George Washington University, February 15, 1971).

Figure 14 - Investment Cost Per Voice Circuit Per Year Via Satellite

TABLE 7

DOMESTIC AND OVERSEAS TELEPHONE AND TELEGRAPH TRAFFIC, 1968
(In millions)

U.S. Domestic	Calls	Revenue
Local	150,198	$7,701
Long Distance		
Telephone	8,264	6,759
Telegram	86	358
	8,350	$7,117
Overseas		
Message	13	$ 176
Private Line	5 a/	15
Telegraph	31	153
	49	$ 244
Comsat Corporation		$ 29

Source: FCC, Statistics of Communications Common Carriers, Year Ended December 31, 1968, GPO: 1970, Tables 1, 11, 13, 14, and 33.

a/ Number of calls not reported--estimate based on approximately $3/call.

Of even more significance is the potential for domestic communications satellites. Assuming that intercity service is representative of the market for domestic communication by satellite, the table shows that the economic potential in the U.S. alone is 30 times as great as overseas traffic. If calls are taken as the unit of measure, domestic long distance service is 170 times as large as overseas traffic. Growth in both services has been dramatic in recent years and can be expected to continue (Figure 15).

Domestic Distribution

In 1966, the American Broadcasting Company submitted its application to distribute television throughout the nation via satellite. Since then, there have been other proposals to provide a variety of services--network TV, voice, data transmission, instructional and education TV, etc. But, because the new communications mode has raised sweeping regulatory, economic and social implications, the FCC has moved very cautiously in its examination of the applications. As yet, no U.S. system has been approved.

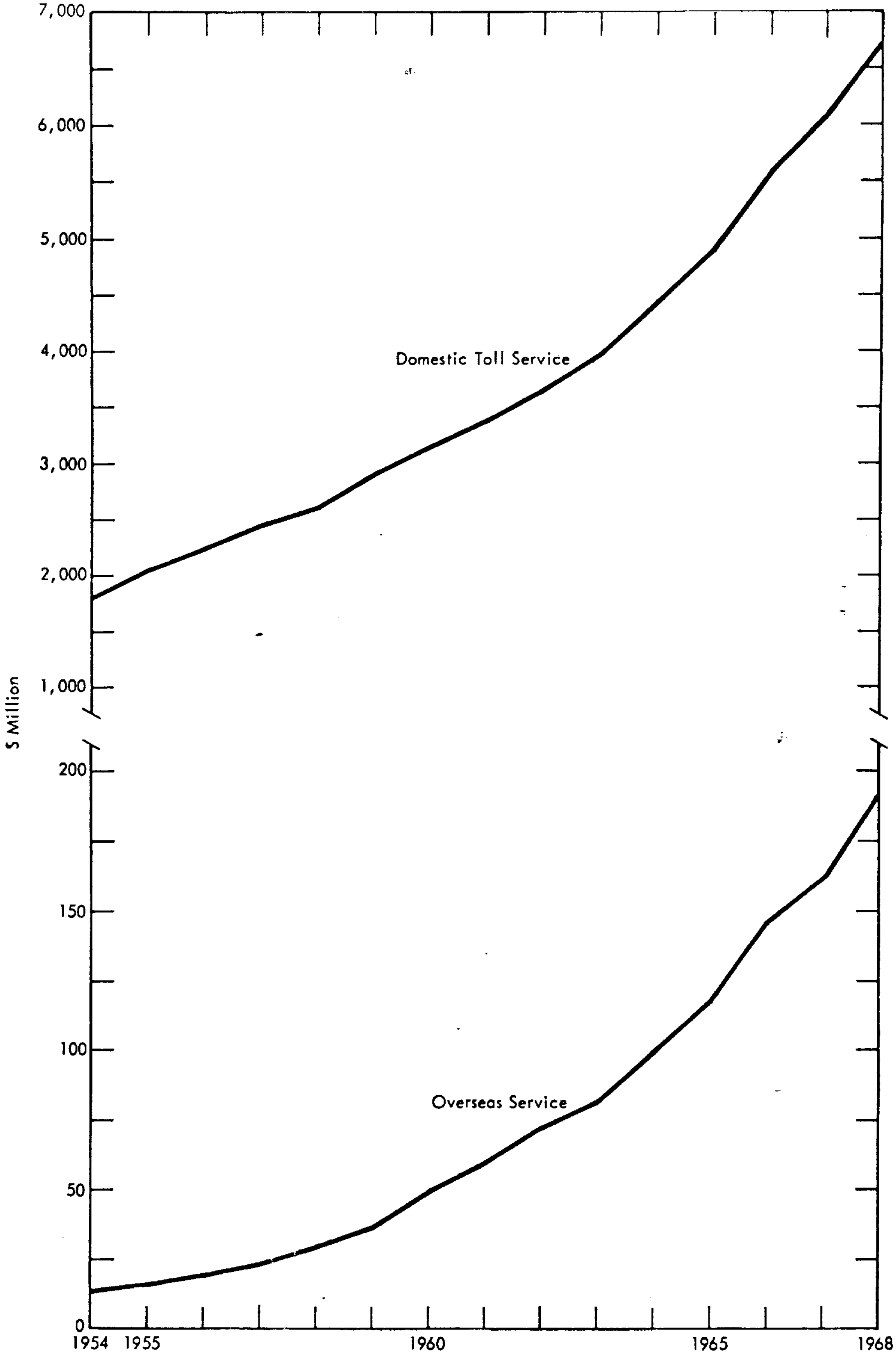
Canada, with less established communications and somewhat different regulatory environment, has moved to establish a domestic satellite system. Legislation was enacted in 1969 to establish the Telesat Canada Corporation which will own and operate the system. The network will provide color television, ETV/ITV, voice and other services to stations across the country. The first phase calls for two major ground stations with 85-foot antennae, five regional ground stations, and about 30 receive-only stations. The first satellite is to be launched late in 1972. The system will become operational in mid-1973.

Hughes Aircraft is producing the three satellites for the system at a cost of $31 million of which 20 percent is subcontracted to Canadian firms. Total investment in the space segment will be about $45 million. An equal amount will be invested in the initial portion of the ground system. Telesat Canada satellites will have 12 channels, each capable of carrying one color TV signal or up to 960 voice signals.

In the United States, the FCC has eight applications for domestic satellite networks. The investment pledged in these applications totals over a billion dollars. Most of the proposed systems contemplate initial investment in the range of $200 million.

Brief descriptions of the proposed systems follow:

Communications Satellite Corporation. This application calls for three satellites, each with a capacity of 14,000 telephone circuits or 24 color TV channels (or combinations of both). Two satellites would be active



Source: Statistics of Communications Carriers,
FCC, Year Ended December 31, 1968,
GPO, Washington: 1970.

Figure 15 - United States Telephone Carrier Revenues
(1954-1968)

at all times and the third would be an in-orbit spare. A fourth satellite would be maintained as an on-ground standby. The cost estimate for the first phase is $248 million. The major TV networks would use the services to distribute their programming and two channels would be available for noncommercial public broadcasting. Savings to the broadcast networks have been estimated to be almost 50 percent of their current payments (from $75 million to about $40 million annually).

Western Union Telegraph Corporation. Three multipurpose satellites and six initial earth stations are proposed with a cost of $95 million and estimated annual revenues of $28 million. Each satellite in the WU plan would be capable of handling 9,600 channels. The first six earth stations under this plan would be located in New York, Los Angeles, Atlanta, Chicago, Dallas, and Portland. While specific mention is made in the proposal for additional stations in all 50 states, there are no exact time and cost figures for this portion of the network.

The proposed monthly charge for a video channel in the Western Union system is $105,000 for full time, 24 hour/day utilization. The firm believes that 10 video channels and their associated audio should be allocated to the system and that there would be no problem in marketing the full complement on a long-term basis.

Another service that Western Union could implement by satellite is the Mailgram experiment being explored in conjunction with the U.S. Postal Service. This two-year study started in January of 1970 when some 6,100 businesses and 113 post offices equipped with Western Union Telex machines began participating. Messages transmitted over this service are received at the local post office and carried to the recipient in the next delivery.

Mailgram rates are based on the length of the letter and the distance between correspondents. A 100-word Mailgram from Washington, D.C., to Chicago costs $1.55. When the present experiment ends in January of 1972, the U.S. Postal Service is expected to make a decision on whether a nationwide Mailgram system via satellite at perhaps even lower rates should be established. Estimates are that 50 million messages per year could be expected by that time.

General Electric has submitted a somewhat similar "Telemail" proposal to the FCC for consideration. This service would utilize satellites and would provide instantaneous communications among businesses with terminals. GE claims that the cost of a 600-word letter would eventually drop to 10 cents, a rate competitive with the existing mail service.

Fairchild Hiller. One of the more complex satellites proposed to the FCC for use in a domestic communications system is from Fairchild Hiller. This proposal calls for two satellites in orbit and one spare on the ground. Each satellite would handle 24 color TV channels and over 50,000 telephone circuits. Initially, six transmit and receive earth stations would serve the continental United States. Eventually, the system would add 100 receive-only stations to serve 50 states, plus Puerto Rico and the Panama Canal Zone.

Fairchild Hiller states that their multichannel system can be completed in 33 months for an initial cost of $216 million. The various receive-only stations would be added following the completion of the original effort.

American Telephone and Telegraph. AT&T requests permission to build five ground stations in the continental United States. These stations would serve New York, Chicago, Los Angeles, Atlanta and the Dallas-Houston areas. Interconnections to other cities would undoubtedly be provided by existing AT&T cables. The three satellites for use with the system would be owned by Comsat Corporation, and would be leased by AT&T at an annual cost of $65.3 million. The ground station investment would be $96 million.

Each satellite would have 10,800 circuits and would handle a combination of telephone, picturephone, data services, and television. Two satellites would be operational and the third would be a spare. The system would be in partial operation within 30 months with full service to follow in another six to nine months.

MCI/Lockheed. Microwave Communications, Inc., and Lockheed Aircraft Corporation have formed a joint venture to utilize satellites and terrestrial microwave links to provide service throughout the United States. Their application is for permission to construct a $168 million system for operation by 1975.

The satellites would operate in both the 4-6 GHz and 12-13 GHz ranges and would weigh 3,900 pounds. The application is for two satellites in orbit and one on the ground as a spare. Each would have a 48-channel capability.

Initially, 15 metropolitan areas would be included in the ground station network. By utilizing the 12-13 GHz portion of the spectrum, earth stations could be located within major metropolitan areas. The other systems proposed to the FCC would utilize the 4-6 GHz band and would encounter frequency congestion and subsequent interference in more populous areas. MCI's role in the venture will be to distribute signals to and from major ground stations over terrestrial microwave links. The company has a number of applications for such microwave links pending before the FCC. A link between St. Louis and Chicago has already been awarded.

RCA Global Communications. RCA Global Communications, Inc., a subsidiary of RCA, has applied to launch two satellites, with an on-ground spare, to carry television, data, and other communications. This system would initially cost $198 million and provide 11 ground send-receive stations. The network would eventually provide communications to all 50 states and Puerto Rico. RCA believes that increased demand for the services would necessitate a third operational satellite and two additional transmit and receive earth stations by 1976. In the second phase an in-orbit spare satellite would be available at special rates to instructional or public television.

Western TeleCommunications/North American Rockwell. Western TeleCommunications, Inc., presently operates an 11,000-mile terrestrial network for relaying network television programs in 17 western states, making it second to AT&T in this particular service. In a joint venture with North American Rockwell, the firm has proposed a two-satellite system with a total capacity of 20 television channels and up to 2,400 channels of voice or high speed data communications. Initially, this system would contain six ground stations. In subsequent expansions, hundreds of ground receiving stations would be placed in operation.

The total initial cost of this satellite system would be $66 million. North American Rockwell would perform all design and construction of the satellites, while Western TeleCommunications would operate the ground-based portion.

Hughes Aircraft Company/General Telephone & Electronics. This application differs somewhat from the other proposals. GTE would build earth stations in areas where they operate telephone systems. Hughes would supply the satellites. The GTE earth stations would be constructed near Los Angeles, Tampa, Indianapolis, and Harrisburg, Pennsylvania. The total cost of the send-receive stations would be $27 million. Annual operating costs of the system would be $16 million. This would include $7.2 million per year paid to Hughes for leasing the satellite.

In a separate application to the FCC, Hawaiian Telephone Company, a subsidiary of GTE, proposes to tie into the system (or any other system winning FCC approval) with a ground station near Honolulu. This station would provide live television programs from the mainland of the United States for distribution to transmitters in Hawaii.

GTE's purpose in becoming involved in such a system is to reduce its dependence on long lines operated by AT&T. Expansion of the ground station portion of the system would eventually be carried out in Texas, Iowa and Washington state where the company operates other telephone systems. GTE handles 10 percent of the domestic telephone traffic, while AT&T is responsible for 85 percent.

Hughes proposes to orbit two satellites similar to the ANIK I spacecraft being built for Telesat Canada. The vehicle would have 12 channels of which eight would be leased to GTE. Hughes plans to form its own television and radio network to utilize the remaining four channels. The Hughes ground station system would include two send-receive and seven receive-only facilities. The transmitting stations would be in Los Angeles and New York. The total cost of the Hughes portion would be $47.2 million.

The Hughes network would distribute programming via a combined satellite-CATV system. Such a system would ultimately contain hundreds of receive-only antennas. At present there are 2,500 cable television systems serving 14 million U.S. viewers. The satellite system would also facilitate new CATV networks. With such a system, Hughes believes that charges would be 25 cents to $1.00 per customer per month. One of the larger CATV systems in this country is Teleprompter Corporation, in which Hughes is a minority stockholder.

Direct Broadcasting

In contrast to the international and domestic satellite systems, no commercialization of direct broadcast is in process, as yet. Given the greater technological challenge of direct broadcast by satellite and the many institutional and market alterations required, it is predictable that this application would follow the others.

The sociological implications of direct broadcast via satellite present one of the more intriguing aspects of the effect of technological change on humanity. In many areas populations are so dispersed from cultural centers that they are denied many of the rudimentary 20th Century advantages taken for granted by the inhabitants of the larger cities. Adequate dissemination of cultural, educational, political, and informational communications is impossible in numerous areas. Millions are unaware of changing conditions that affect their lives until so long after the fact that they are unable to cope with the consequences.

The Television Broadcast Satellite Study performed for NASA by the Space Systems Division of General Electric considered the economics of direct broadcast to dispersed and semi-isolated populations. Three land masses were considered for somewhat differing applications: Alaska, where a coverage of 85 percent of the area would reach virtually all the people; India, where community receivers placed in small villages could be viewed by local inhabitants; and the United States, where instructional television would reach 100,000 schools in 10,000 school districts. In all three cases, satellite distribution was compared to an equivalent terrestrial system.

For a 10-year period, the satellite broadcast system for India would cost about $87 million as compared to a terrestrial system of $150 million. In the satellite system, the development and operation of the space segment would account for $62 million of the total cost. The ground receiver investment (antennas and converters) for 500,000 receivers at $50/installation would total $25 million.

The terrestrial television broadcast system for India would include 110 transmitting stations and their microwave interconnections for an investment of $80 million. The 10-year operating cost of these stations would be $60 million. The receiver antenna installations that would be required for 260,000 sites would cost $10 million.

COST COMPARISON FOR COMMUNITY SERVICE TO INDIA
(10 YEARS)

Satellite		Terrestrial	
Develop and Operate	$62 million	110 Transmitters and Microwave Interconnections	
		Investment	$80 million
		Operation	$60 million
Ground receivers (1/2 million installations at $50 apiece)	$25 million	Receiver antennas 260,000 sites	$10 million
	$87 million		$150 million

Savings of almost 50 percent are indicated as the advantage of a satellite over terrestrial system for Alaska. The cost of the former is projected at $155 million while the ground-based equivalent would cost $292 million. In the space system, the cost of development and operation for 10 years is computed at $145 million and investment in 100,000 receiver installations at $100 apiece is an additional $10 million.

The terrestrial system would require 60 transmitters for an investment of $90 million. The 10-year operating cost would be $200 million. Special receiving antennas would be needed at 52,000 locations and these would cost $2 million.

COST COMPARISON FOR ALASKA BROADCAST
(10 YEARS)

Satellite		Terrestrial	
Develop and Operate	$145 million	60 Transmitters	
		Investment	$ 90 million
		Operation	$200 million
Ground receiver investment (100,000 at $100 apiece)	$ 10 million	Receiving antennas (52,000 installations)	$ 2 million
	$155 million		$292 million

One of the more impressive comparisons of the economic advantage of a satellite system over a terrestrial instructional television system is seen in costs for the United States. A terrestrial system would cost $1,280.5 million or more than 13 times the $95 million cost of a satellite equivalent. The terrestrial system assumes a coverage of only 65 percent of the 3 million square miles of the continental United States, while the space borne system would cover 100 percent of the area. The comparisons were made for receivers in each of the 10,000 school districts. If the satellite broadcast were to be expanded to all 100,000 schools in the country, the additional cost would be $100 million as compared to an added $5 million increase in the terrestrial system. This would still make the terrestrial system seven times costlier than a space equivalent.

COST COMPARISON FOR U.S. INSTRUCTIONAL BROADCAST
(10 YEARS)

Satellite		Terrestrial	
Develop and Operate	$85 million	211 Transmitters and microwave interconnections	
		Investment	$610 million
		Operation	$670 million
Ground receiver investment (10,000 at $1,100	$11 million	Receiving antennas (7,500 installations)	$ 0.5 million
	$96 million		$1,280.5 million

In the area of direct television broadcasting, the economic potential of satellites is quite apparent. These technologically advanced systems offer a marked dollar savings over terrestrial systems while expanding the potential audience and area of coverage. In both the Indian and Alaskan system, the savings is about 50 percent over the classical ground station approach. In the U.S. instructional television system, the advantage of satellite over terrestrial is even more pronounced and savings of 85 to 90 percent are achievable.

Mobile

While there has been some controversy over the frequencies to be used for a worldwide Aerosat or satellite air traffic control system, there is little doubt among the various government agencies and industry organizations that such a service must be instituted in the decade of the '70's. Airlines in the U.S. favor an Aerosat operating in the 118 to 136 mHz or VHF frequency range. European interests favor a system that operates in the UHF L-band range of 1,540 to 1,660 mHz. The President's Office of Telecommunications Policy recommended in January of 1971 that L-band be selected, and early development of such satellites should be implemented with preoperational use beginning over the Pacific in 1973 and over the Atlantic in 1975.

Estimates of the economic impact of an Aerosat system are dependent upon the frequency band selected. Commercial aircraft are presently equipped with VHF communications equipment. If the recommendation for L-band is adopted, new equipment will be required for each participating aircraft.

The first application for a Mobile or navigation satellite will be in the aeronautical system for use by transoceanic flights. Now that L-band has been established for this service, estimates are available on the costs involved. Current predictions are for an investment of between $125 to $150 million for a two ocean system.

Economic Impact Conclusion

The preceeding examples demonstrate that the economic impact of technological progress in the communications satellite field has been dramatic and will be much greater in the near future. The investment, associated with commercialization of the technology for International communication, already exceeds one-quarter of a billion dollars and can be expected to grow many times over as the network expands. Significantly, larger investment flows will be triggered by the advent of domestic satellite communication systems. Even so, these indicators of the economic impact of commercial communication via satellite measure only the most obvious direct effects. In many ways the readily identifiable direct economic effects of an increment of technological progress are analogous to the tip of an ice-berg. A case study such as this of any given application of technology can only hint at the full range of secondary or induced economic impacts set in motion by the application. But, given the magniture of the early direct effects and the multiplicative nature of technology in the macro-economic growth equation, it is clear that the national R&D effort underlying communication satellites has been an excellent investment.

VI. TECHNOLOGY DIFFUSION THROUGH PARTICIPATING COMPANIES

The reasons for studying a sample of companies that were active in communications satellite development were to:

1. Determine how they were involved in the NASA communications satellite programs.

2. Identify how the capabilities of the firms, augmented by their interaction with the NASA work, were applied to commercial communications satellite systems.

3. Assess the effects of satellite work on the subsequent development of each company--in its day-to-day as well as longer range operations, and in nonspace and possibly even noncommunications efforts.

Interviews were conducted with 16 companies. They were designed to illustrate the ways companies are altered and to construct a model of how technology affects industry.

Although at least 277 firms were prime contractors in the SYNCOM and ATS programs, only 14 could be examined within scope of this study. The first step was selection of a sample of large and small firms which were satellite and ground station contractors. The screening process is described in Appendix A. Two firms which were not prime contractors were added to the sample. One is a spin-off from a prime contractor; the other is a new company utilizing satellite technology in navigational systems.

The interview schedule began on 12 October 1970, when Midwest Research Institute personnel called on the Rantec Division of Emerson Electric. Subsequent interviews were held with the following contractors. In some cases repeat calls were made when insufficient information was obtained on a first visit or where a first contact provided leads to other researchers or divisions within the company.

1. Ampex Corporation, Redwood City, California, 16 October 1970.

2. Bendix, Towson, Maryland, 8 December 1970.

3. Electronic Communications, Inc., St. Petersburg, Florida, 2 December 1970.

4. General Dynamics, San Diego, California, 24 November 1970.

5. General Electric, Valley Forge, Pennsylvania, 9 December 1970.

6. Hughes Aircraft, Culver City, California, 21 and 22 October 1970. Hughes Aircraft, Los Angeles, California, 23 November 1970.

7. International Telephone and Telegraph (IT&T), Nutley, New Jersey, 10 December 1970.

8. Martin Marietta, Orlando, Florida, 3 December 1970.

9. Rantec Division of Emerson Electric, Calabasas, California, 12 October 1970.

10. Satellite Positioning Corporation, Encino, California, 12 October 1970.

11. Sylvania, Waltham, Massachusetts, 4 December 1970.

12. TRW, Redondo Beach, California, 25 November 1970 and 4 February 1971.

13. Watkins-Johnson, Palo Alto, California, 14 October 1970. Watkins-Johnson, Santa Cruz, California, 15 October 1970.

14. Wavecom, Northridge, California, 3 February 1971.

15. Westinghouse, Baltimore, Maryland, 8 December 1970.

16. Wiltron, Palo Alto, California, 14 October 1970.

Of these companies Wavecom is a spin-off firm of scientists and managers formerly with Rantec. Satellite Positioning Corporation assembles, sells, and installs navigational and geophysical position location equipment utilizing satellites.

Evaluation of Technology Diffusion at the Company Level

There are a multiplicity of ways in which technology is generated and diffused by firms involved in goal-oriented R&D. The economic effects come about in many ways and take many ultimate forms; some are directly related to the original undertaking; others are not. Many factors within and without the individual company condition the when, what, and how, where and whether--associated with the applications of acquired and augmented technical capabilities.

Cause and effect linkages are ephemeral in many instances, but analysis of the experience of individual companies allows the researcher to better understand how diffusion of technology occurs and impacts on the economy. Dramatic economic gains are rarely attributable to a single technological event. Within technologically oriented firms, technical progress and its economic application is a continuing, day-to-day function--at which some are better than others. Cumulatively, the economic impact is great, as Part I of this report demonstrated.[1/] Technology, operating within a milieu of other factors, is a motivator toward the final impact. While a simple summary of the ways companies are affected by the emerging technology from mission-oriented R&D is not possible, Figure 16 displays some of the more obvious elements of the process. The findings drawn from the interviews at each of the 16 companies are as follows:

Hughes Aircraft. Figure 17 illustrates how Hughes Aircraft expanded its initial involvement in communications satellite R&D into commercial systems. Hughes was a high technology firm that expressed interest in synchronous devices when others still favored lower orbits. Staff scientists Harold Rosen and Donald Williams were convinced that synchronous, geostationary devices would minimize the number of satellites needed for global coverage. They also recognized that such satellites would eliminate the need for rapid slewing rates required on large terrestrial antennas tracking the lower altitude vehicles.

Funding within Hughes would not allow rapid development of synchronous satellites, but NASA support of Hughes technology accelerated production, flight and test of such devices. Consequently, Hughes produced the successful SYNCOMS orbited in July and August of 1963. The firm also contributed heavily to the ATS program in developing an electronically phased antenna, millimeter wave (31.65 GHz) systems, reaction jet controls, station keeping and other subsystems.

Concurrently, Hughes added to its in-house synchronous satellite capability and the national knowledge of these devices. They influenced the technology of other firms called upon to supply components for the program. While some subcontractors and suppliers were already making high reliability components, Hughes developed a program of rigid inspection and qualification that was applied to subsequent government and commercial satellite work.

1/ See: Overall Economic Impact of Technological Progress--Measurement.

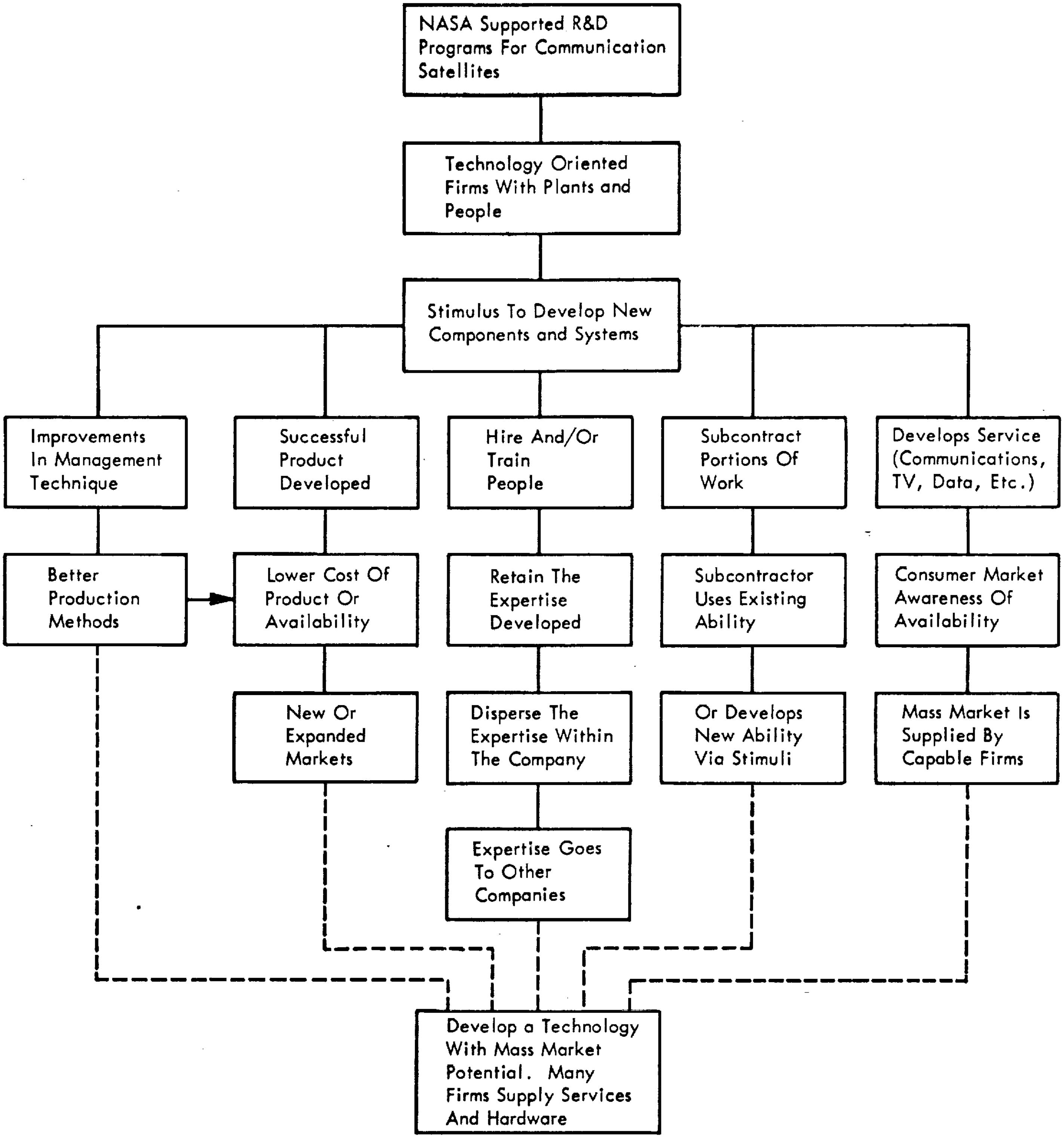


Figure 16 - How Mission-Oriented Research and Development Could Affect the Economy

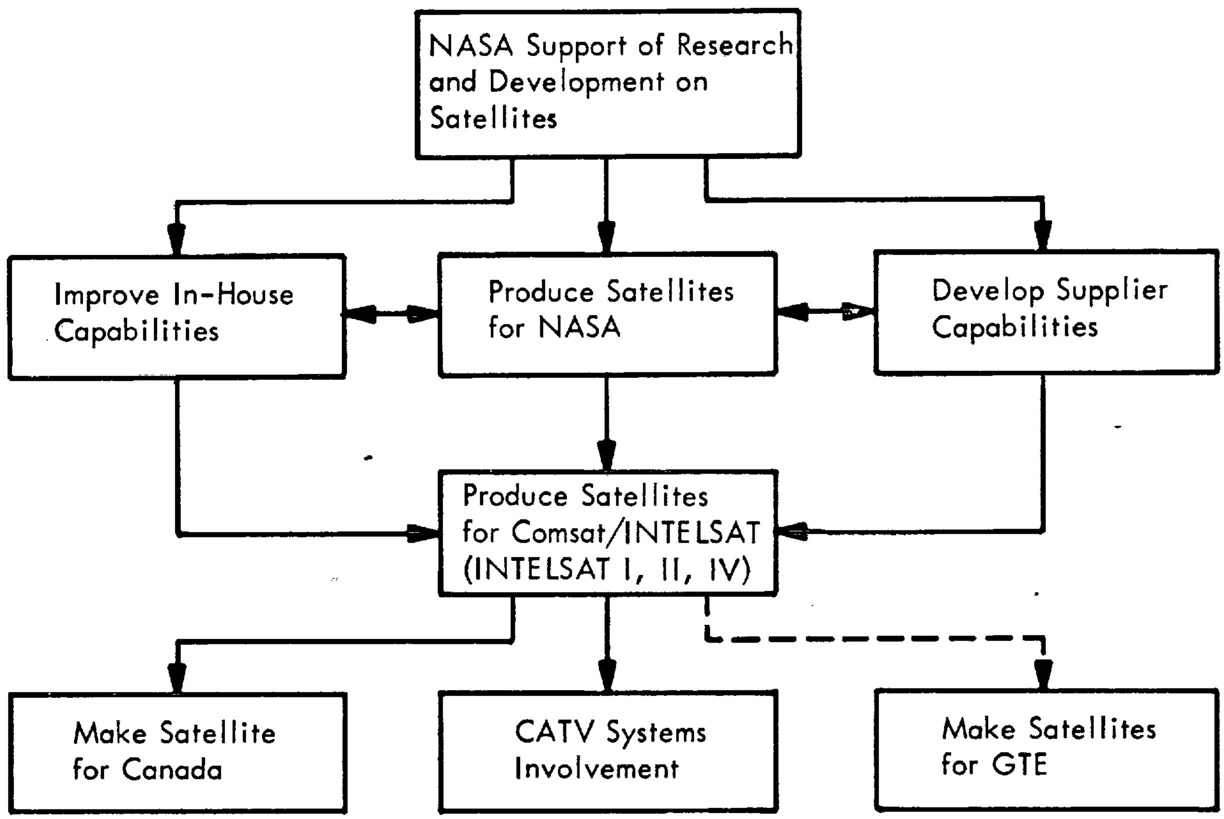


Figure 17 - Hughes Aircraft Company

Hughes staff members stated that NASA-influenced communications satellite R&D affected quality control, reliability, traceability, and documentation in their company. Prior involvement with military contracts had already created a staff awareness of these controls. However, in fulfilling the rigid requirements for vehicles in the space environment, superior methods of qualifying suppliers were initiated. These are retained as a positive benefit of the past efforts.

Involvement with NASA placed Hughes in a position to further apply developing technology to commercial satellites and the company supplied INTELSAT I (patterned after SYNCOM), as well as INTELSAT II. The firm was selected to manage the INTELSAT IV program, the first internationally built satellite, fabricated by companies in Intelsat member nations. Hughes is the training facility for scientists from these countries.

The company is also the prime contractor in the Canadian Telesat program, the advanced satellite serving that nation with voice and television. This $31 million contract is the first major sale of satellite technology to another nation. Hughes' involvement has not stopped with Comsat, Intelsat, and the Canadian system. The firm has applied to become a domestic (United States) satellite operator. This is a different endeavor for an R&D company. To perform this function, it has agreed with General Telephone & Electronics to provide services to the continental United States and Hawaii. Some clue to the worth of such a system can be gleaned from a Wall Street Journal article of 23 December 1970 (page 8), entitled "General Telephone Plans to Use Satellites Owned by Hughes in Communications Grid." The article states:

> "General Telephone & Electronics Corporation said it has agreed to use Hughes Aircraft Company-owned satellites in connection with a $27 million domestic communications ground-station system proposed yesterday by General Telephone."

General Telephone proposes to build four earth station to utilize the 10,560 voice or eight television circuits leased from Hughes. Annual system operating costs were estimated by General Telephone to be $16 million, including $7.2 million for satellite leasing.

Hughes personnel stated that another factor in applying for permission to become a satellite operator was their interest in CATV. In such a system, Hughes would supply ground receiving stations for reception of satellite signals. These Hughes designed stations consist of an unattended 35-foot antenna feeding receiver/converter electronics in an adjoining shelter. One configuration would sell for about $110,000 but a limited capability version would be in the $2,000 to $3,000 range. Coaxial cable would carry the signal to the homes in the nearby community.

Thus, Hughes is transferring technology from satellite research, development and production to more commercial areas. Hughes capital, as well as capital from GT&E may be infused into the process that will utilize labor from both firms as well as, other suppliers.

Watkins-Johnson. Not all firms active in communications satellite development were large, multidivisional companies. Watkins-Johnson is a small, growing producer of traveling wave tubes and microwave components. From sales of $1,586,000 in 1960 to $30,000,000 in recent years, this organization has been predominantly technology oriented. Both founders were formerly with Hughes in the microwave tube section. Dean Watkins left Hughes to become professor of electrical engineering at Stanford where he was one of the principal inventors of the low noise electron beam gun for TWTs.

Watkins-Johnson was called upon to develop a space qualified traveling wave tube for the SYNCOM satellite. The company was selected as a second source to Hughes when there was some concern that the latter would not be able to meet the full requirements for this particular component.

While the Watkins-Johnson device met the exacting specifications, it was not used since Hughes was able to develop an equivalent tube. However, Watkins-Jonnson's growth after completion of this program can be followed in Figure 18. Of particular interest is the company's application of goal-oriented R&D to products subsequently purchased for commercial application.

Product improvement is the most direct effect of the satellite activity at Watkins-Johnson. Experience accumulated in tube design, materials, and fabrication techniques was applied to extend tube life from a mere 3 weeks to over a year. Instrument manufacturers incorporating the tubes into laboratory equipment are the beneficiaries of the extended lifetime guarantee. Other tube improvements were increased operating efficiency, reduction of size and weight, increased dynamic frequency range, improved resistance to shock and vibration, and improved cathode designs. Glass to metal seal technology was also advanced by this R&D effort, and these better bonding techniques have been applied to other vacuum devices made by the company.

The SYNCOM TWT was an early application of periodic permanent magnet principle for electron beam focusing. Previously, electromagnets had been employed. In addition, the SYNCOM tube was the company's first use of platinum-cobalt in magnets. Both principle and material are now incorporated in a variety of tubes produced by the firm. John Foster, the production manager of the new Stewart Division of Watkins-Johnson,

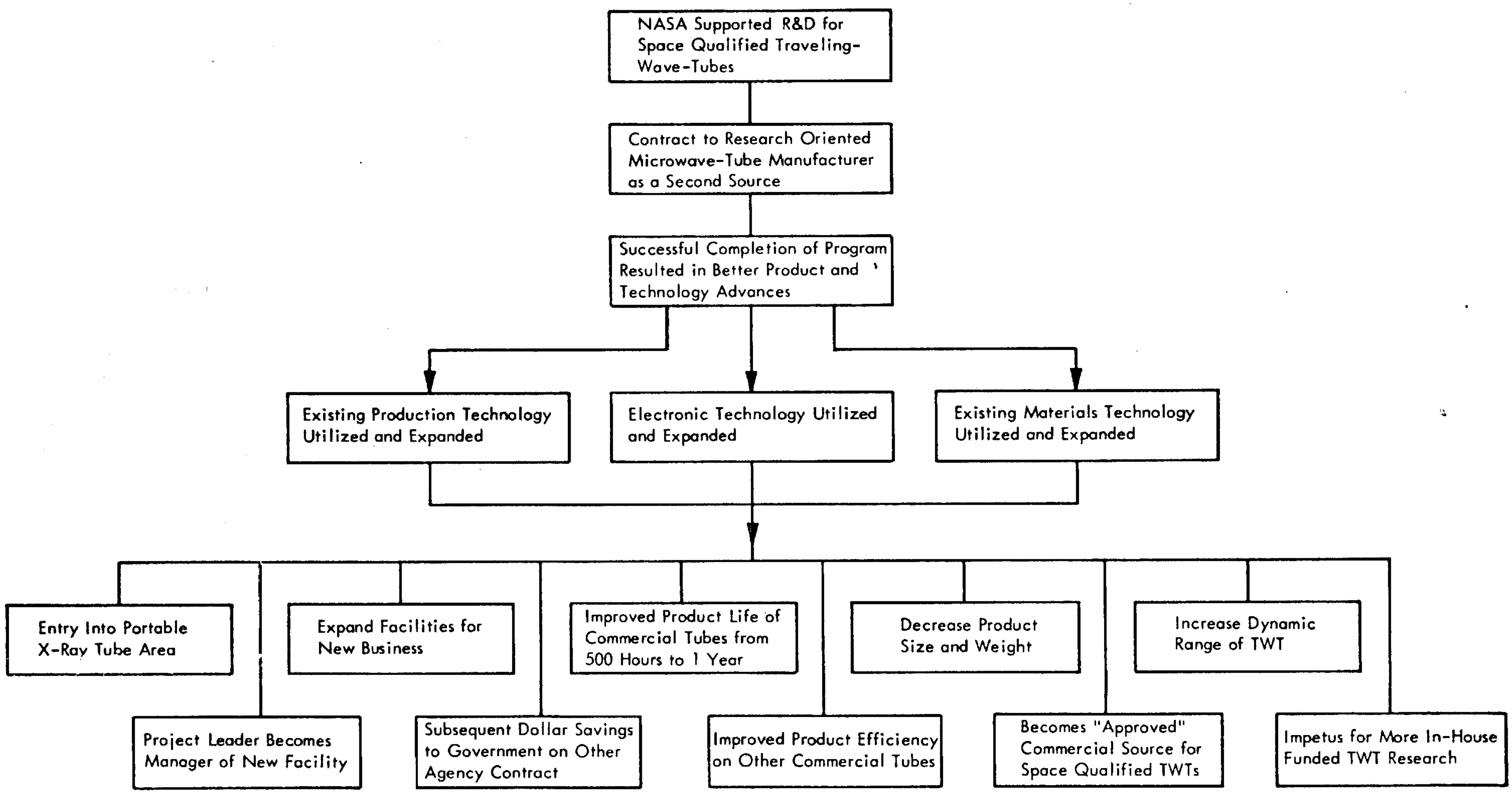


Figure 18 - Watkins-Johnson

stated, "Many of the practical developments first pioneered on the SYNCOM satellite tube have subsequently influenced our work on traveling wave tubes for other purposes, and some of the design modifications and techniques employed have been successfully used in later TWTs, military tubes, and commercial traveling wave devices." Foster was the project engineer on the SYNCOM tube and has since moved to the new facility in Scotts Valley, California, where his technological expertise is applied to production of portable x-ray tubes and other components.

Another tangible example of diffusion of technology from the SYNCOM program occurred about 1 year after completion of the effort. In May 1963, Watkins-Johnson was awarded a study contract by Fort Monmouth to more clearly define distortion in traveling wave tubes and klystrons. This contract, DA-36-039-AMC02321(E), was for $147,000 over a 2-year period. The drawings produced in the development of the SYNCOM tube were used to construct the TWTs for the study program. Sources of distortion and possible noise reduction were examined. The SYNCOM tube was used as the test vehicle, and a $25,000 saving was passed along to the government.

Prior to the SYNCOM program, Watkins-Johnson had not built space qualified tubes, but in the ensuing 4 years they became well established in the field. The efforts of the firm established its reputation as a reliable alternate source of TWTs.

As shown in Figure 18, other changes occurred at Watkins-Johnson. While is is virtually impossible to assign specific percentages of influence in the areas depicted, they are indicative of channels by which technological progress and diffusion move to application in a smaller component-oriented manufacturer.

Sylvania Electronic Systems. Sylvania was heavily involved in building ground stations and despun antennas for ATS. It produced a ground station for Cooby Creek, Australia, that differed from existing units in that it was transportable and could operate from an auxiliary power system. Sylvania also modified two U.S. stations to meet the operational specifications of the transportable unit. One notable contribution of Sylvania to satellites was the mechanically despun antenna for ATS. This antenna, driven by a motor synchronized to the satellite's rotation, is constantly turned earthward and exhibits a gain of 17 db, which effectively increases the satellite output power by 50 times. Other supporting research for the ATS program covered various components in the system. (See Figure 19.)

Another area of improvement attributable to Sylvania is in ground station receiver performance. Improved carrier-to-noise ratio of the wideband intermediate frequency amplifiers was a notable state-of-the-art advance from the company. Improved ground station antennas and feed systems

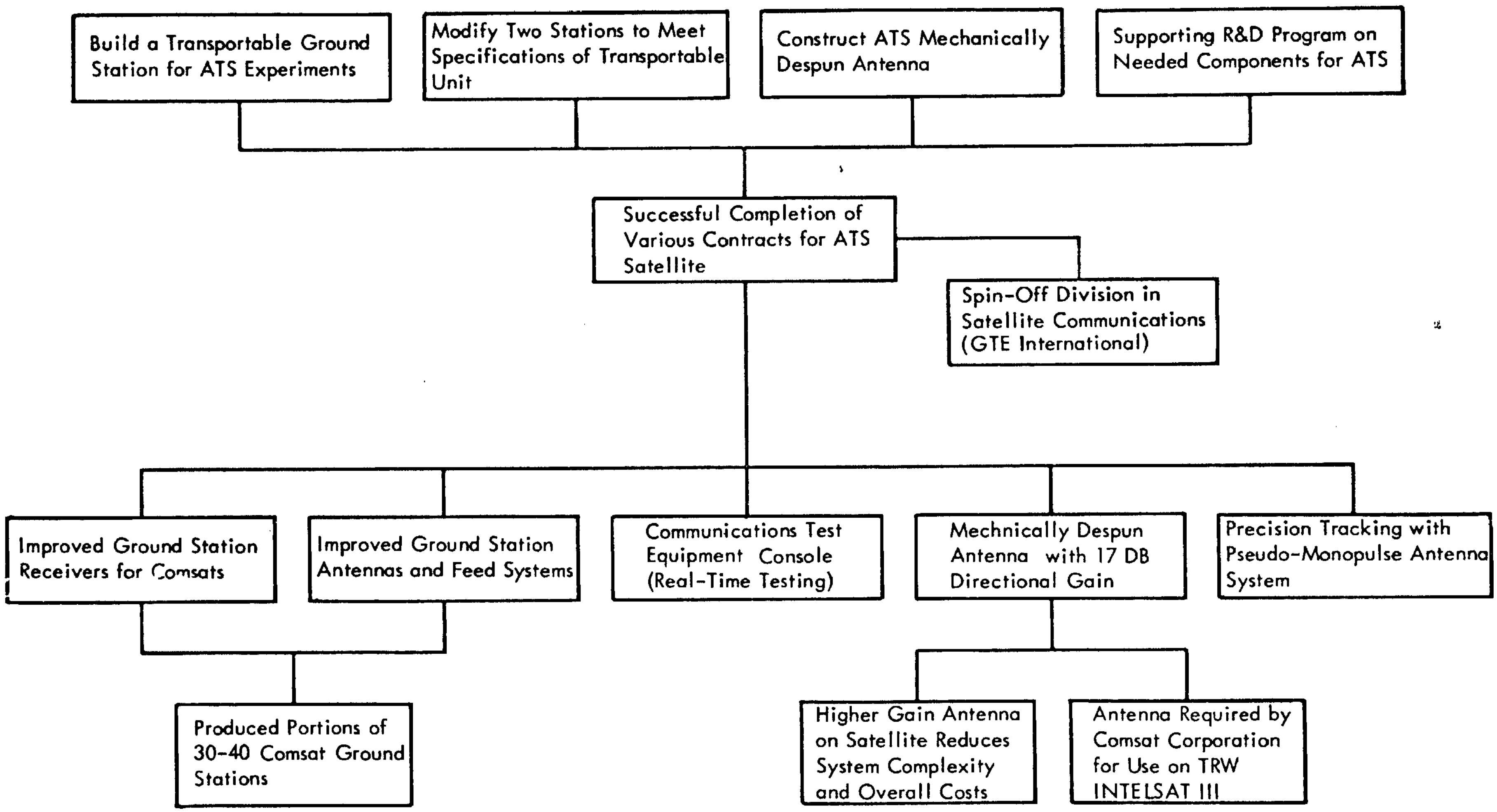


Figure 19 - Sylvania Electronic Systems

were other results. As a residual of its successes in ground station development, the company produced portions of 30 to 40 Comsat/Intelsat ground stations.

The mechanically despun antenna represented a considerable improvement over electronically despun antennas. It also exhibited higher gain and concentration of the signal over older omni-directional devices. The capability of the array was recognized by Comsat which required TRW to use the Sylvania antenna on INTELSAT III. With this satellite antenna, ground station receivers can be constructed with lower performance figures and higher reliability as the incoming signal is now much stronger. This reduction in receiver complexity also lowers the overall system costs. Further, it is possible to use lower satellite transmitter powers to produce the same signal, reducing weight and primary power requirements of the vehicle.

Satellite technology has been dispersed from Sylvania in yet another way. About 100 employees of this group formed a new division of General Telephone & Electronics (the parent company). This division, GTE International, is involved in satellite communications systems and utilizes technology solidified at Sylvania Electronic Systems.

Thus, Sylvania diffused technology through another entity of the company started by personnel trained during satellite system development. It also applied NASA supported technology to ground stations built for Comsat/Intelsat as well as the antennas used on INTELSAT III. In addition, Sylvania added to the technology of ground station receivers for use with future satellite systems.

IT&T, Defense Communications Division. The main effort of IT&T has been to combine newer technologies of satellite communications with those already existing within the company to maintain and improve its position as an international supplier of service and systems. (Some of the contractual work of IT&T is shown in Figure 20.) Unlike some aerospace firms who had to market their communications capabilities to an audience more familiar with their airframe proficiencies, IT&T was already established with its prospective customers. The combination of existing international marketing and research facilities undoubtedly eased the problems of initial establishment as a source.

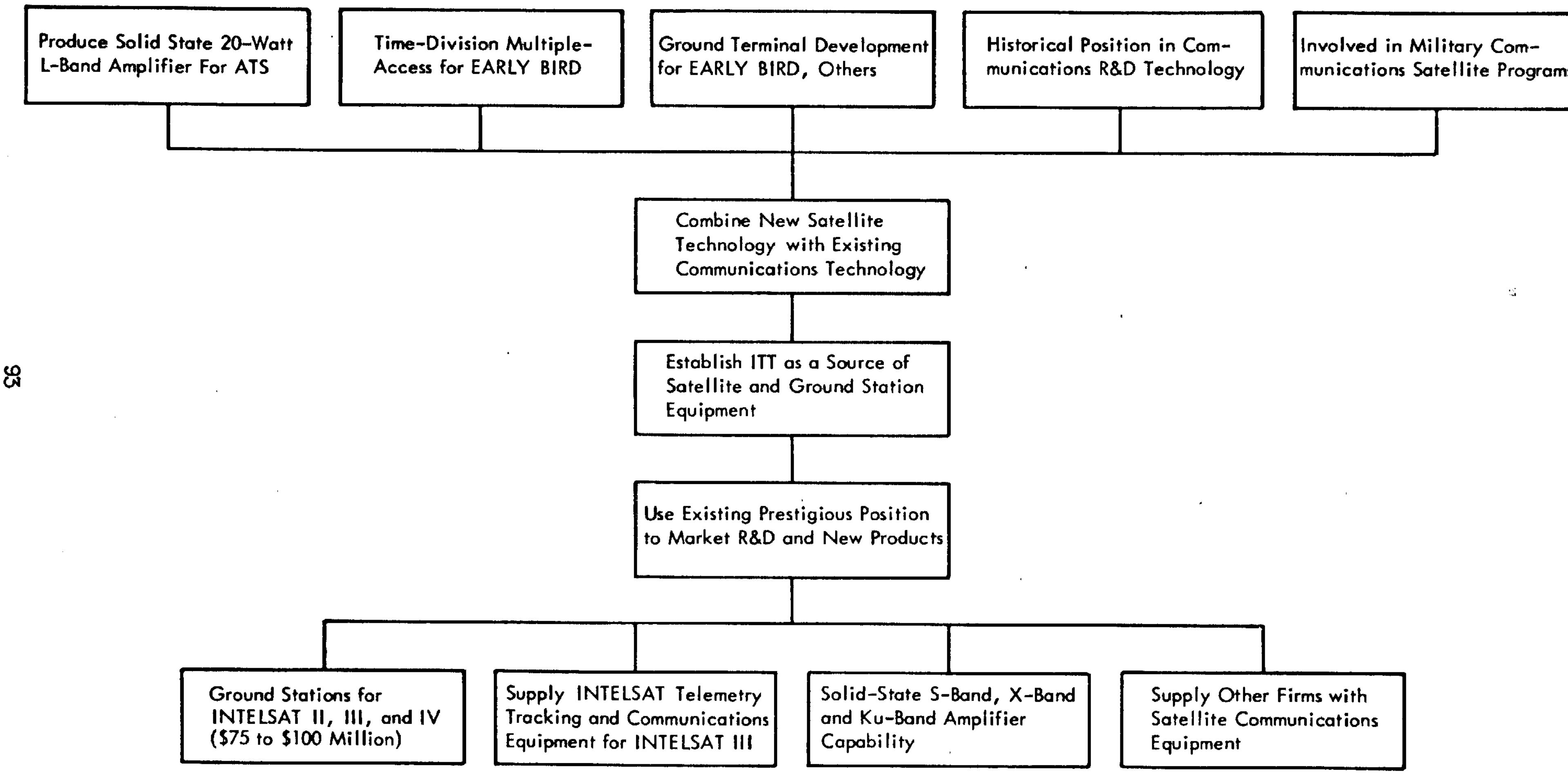


Figure 20 - International Telephone and Telegraph (ITT) Defense Communications Division

One activity at IT&T is the development of improved multiple access techniques so many different size ground stations can simultaneously use a single satellite. In the mid to late sixties, IT&T utilized time division multiplex (TDM) and voice bandwidth compression to increase the capacity of small terrestrial stations to work through satellites. This effort, carried out for the NASA Goddard Space Flight Center, has subsequent application in any communications system for maximum utilization of the available bandwidth. Representatives of IT&T stated that this supportive research and technology produced the first high bit-rate, high packing-density, digital multiple-access system for satellite communication.

IT&T applied space technology to commercial systems and produced ground station electronics for INTELSAT II, III, and IV following their production of terminals for EARLY BIRD. The firm built 40- to 85-foot dishes for INTELSAT II and 98.4-foot dishes for INTELSAT II and IV terrestrial stations. Large antennas have been a forte of this company and the INTELSAT IV array was an outgrowth of prior NASA-funded research. IT&T estimates that its worldwide commercial sales of satellite ground terminals have been $75 to $100 million.

The staff at IT&T also credits NASA-funded research with one of the major breakthroughs in satellite communications: The use of high frequency conversion techniques in transponders. The system, now common to most satellites, reduces the cost of modulation systems, and lowers the overall complexity of the orbiting vehicle.

General Electric. Many of the firms engaged in communications satellite development are primarily aerospace or electronics companies. General Electric is an established full-line organization with major manufacturing interests in the power equipment, consumer and industrial areas. This commercial aspect of GE is supplemented by military and space work, but company dependence on such contracts is minimal. While GE has performed successfully on space program work, company personnel see the greatest economic advantage of such technology in the future mass production of equipment which will be needed as commercialization proceeds. (See Figure 21.)

Because of its broad base of scientific and technical competence, the company was an early participant in satellite communications programs. GE was a major contractor on ADVENT and has contributed to a variety of NASA programs including: the attitude control system for ATS-F and -G, the gravity-gradient system on ATS-2 and -5, and small ground stations for ATS-1 and -3. In a study for NASA, the company also explored the requirements for and feasibility of direct TV broadcasting from satellites.

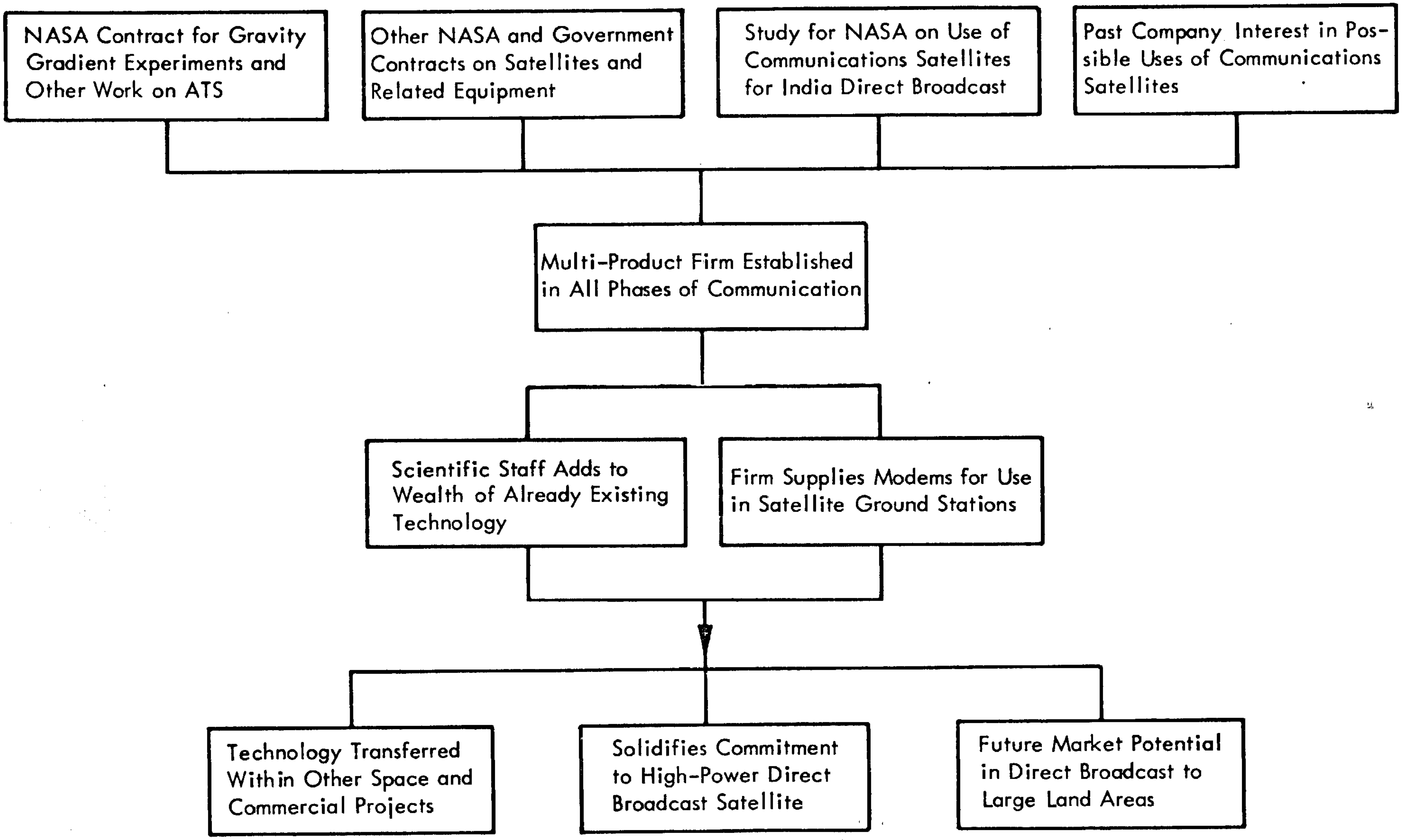


Figure 21 - General Electric

GE foresaw the economic potential of satellites rather early in the exploration of space. In 1962 to 1963 the company studied entry into the communications services industry. The investigation proceeded to a point that even a name, Communications Satellite Company, had been selected. The venture was stopped when the nation chose to sanction the quasi-public Comsat Corporation.

However, the company has maintained its interest in commercialization. In particular, GE has championed the high-power, high-performance satellite for direct home broadcast and air traffic control. As such systems emerge, the firm sees itself to be in an excellent competitive position because of its many years of R&D on the necessary technologies. One specific example is the design of small 10-foot receiving antennas and simple converters for adapting the home TV receiver to satellite reception.

Studies have also been made on mass production of small antennas and converters. The findings indicate that the installed cost of a system allowing direct TV reception via satellite would be less than $100 per household. These particular studies were performed under NASA contract and the company possesses a wealth of technical talent on other aspects of direct broadcast. Typical of this activity is the continuing development of high-power-gridded vacuum tubes necessary in direct broadcast satellites.

GE has also supplied about 80 percent of the modems used in ground stations and has found that its share of the Comsat/Intelsat purchases is comparable to that of other segments of the communications equipment markets.

In summation, the impact on GE has taken two basic forms:

1. Through a combination of GE, NASA and other funding there has been significant progress toward satisfying the technological requirements of direct broadcast and ATC satellite systems. The attainment of such systems will significantly expand the markets for a variety of products and services.

2. In the meantime the company has enjoyed sales of its pre-existing products (e.g., modems) to the operators of communications satellite systems.

A more generalized impact was discussed by the GE staff. The view was expressed that in the past, technology from terrestrial microwave links was a major influence in satellite transponder design. But now there is evidence that the direction of influence is reversing. Space developments are beginning to have significant impact on the hardware used in earth bound microwave communication systems. In particular, developments in wideband, high-power tubes for the space program are now being applied by GE to ground-based communication systems.

Electronic Communications, Inc. Electronic Communications, Inc., is a diversified electronics manufacturer that contracted to produce a lightweight omni-directional antenna with circular polarization for OPLE (Omega Position Locator Experiment) on ATS-III. As a result of a prior NASA program, the company held a patent on the electrical construction of a "loop vee" antenna that would fulfill the requirements of the contract. However, to scale this antenna to the dimensions required at the low VHF frequencies would have resulted in a 300-pound metal device exceeding the weight restrictions of this particular application.

ECI had an existing in-house capability for producing lightweight microwave components by plating metal on precision molded or cast plastic. This method of producing chassis for their microwave equipment had been developed to eliminate the precise machining of brass blocks and then silver plating their surfaces, a practice which had been fairly standard in this industry. By casting VHF antenna from lightweight plastic and subsequently plating this material with metal, ECI combined tooling technology with electronic technology to produce a durable 50-pound antenna. Problems of precision machining, metal fabrication and weight were eliminated with no detriment to the structure's operational characteristic.

ECI personnel stated that a market exists for such antennas on buoys used in oceanographic studies. Other markets are in any area where lightweight metallic plated structures are required with discontinuous surfaces or where weight is at a premium.

Another application for such an antenna is in air traffic control and surveillance. The unique characteristic of the circularly polarized antenna is that rotation around its axis does not affect signal strength. This is in contrast to the conventional antenna that is polarized in a single plane and deteriorates in efficiency if rotated about its pointing axis. In air traffic control, the antenna must be circularly polarized to prevent loss of signal as the aircraft is turning. The ECI development contains two desirable features for aircraft: it is lightweight and it is circularly polarized.

ECI has also supported in-house R&D on a transportable satellite terminal for voice communications. This device, similar to the "handie talkie," is a small transceiver suitable for field use in contacting any other station within range of the satellite. The firm built prototypes of the transceiver and proved feasibility of long-haul communications by using a satellite as the intermediary relay. The units operate in the 225 to 400 MHz range utilizing narrow band frequency modulation and a power output of 4 to 5 watts. A satellite with a sensitive receiver, a transmitter power output of 1 kw and a 10 to 15 db gain antenna, allows two transportable stations to establish communications between any two points on earth.

One application for such transceivers is in the location of downed aircraft and pilots. ECI has also produced a suitcase size transportable ground station with a 50 to 100 watt power output. The latter has a three channel capability and is teletype adaptable.

ECI has been involved in other communications satellite research that has added to the technology within the organization. The firm produced the earth stations for the LES-5 experiment (Lincoln Laboratories Experimental Satellite). Other work has included military and commercial efforts in communications. (See Figure 22).

This firm has demonstrated two phenomena that can occur within a company that is innovative and has access to new technology. In the production of the improved antenna, ECI mated in-house technology in metal plating on plastics to existing NASA supported technology on circularly polarized antennas and produced a device embodying the good characteristics of both that met a new requirement. The antenna has application to yet another field, data buoys, that would transmit useful information to a satellite and thence back to earth. Thus, rather divergent technologies can be combined to achieve a solution.

In the development of the transportable, low-power transceiver, a firm with existing skills uses a new technology for application of innovative ideas in communications. By demonstrating such expertise, the company places itself in a position to market equipment in the low-power terrestrial station field. Both ECI developments have application in air traffic control. Thus, experience plus emerging technology combine to produce a potential market.

Martin Marietta. Martin has made numerous contributions to satellite communications and peripheral fields of science. It has also been heavily involved in millimeter wave (or super-high microwave frequency)

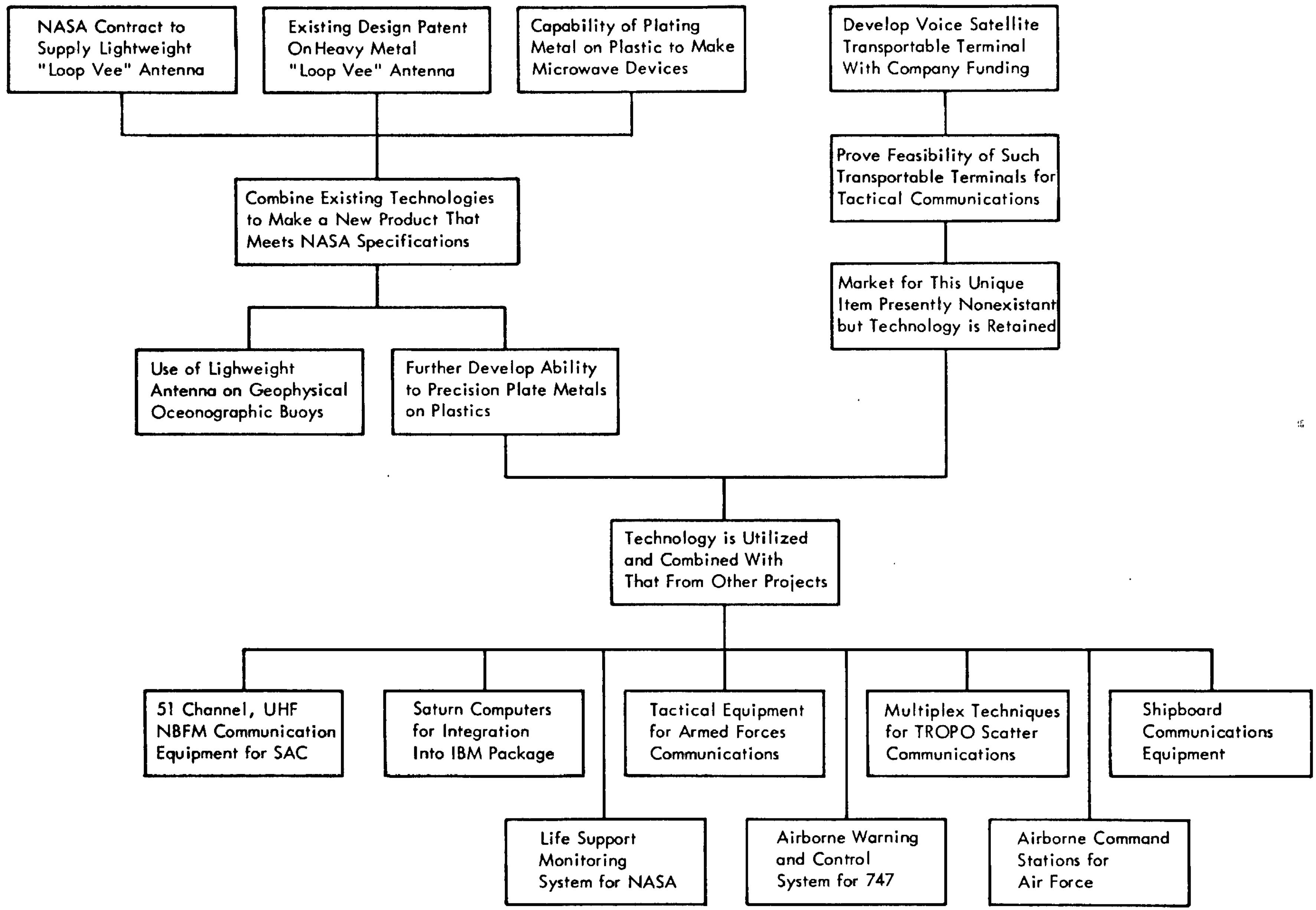


Figure 22 - Electronic Communications, Inc.

communications, data processing, computers, digital signal enhancement, optical communications, lasers, ground stations, lumped circuits, and synthetic production of rare gems and crystals. As a result of diversification efforts, programs have been implemented to draw upon Martin knowledge built on aerospace and satellite technology. Some of these efforts are shown in Figure 23.

Of particular interest to a study of technological progress and its dispersion to commercial application is the company's activity in millimeter wave data links. Millimeter wavelengths, a relatively unused portion of the radio spectrum between 30 and 100 GHz, have several potential advantages: low spectrum crowding, wide bandwidth capabilities, high-gain small aperture antennas, and possible plasma penetration capability.

Martin's interest in millimeter wavelengths (then a laboratory curiosity) began some 10 years ago with a study of the absorption properties of water molecules and hydrogen. Components were not available commercially so the company developed its own. Engineering interest in propagation at millimeter wavelengths soared when the possibilities of obtaining gains of 50 to 60 db with very small antennas were realized. In addition, the solving of increasing problems associated with spectrum crowding at the lower frequencies would be realized if the millimeter wave area could be exploited. NASA became interested in the experiments and funded the initial study with Martin in 1962. A series of other efforts followed, including millimeter wave experiments to fly on the ATS program.

A number of firms have recognized the potential of millimeter wave propagation as a communication device. AT&T and Comsat Corporation have both constructed ground stations to check the millimeter wave signals from ATS-5 and are investing their own funds, as has Martin, in additional research. Millimeter waves also have potential application in ground based communications as replacements for coaxial cables and microwave relay systems. However, millimeter waves are attenuated by particulate matter in the atmosphere, especially water. There are several approaches to the resolution of this limitation, all of which Martin, NASA and others are investigating.

Martin is transferring its technology to the international market. The firm is working with Italy on that nation's SIRIO Satellite and with the Heinrich Hertz Institute in Germany. In the longer term the company expects to apply their operational millimeter wave capabilities to systems such as those proposed by Datran and Microwave Communications, Inc. The inherent ability of millimeter waveguides (essentially tubes through which the waves are transmitted to protect the signals from atmospheric attenuation), is that--in terrestrial links--they can carry three times more phone calls or TV signals than coaxial cable. This factor is a strong argument for such commercial systems.

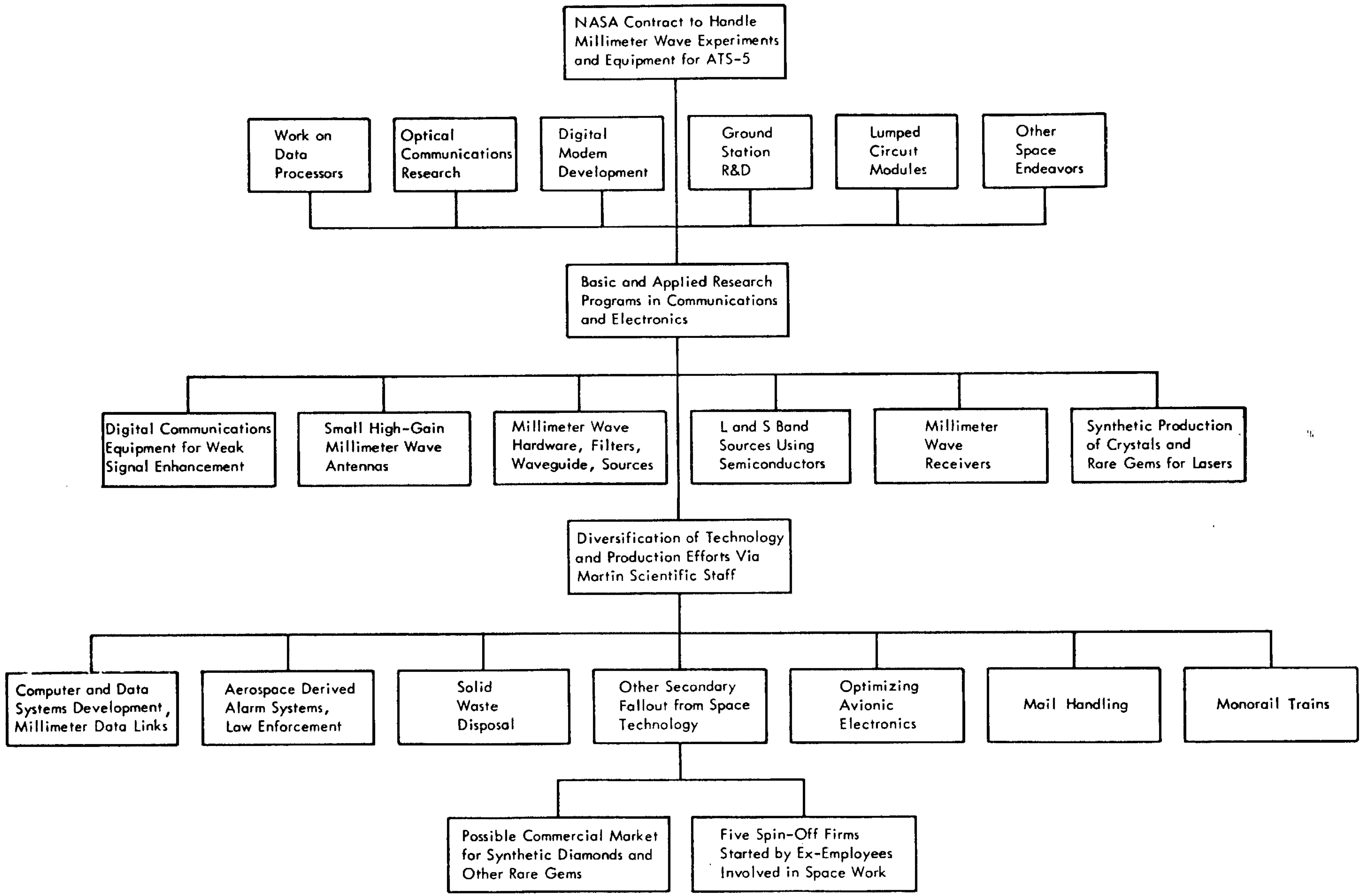


Figure 23 - Martin Marietta (Orlando Group)

Other business areas in which the company has found applications for its technological skills--in part derived from space communication work--include: alarm systems for police departments, airport and avionic electronic systems for equipment optimization in the face of increased air traffic, and mail handling techniques for improved postal systems.

The Orlando group of Martin Marietta also provided the personnel for starting five spin-off businesses that can be traced to satellite technology. These are Control Laser Manufacturing, International Laser Systems, Methonics, Inc., Reaction Metals and Custom Millimeter Wave Components. Two other firms were started by Martin people involved in data handling.

Rantec Division of Emerson Electric. Rantec's involvement with NASA in the modification of communications satellite ground stations is shown in Figure 24. The firm is a fabricator of microwave components requiring precision machining techniques. The Rantec engineering staff has converted basic theory into practical technology amenable to their production facility. The founders of the firm, Robert Krause and Robert Elliot, were formerly with Stanford University and Hughes Aircraft, respectively.

During the mid-sixties, Rantec worked for NASA Goddard Space Flight Center to modify the ground station at Rosman, North Carolina, for use with SYNCOM and ATS. Rantec updated the older lower frequency ground station and adapted it to the higher frequencies used with synchronous orbit satellites. The subsystems furnished were a cryogenically cooled maser preamplifier, a cassegrain cone feed system for the antenna, a collimation tower, a transmit diplexer, a diplexer cooling assembly, a monopulse converter, a boresight antenna and optical target, and the overall system console.

In fulfilling the goals of this program, Rantec improved its position as a supplier of terrestrial and space microwave electronics. Some of the results achieved from the work are in the following areas.

Production expertise has improved as a result of communications satellite work. The firm has installed numerically controlled machine tools for the very precise manufacturing of intricate and small microwave components.

Product development from the NASA ground station program has been applied to commercial items used by Comsat, Intelsat, British Marconi, ITT and others. Rantec has also expanded its product line in test equipment through the various programs. Some of the test equipment, originally produced for in-house use, has since been offered to others and proved to be very salable.

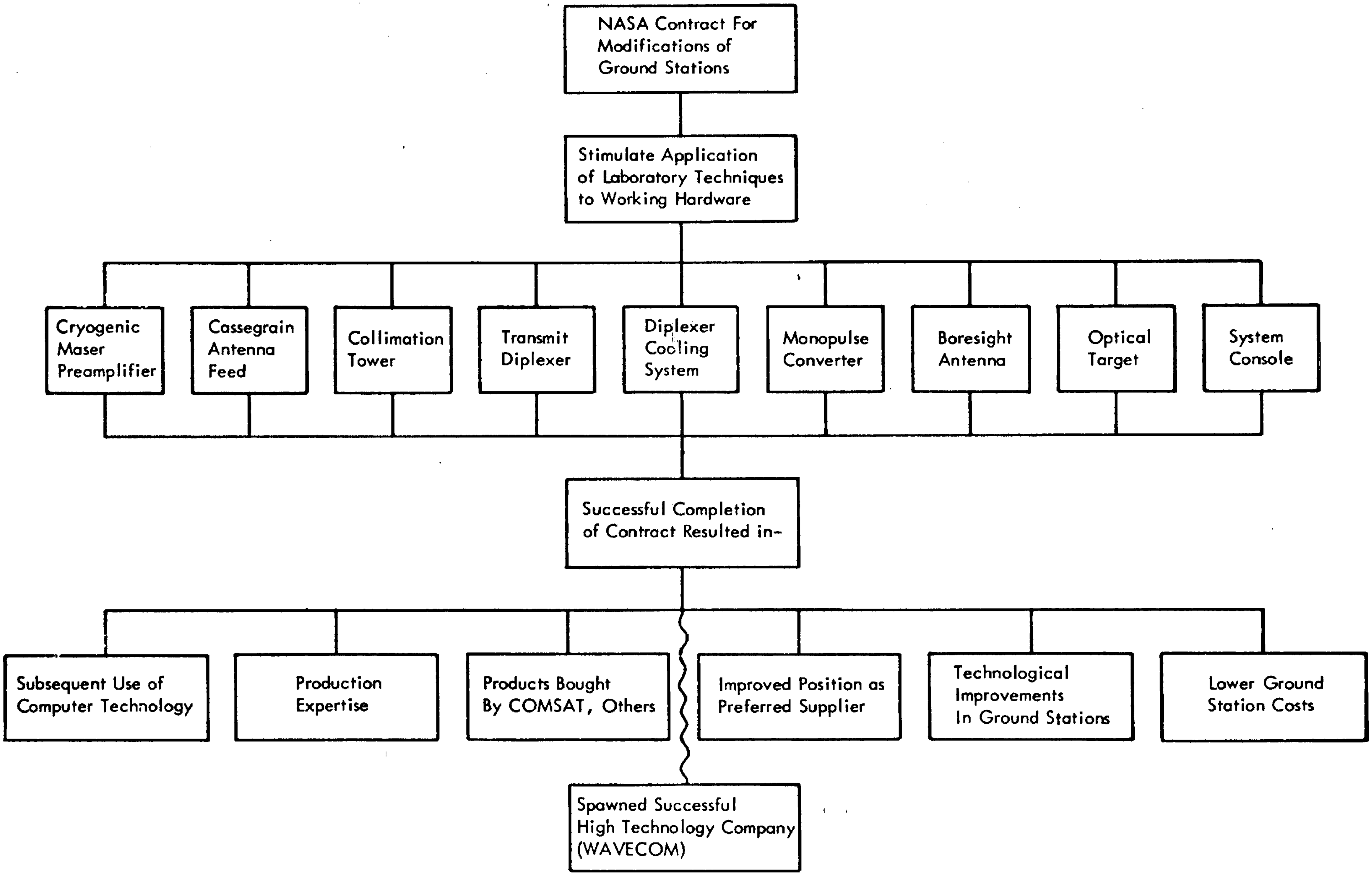


Figure 24 - Rantec Division of Emerson Electric

Preferred supplier position of Rantec has improved as a result of building reliable equipment for NASA. Its share of a $4 to $5 million ground station now runs about $200,000.

Technical improvements from satellite programs allowed Rantec to develop microwave receiver front-ends capable of bandwidths up to 500 MHz instead of the former 200 MHz. These are adaptable to terrestrial systems as well as commercial space stations. There have also been improvements in geometric perfection of dish microwave antennas.

Computer technology is now available to Rantec that was formerly available to only the very large companies. Rantec's time-sharing terminal implements better antenna designs. Charles Chandler, director of engineering, noted that JPL computer programs have improved Rantec's technological expertise.

Lower ground station costs have resulted. Chandler estimates that each decibel of improvement in the ground station antenna and receiver is worth about $1 million in lowering the total system cost. Another factor in lowering cost of ground stations is attributable to Rantec's effort. The early ground station antennas were constructed on the premise that Comsats would be medium altitude devices requiring a high degree of continuous tracking. Large and expensive autotracking drive motors shifted the mass of the structures. With the adoption of high altitude, synchronous orbit, geostationary satellites, these costly tracking drives are eliminated and lower cost systems can be substituted.

Rantec's position as a supplier of equipment for use in satellites is a result of successfully applying existing theory to problems of immediate urgency. The significance of its work can be considered a conversion of science to technology to production. Chandler pointed out that Rantec did not invent the cassegrain antenna feed system. Theory was described in papers on optics before electronics existed as a science. The advantages of such feeds had been recognized by the electronics community in further theoretical treatises on the subject. When Rantec became involved with satellites, it successfully applied the theory to working hardware.

Another extension of technology from the satellite program is seen in a company spawned by Rantec. Personnel formed an organization by the name of Wavecom that is operating successfully in Chatsworth, California. Some of the products of Wavecom are competitive with Rantec, while others are extensions of the space developed technology.

While Rantec is owned by a large company, it was one of the smaller facilities interviewed. Its annual sales are in the $3 to $4 million range and it employs about 150 people. Its products are marketed, about evenly, to three customers: NASA, Comsat and the military. Thus, approximately a third of the company's sales are in a new market--commercial communications satellites--which owes its existence to the space program.

Wiltron Company. The smallest contract to come under the surveillance of this study was received by Wiltron Company for the production of three identical test sets for satellite ground stations. The total cost was $14,000. Wiltron is a small concern with sales totaling $1,431,000 in 1969. The firm designs and produces specialized test equipment for the electronic and telephone industries. Its potential market is limited, presumably by choice, as Wiltron does not manufacture the more popular (and competitive) types of equipment. (See Figure 25.)

Our interview indicates Wiltron received few identifiable residual benefits from work on the ground station test set. The equipment produced was so specialized that it would probably not find application in any of the ground stations presently being constructed.

However, one aspect of the contract merits mention. The equipment required a very precise crystal filter as a component in each unit. This filter is centered at a frequency of 70 MHz and the rigid requirements represented an almost breaking-point stretch of the state-of-the-art. At frequencies this high, crystal filter production techniques pass through a transition from well known, available theory and practice into the area of hand craftsmanship and tedious individual adjustment.

Wiltron does not produce such components and special ordered them from McCoy Electronics, a company with a reputation in quartz crystal technology. The fact that McCoy was able to produce units meeting the rigid specifications indicates an advancement of filter technology.

Westinghouse Electric, Defense and Space Center. The involvement of this division of Westinghouse in communications satellite development can be grouped into three general areas:

1. Development of the gravity gradient booms for ATS-II, -V, -F, and -G.

2. Ground station development for ATS including programs for the detailed analysis of ATS data.

3. The integration and packaging of scientific experiments aboard ATS satellites.

Westinghouse makes a concerted effort to disseminate and use new technology by intergroup transfer of competent personnel and circulation of technical literature. One example is in electromagnetic interference

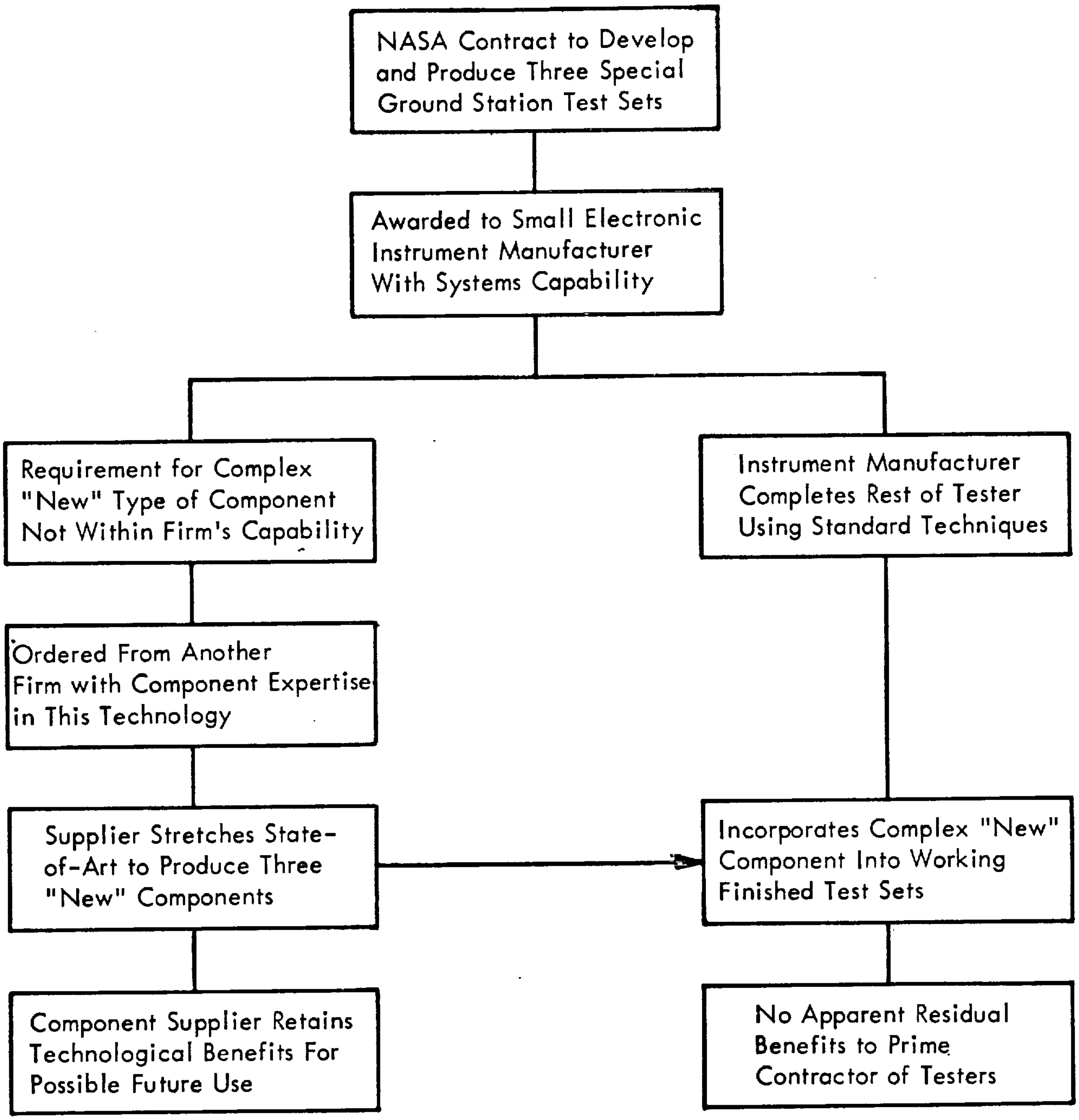


Figure 25 - Wiltron Company

reduction. While working on improved shielding of satellite systems, Westinghouse developed a storehouse of knowledge on the subject. These improvements, primarily in environmental packaging, were incorporated into a series of "Electromagnetic Design Notes" initially intended for those groups packaging satellite experiments. The Underwater Division at Westinghouse discovered that it had similar requirements for underwater RFI techniques. Many of the existing solutions were transferred intact.

"The Westinghouse Engineer," a publication diffusing technology within the organization, is also used as an information source. Staff members are encouraged to obtain patents and to deliver papers at seminars as a part of the technology dissemination program.

Figure 26 indicates some paths of technology movement within Westinghouse. Benefits attributable to space research range from those with a high technology content to others with a high economic potential. Brief descriptions of some of the potential benefits show how they are extensions of prior involvement with communications satellites.

Beryllium copper extendable booms. The gravity gradient booms developed by Westinghouse for the ATS program are extension arms produced from flat beryllium copper strips that have been preformed to produce a tube when unwound from a storage reel (where they are stored in the flat configuration). Bending of the booms in the extended position is partially overcome by a zippering arrangement that locks the seam with V-notches every few inches and provides a degree of rigidity to the structure. To avoid deformation caused by this interlocking notched side, the seam is spiralled about the tube. Thus, any tendency to curving is self correcting over the length of the system. Possible terrestrial applications of such extendable booms include experimental tools, equipment for land surveying, and antennas where the length of the elements must be changed to vary the operating frequency.

Gray-level to color conversion. The involvement of Westinghouse in data reduction and display of information from the ATS-1 satellite was the basis for converting different levels of grey to color in infrared photographs of the earth. Such a conversion allows the examiner of the photo to rapidly distinguish temperature discontinuities that might otherwise escape detection. Subsequently, eight-level digitized weather data have also been enhanced by such color techniques to provide a major improvement in synoptic meteorology.

Power budget systems. Personnel at Westinghouse stated that their abilities in handling electrical power distribution systems had improved as a result of work on advanced space vehicles. The company is particularly capable in the area of automating the control of power switching.

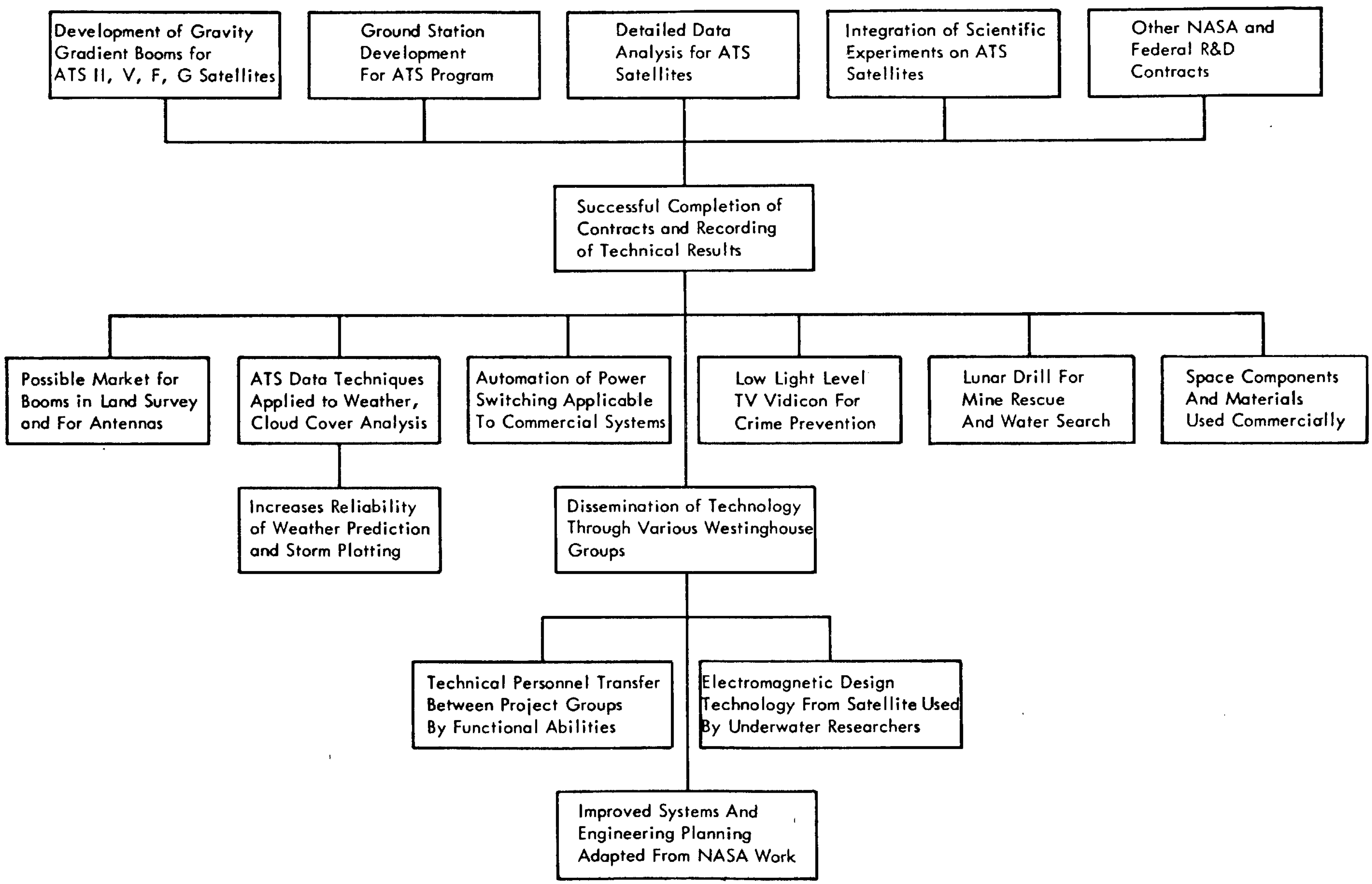


Figure 26 - Westinghouse

These power budget programs are directly applicable to use in jet aircraft or any large complex system where monitoring and control become an important factor.

Systems planning. Westinghouse personnel specifically noted that improved systems and engineering planning had been adapted from work on communications satellite and other space programs. These "adapted" planning procedures have been used in the commercial operations of the firm. Improved logical planning has been one of the more viable advantages gained by those active and successful in space program R&D.

Other space-derived products traceable to satellite R&D programs are low light level TV vidicon camera tubes and a lunar drill. Westinghouse states that the vidicon camera tube holds promise as a monitoring device in crime prevention while the drill could be used in mine rescue operations and water exploration where there is no cooling fluid available for the bit.

Westinghouse is quick to credit the advantages of technology adaptation and diffusion from communications satellite research. The firm is rather typical of those where research groups are able to work with new technologies on an orderly and funded basis. The program of diffusion of technology is resulting in direct fallouts from space research, and technical personnel indicate they will soon announce other impressive derivatives of this effort.

General Dynamics/Electronics. General Dynamics/Electronics developed a sophisticated and accurate system for measuring range and range-rate on ATS. One contribution of the development was in very advanced circuit and systems design. Some typical examples of circuit development achievements are shown in Figure 27.

High accuracy range and range-rate systems were of importance in the early days of satellites when problems were encountered in obtaining the desired orbit. As complementary systems improved and greater control over trajectory and station keeping was achieved, range and range-rate became less of a problem.

With the emergence of air traffic control and navigation satellites, the requirement for accurate range and range-rate equipment may be reinstated. Also, as the equatorial synchronous altitude orbit area becomes filled with more satellites, the need for accurate positioning within the available area could call for renewed emphasis on such systems.

The company has transferred technology from the ATS work to other divisions. Research and development personnel and circuit design techniques have been employed by other groups within the firm. The technology

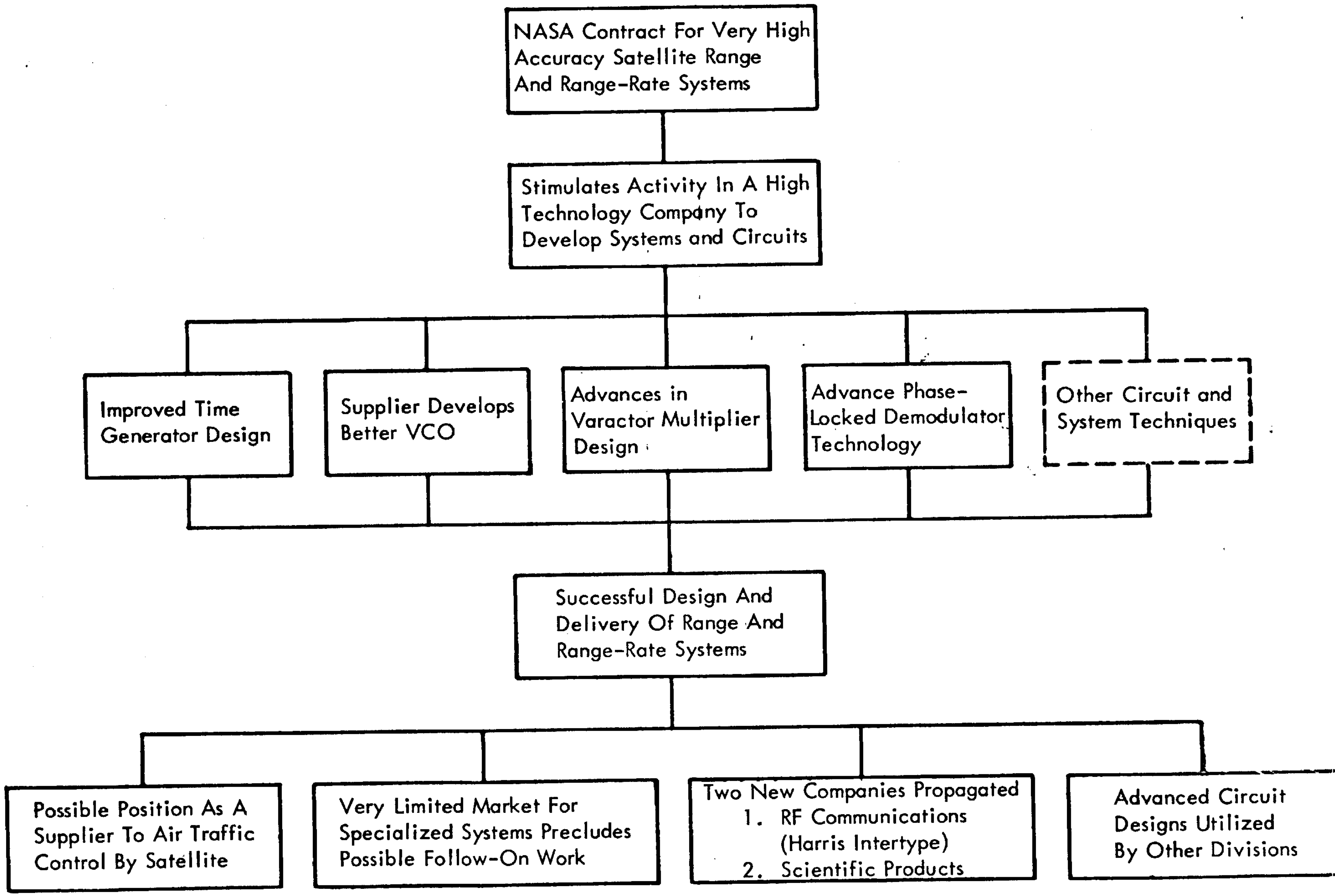


Figure 27 - General Dynamics

has been incorporated into a time generator produced by the company as a standard off-the-shelf item, Model No. 173. This time generator embodies frequency dividers and pulse handling circuitry originally designed for the range and range-rate system.

As a part of the ATS program, a subcontractor, Frequency Electronics of Astoria, New York, developed a high accuracy voltage controlled oscillator (VCO), that is also available for incorporation into other equipment. This VCO uses a 5 MHz oscillator to produce, through frequency dividers, signals at subharmonic rates. The device represents an order of magnitude improvement over previous VCOs and is used in the previously mentioned time generator.

The General Dynamics group working on the ATS program produced two spin-off companies utilizing the accumulated technology. The two firms are RF Communications of Rochester, New York, and Scientific Products. The former was subsequently acquired by Harris Intertype.

General Dynamics propagated technology from satellite R&D by two routes--hardware and trained personnel. Technology transfer by people transfer is an effective means of diffusion of innovation in a free, industrialized society. The transfer of labor, one of the components of the production function, occurred within the General Dynamics complex, as well as external to the organization. Any new, emerging technology depends on competent people, and the early adapters or innovators provide this labor force.

TRW Systems Group. TRW has completed a number of communications satellite projects. As shown in Figure 28, these ranged from the development of systems for use on the satellite ground stations to the satellite itself. TRW became involved with SYNCOM by producing range and range-rate systems and providing training for their operation. The firm was also active in the ATS program. Dampers for the gravity gradient system, valveless jets, star trackers, earth sensors, direct conversion transponders, accurate pointing systems for altitude control, and power conditioning systems are examples of TRW's efforts. The firm has also been active in SR&T (supporting research and technology).

TRW was the only firm besides Hughes selected by Comsat to supply commercial satellites. INTELSAT III was produced by TRW and represented a five times increase in circuit capacity over the older INTELSAT II. INTELSAT III also used the Sylvania mechanically despun antenna to increase the spacecraft's performance.

TRW has utilized technology from communications satellites in some rather unique ways. One example is an extension of early work in

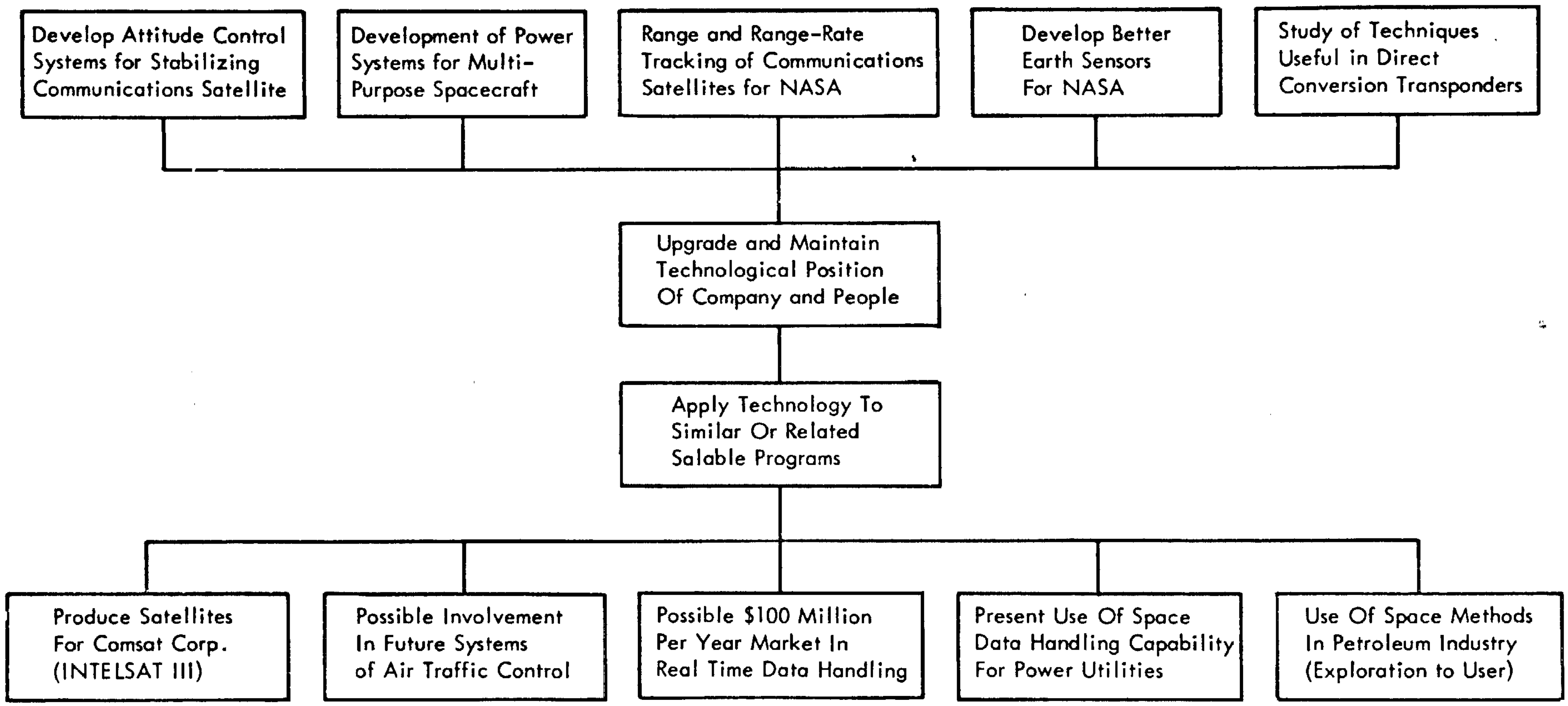


Figure 28 - Thompson Ramo Wooldridge Systems Group

range and range-rate. A scientist responsible for the program explained the subsequent application of the technology. The engineering personnel who developed and operated the range and range-rate networks for SYNCOM built an expertise in handling high speed data and control systems. They viewed the data quite independently from the signal source at the transmitting end of the system. They found that generally they were dealing with high-speed, real-time data acquisition, reduction, formatting, analysis, feedback and control.

Their skill in handling real-time data led the same group into areas of power distribution and load control for the electric power utilities. TRW Houston, the controls division, now has a contract with a utility to handle their complete demand schedule. TRW foresees a market in this area of $100 million per year over the next 5 years. Representatives of the company stated that the more standard analog systems of handling power utility data take too long to process and are not as adaptable to computerization. The digital methods from early satellite programs are readily adaptable to this problem, and former satellite programs people are performing the task.

Another TRW representative stated that well-logging, drilling, storing, transporting, and processing of petroleum products, from the well to the service station, all lend themselves to the methodology of data handling used with satellites. He believes the acquisition and processing of data in both fields contain so many parallels that it is no difficult matter to adapt knowledge from the NASA system to the fuel industry.

Another extension of satellite technology is in air traffic control. TRW is developing expertise in navigation and traffic control satellites, and range and range-rate technology provides impetus to this field. RCA has proposed that round-trip tone-ranging be used. TRW proposes a one-way link using tones from satellite pairs. The company, however, is flexible and will adapt to the system selected. All of the techniques are known to staff members who worked on satellite systems and the trade-offs between the two methods are well understood. TRW is awaiting the final legislative decision so it can apply retained technology to the production of systems. A staff member summed up the benefits from satellite range and range-rate systems: "If a satellite can be located within 1.5 meters when it is orbiting 22,300 miles from the earth, there is little problem in locating an aircraft to within 100 feet when it is traveling at hundreds of miles per hour."

The size and diversity of TRW make it possible to transfer technologies (and people) interdivisionally to take advantage of existing capabilities. There is an awareness of the advantages of technology utilization and a position has been established to implement the process.

Bendix - Communication Division. Bendix's contribution to the NASA communications satellite program was confined to supplying field engineering services and support for the ground stations. The principal products of this division are mobile radios and commercial aviation equipment. As a result of the disparity between the major thrust of the division and the services provided to NASA, there has been little direct traceable commercial follow-on. (See Figure 29.)

However, through involvement with aviation communications and exposure to satellite communications, the division did explore the potential of air traffic control and surveillance via satellite. In cooperation with the Air Transport Association, Bendix performed one of the early experiments in long distance aircraft communications by using a satellite link. The group produced a VHF, teletype, transmitter-receiver, which was installed on a Pan American craft for the initial experiment. Later, Boeing and TWA craft were also used. The transmissions were relayed through a SYNCOM channel made available by NASA. This demonstration proved that long-haul, continent-to-continent communications could be achieved at VHF frequencies. This represents a vast improvement over high frequency signals that depend on skip propagation for long-haul communications.

Another important aspect of this experiment lies in the fact that all commercial aircraft are currently equipped with VHF communications. Adaptation of existing equipment and methods to traffic control and navigation would minimize the conversion costs. The alternate is to use L-band frequencies championed by the European nations which would require extensive conversions and new equipment.

Diffusion of satellite technology at Bendix was not directly traceable to the division's work for NASA. Instead, it resulted from the furnishing of a test bed (SYNCOM) used to explore the feasibility of applying satellites to air safety. NASA, through ATS, is exploring more comprehensive means toward this end. These efforts will result in air traffic control via satellite and new markets will be opened to Bendix and others producing aircraft communications and navigation equipment.

Ampex Corporation. Some firms supplying equipment or technology to the communications satellite programs acquired residual benefits in areas other than the direct aftermarket. One of these, Ampex, with a consumer and commercial oriented marketing philosophy, is a technology-conscious company that turns approximately 10 percent of sales back into R&D programs. Yet, historically the company shuns high risk, fixed price contracts. Ampex is credited internationally with the development of practical video tape recording and has advanced the state of the art in all areas of magnetic recording.

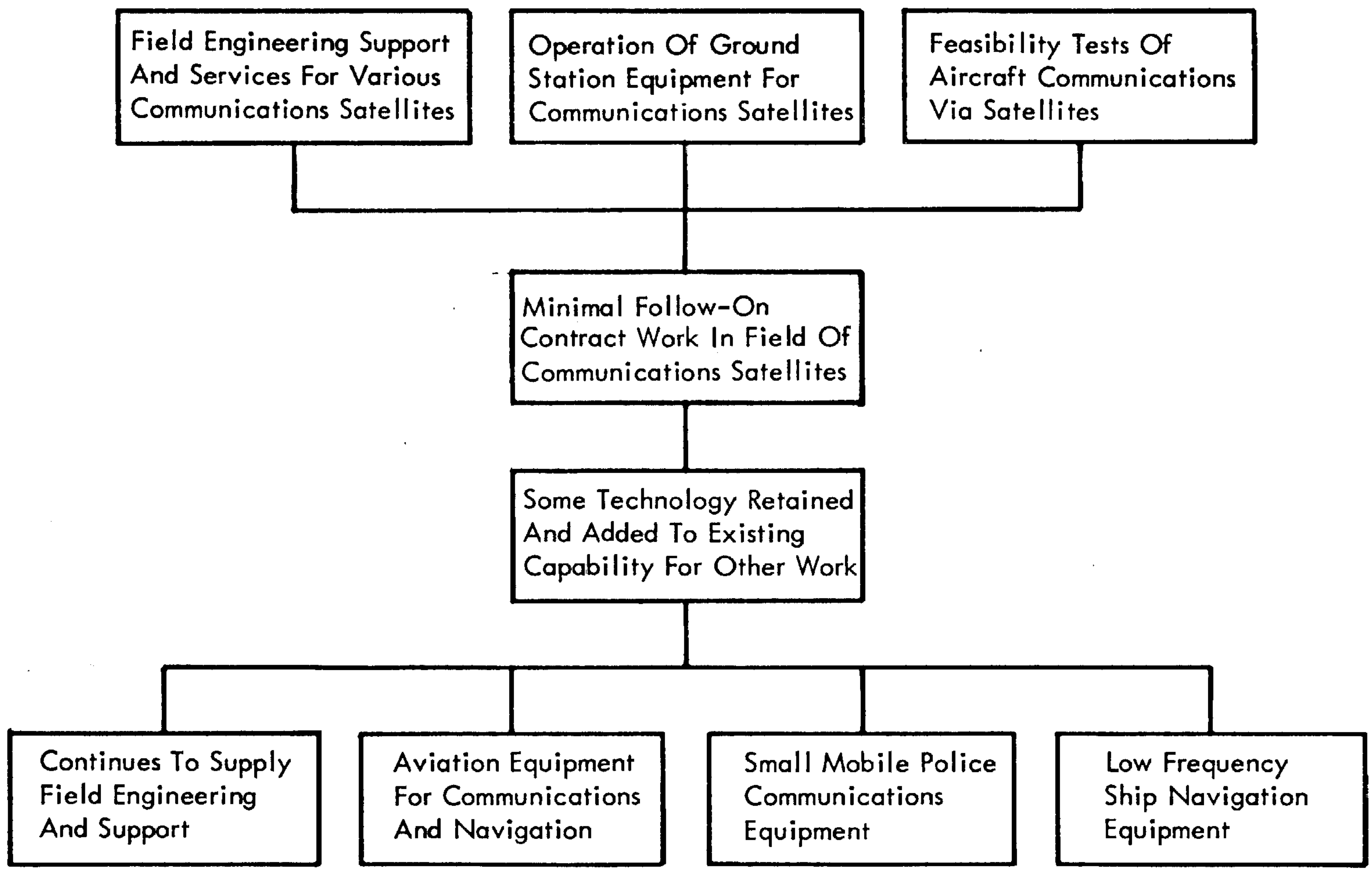


Figure 29 - Bendix Communications Division

Ampex became involved in communications satellites in 1964 when it produced 47 instrumentation tape recorders of the seven track, 1/2 inch tape variety for the ATS program. Ampex had never filled so large an order to such rigid requirements. The company was faced with a number of challenges: high operational standards, interchangeability of all components, complete and explicit documentation, large quantity, serviceability, and a tight delivery schedule. The recorders were to be about 95 percent off the shelf with a few modifications for compatibility with other control configurations. At the time Ampex bid on this work, a standard unit of similar capabilities sold for about $65,000.

In 1964, this order was of sufficient size to attract the attention of Ampex management. There was some concern that Ampex would not be able to meet all the requirements with the operating procedures that existed within the company at that time.

Figure 30 indicates how Ampex coped with the requirements of the order. After high management visibility was obtained, the decision was made to improve the overall capability of the instrumentation recorder group. The major areas needing improvement were scrutinized and a goal-oriented problem-solution approach compatible with commercial marketing was begun. The following received particular attention.

Engineering awareness of schedules had been a problem within Ampex. Traditionally, engineers have considered themselves an integral portion of the scientific community, and as such have encountered the classical conflict between creativity and fixed deadlines of production schedules. Ampex management instituted a successful program stressing the importance of maintaining rigid schedules which included frequent reviews.

Automated tooling was not used by the company at the time of the contract. Recorders were frequently manufactured on a one or two basis and metal frame castings were drilled or machined on separate, individual setups. While this worked well on small lots, it was not economically optimum for quantity production. Automated tooling was introduced in the instrumentation division. The results were increased tolerance control, reduced manufacturing costs and interchangeability of components.

Production scheduling was also introduced. Various portions of the recorder were broken out and times were assigned to their production. Logical sequences were set up and working back from the deadline, a program plan was formulated.

Improved financial control was used to record and regulate program costs. Both labor and materials were included in the planning.

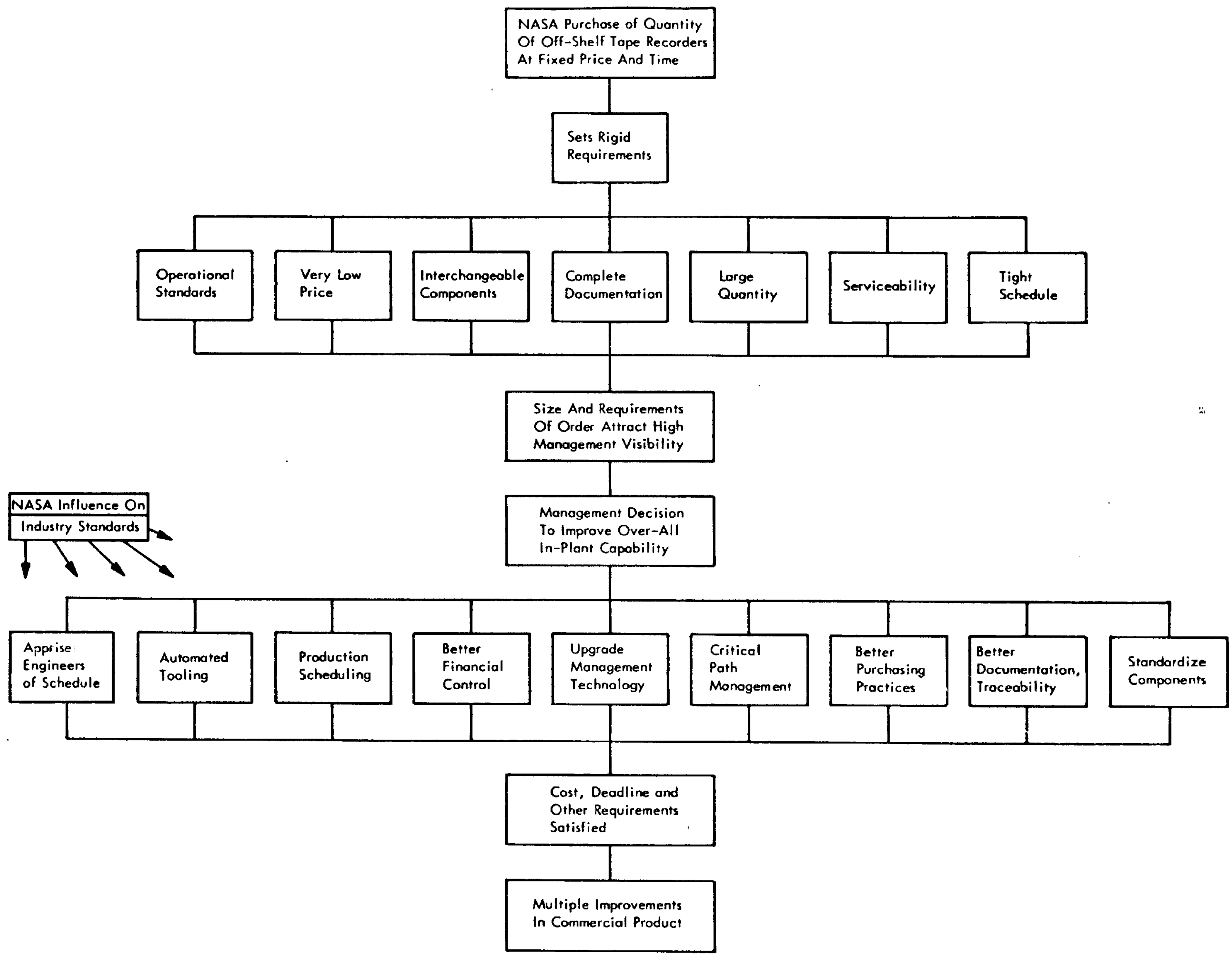


Figure 30 - Ampex

Better purchasing practices were instigated. The use of technically trained and experienced purchasing agents was stressed.

Better documentation and traceability were NASA requirements that exceeded those previously encountered in dealing with commercial customers. After developing the capabilities on this program, the firm found it advantageous to continue with the effort. Minor engineering changes without a valid reason are now subject to scrutiny and approval.

Standardized components were required by NASA. Standardization was implemented by almost all of the previously discussed areas.

An immediate and direct result of this effort was the delivery of the units on time at a cost of $26,590 each--less than half the previous unit costs. Secondary results of the effort were, according to Robert Owen, the Vice President of Instrumentation, a multiplicity of improvements in their commercial instrumentation tape recorders. These improvements ranged from better products to price reductions, that in turn allowed expansion of the market to the point where the advantages of the mass production techniques could be fully realized.

Owen of Ampex indicates that while many firms receiving contracts from NASA to work on communications satellites directly influenced the national economy in a positive manner via inherited technological capabilities, a more subtle and--to his mind--influential fallout of this work is found in improved management techniques. The difficulty of quantifying the economic impact of better management technology is apparent. But, as the Ampex example indicates, it can be profound.

The positive stimulus of various space oriented programs to corporation management should not be underrated. Space work, by its very nature, precipitates two inherent requirements that challenge the older paradigms of business and science. A degree of reliability is required that supersedes any prior standards. The costs of a failure are high, and each supplier must initiate systems of control and test exceeding past capabilities. Also, optimal chronological periods for space shots place inflexible deadlines on the system. To maintain a workable sequential calendar of achievements, scheduling in research, development, purchasing, production, test and delivery must be carried out with no failures. Having coped with such requirements, the skills obtained are retained and applied to subsequent company endeavors.

Owen also noted that better operational practices introduced to Ampex during 1964 as a result of the communications satellite effort are being used within the company today. They are presently supplying 30 recorders at a total cost of $600,000 and the same organized management technology approach acquired as a result of their past NASA work is being applied to this order.

The interview with Ampex disclosed other effects induced by the space program on the company and the tape recorder industry in general. One effect is traceable to the significant expansion of the then-existing market for instrumentation recorders. The volume of information transmitted to and from satellites during short periods of time required greatly increased packing densities or cycles of information per-inch-per-second by the tape head. Today, packing densities are 28 kilobits-per-inch-per-track. This is a one-hundredfold increase over the densities of 220 bits-per-inch-per-track which were common when the discussed contract was let. Ampex is also now supplying recorders at a price of $28,000 which would have cost $60,000 in 1964. Thus, NASA has stimulated the instrumentation recording field in a manner similar to commercial broadcasting's stimulus to the video recording field.

Another industry-wide effect concerns the development of standards for instrumentation recorders. The establishment of standards is a necessary precondition for a large-scale development in any industry. NASA in particular played a large role in accumulating data and influencing the decision to set specifications or standards for the tape recording industry. Such specifications as a commonality of reference frequency, and criteria for flutter and wow are an outgrowth of this collection of technical information. Owen cited this as "a great contribution of NASA technology and influence." He further noted that he believed few purchasers of instrumentation tape recorders realize the service the space agency performed toward the establishment of standards.

Satellite Positioning Corporation. Satellite Positioning Corporation integrates sytems for obtaining position fixes by utilizing rather standard items furnished by other companies. This package is then sold to the user. A force of field engineers is maintained to install the systems, field check them, and provide any needed follow-up services.

The positioning equipment marketed by this company utilizes five Navy satellites in polar orbit to provide the necessary fix information. These satellites receive their original position information from Navy range and range-rate stations in Minnesota, Point Mugu, and other locations. The Navy broadcasts positioning information to the transponders in the satellites and this is relayed to the transportable stations on the ground or in the ships. The satellites broadcast information on their position at 2-minute intervals.

The Satellite Positioning Corporation system uses rather standard sonar doppler techniques to perform the initial position calculation. Information from the satellites is then used as a check as the ship becomes more isolated from the known point of embarkation. The satellite essentially resets the system with each reading by the receiver. One observation of one pass of the satellite will give a radial position fix to within about 300 feet. Each subsequent pass increases the accuracy by one divided by the square root of the number of observations. The system is useful for determining the position of a ship or offshore drilling station.

An integrated marine system from Satellite Positioning Corporation sells for $300,000 while a portable system costs about $100,000. To appreciate the worth of such a system, it should be understood that a geophysical exploration ship costs about $10,000 a day to operate. The time required to make a position fix is lowered to 1 hour, where 5 to 7 days were required. Similar reductions can also be achieved with rig tenders which cost about $15,000 a day to operate.

Engineers at Satellite Positioning Corporation could lower the cost of their system about one-half if three fixed synchronous satellites with power sufficient for simple ground receivers and antennas were orbited. The reliability of their system could also be increased.

Another argument was presented by this company on the behalf of high-power navigation satellites. As the need for more oil field development arises, the United States will have to more fully explore offshore drilling for supplying domestic markets. The positioning of drilling platforms by satellite would lower the total cost of such ventures.

As the marine traffic problem becomes more serious, the need for improved navigation aids also will become pronounced. The use of larger oil tankers carrying loads at higher docking speeds with increased ecological consequences resulting from collision is another factor in this problem. Such systems also could overcome the difficulties in docking a ship in a port such as New Orleans, especially during bad weather or at night. Their usefulness to fishing ships in locating schools and on obtaining accurate positioning information on other ships in the fleet represent further benefits of such a system.

While the positioning system presently assembled by this firm does not use NASA satellites for obtaining the fixes, it is representative of a benefit resulting from the existing technology. More important, this case study indicates how a private business can adapt technology developed for other uses and how the public can eventually benefit from this same technology.

Wavecom Industries. Wavecom is a spinoff from the Rantec Division of Emerson Electric discussed earlier. The company was started in 1967 with almost the same product line that Rantec was producing as a result of space work. The firm is basically owned by the employees. A special product development and research group of Wavecom is in operation in the northern part of California at Sunnyvale.

The facility at Northridge, California, is involved in manufacturing passive microwave devices; however, the research organization has developed active filters working at S-band that utilize technology uncommon to this field. These low insertion loss filters could be used as the input tuned circuit in microwave receivers. Both Wright-Patterson and Comsat have expressed interest in these components.

Wavecom utilizes existing technology, some of which has migrated from projects at Rantec, to produce microwave components for such customers as Varian, Litton, Microwave Electronics Corporation, Westinghouse, Hewlett-Packard, ITT, Intelsat, Comsat, RCA, Philco-Ford Western Defense Laboratories, General Electric, Lockheed and Martin. About 75 percent of these products eventually are used in satellites and 25 percent go into ground stations.

The Stimulus of a New Technology

The effects of a new or emerging technology upon the firms directly involved in the process have been pronounced and positive. The companies that performed the technical work in developing or experimenting with NASA communications satellite systems were affected in a variety of ways. The most significant finding is simply that every firm interviewed indicated some residual economic stimulus.

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

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

Direct commercialization. The majority of firms studied utilized the knowledge, expertise, and product capabilities that were augmented through NASA satellite work to establish or to strengthen their position in supplying 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.

Transfer to non-space, non-satellite markets. Other firms utilized new knowledge, experience, and heightened perception of non-space markets. New ventures, new services, non-governmental markets needing similar skills, and what has traditionally been called "spin-off" was found in this category of 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 firm 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 in Figure 31.

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 of abandoning old ways and adopting new ways of performing the firm's economic function--obsolescence and sunk-costs.

Recent studies of innovation have indicated 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.

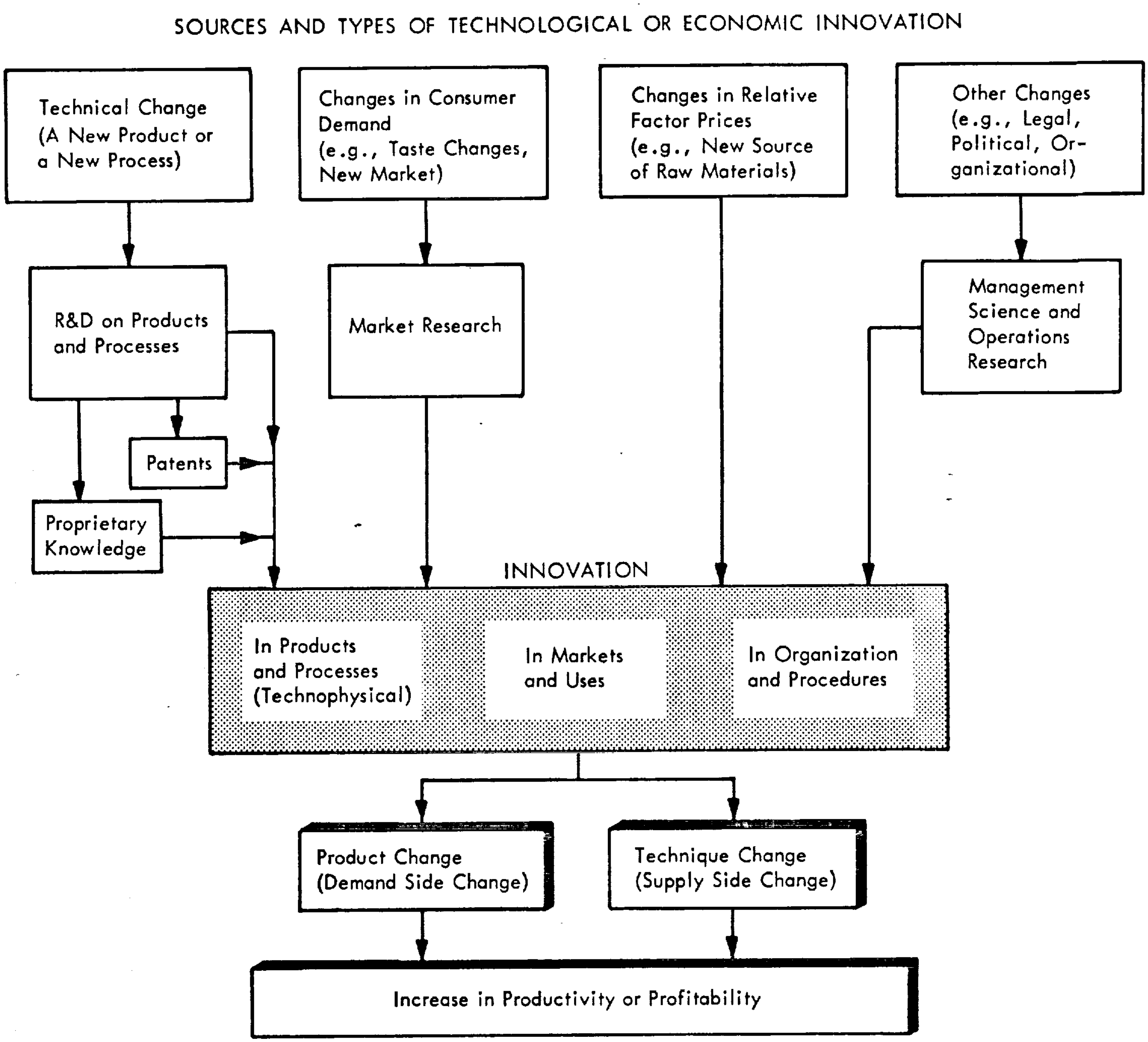

SOURCES AND TYPES OF TECHNOLOGICAL OR ECONOMIC INNOVATION
Technical Change (A New Product or a New Process)
Changes in Consumer Demand (e.g., Taste Changes, New Market)
Changes in Relative Factor Prices (e.g., New Source of Raw Materials)
Other Changes (e.g., Legal, Political, Organizational)
R&D on Products and Processes
Market Research
Management Science and Operations Research
Patents
Proprietary Knowledge
INNOVATION
In Products and Processes (Technophysical)
In Markets and Uses
In Organization and Procedures
Product Change (Demand Side Change)
Technique Change (Supply Side Change)
Increase in Productivity or Profitability

Figure 31

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. So we say. So too, said NASA's industrial contractors.

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 31. 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.

New Technology Dissemination

In addition to the previously discussed ways by which technical advances affect subsequent work, and thereby contribute to progress, the NASA Technology Utilization program provides a specialized channel for accelerating the transfer of innovation.

New technology created in support of mission requirements has many avenues of use and distribution. Among the myriad "better-ways" that evolve in performing work at the leading edge of technology, only a few advances are perceived as singularly important--and, therefore, worth explicit description. Some innovations are proprietary and protectable. The majority of significant advances achieved in performance of R&D are described in the technical literature. Those who wish to take advantage of reported advances may do so.

NASA contracts incorporate a special provision requiring the identification and reporting of new technology. After screening the items reported, advances are recorded in various ways--"Tech Briefs," compilations or surveys and monographs. "Tech Briefs" are brief (usually one page) descriptions of the problem, the improved solution, the advantages provided by the innovation, and where to obtain additional information about the idea.

The contractor organizations interviewed regarding synchronous communications projects have identified and reported to NASA a total of 551 technical advances. These innovations, called Reportable Items of New Technology, identified over the period studied are summarized in Table 8.

This form of technology dissemination involves recognition of advances, description of the innovation in ways that will facilitate acceptance, and special channels of announcement followed by distribution of information to potential users. Thus, the reporting and dissemination of new technology is one further means of augmenting the natural process by which useful advances are diffused, adopted and used by others.

TABLE 8

NEW TECHNOLOGY REPORTING ACTIVITY SUMMARY
(1963-1969)

Contractor	Items Reported	Items Evaluated Not Published	Tech. Briefs Published
Ampex	9	5	1
Bendix (Aerospace Systems)	84	35	2
Electronic Communications	4	3	1
General Dynamics (Electronics Division)	19	13	2
General Electric (Valley Forge Space Tech. Center)	11	9	-
Hughes Aircraft (Aerospace Group, Space Systems)	55	18	9
IT&T (Federal Labs)	16	9	-
Martin Marietta (Orlando)	12	5	3
Rantec	-	-	-
Sylvania (Electronic System)	27	5	10
TRW (Systems Group)	241	83	16
Watkins-Johnson	2	1	1
Westinghouse (Aerospace Div.)	71	26	13
Wiltron	-	-	-
Total	551	222	58

Source: National Aeronautics and Space Administration, NT Prime Contract Activity Summary, Format NTP 13, as of 31 May 1970. Prepared by: Management Systems Division, Office of Technology Utilization, Washington, D.C.

APPENDIX A

METHODOLOGY - COMMUNICATIONS SATELLITE CASE STUDY

With one exception, the conduct of the case study posed no methodological problems. Standard literature searches and interviews with knowledgeable professionals are the mainstay of any case study; this was no exception. However, we were concerned that the companies selected for study would be representative of the universe of participants in the NASA, SYNCOM, and ATS programs. Accordingly, an elaborate and lengthy screening process of all prime contractors participating in the programs was applied.

Departure point for the screening process was the decision to select synchronous communications satellites for case study. This aspect of the overall NASA program was selected for the case study because: (1) it is representative of the way in which technological advance and application is stimulated by space missions, (2) it has already achieved direct commercial application, and (3) it did draw upon the technical skills of a number of contractors who should have applied these skills to other problems. Thus, the selected area of investigation had the potential for illustrating the full range of the types of applications and the paths--direct and indirect--followed to commercial application that is characteristic of mission-oriented research and development.

The screening process began with all contractors who have participated in the SYNCOM, ADVANCED SYNCOM, or Applications Technology Satellite programs. Specifically, the SCAG System (Status of Contracts and Grants) was queried for all contracts classified under the Unique Project Numbers (UPN's) associated with the above three programs. The search produced a total of 244 prime contracts:

UPN	Program	Number of Prime Contracts
627	SYNCOM	30
629	ADVANCED SYNCOM	2
630	ATS	212

The ATS program includes a number of aspects not directly related to communications; i.e., navigation, meteorology, geodesy, etc.; therefore all contracts "identifiable" as noncommunications were eliminated from further consideration. This screening was made based upon the brief contract descriptions contained in the SCAG print-out plus report abstracts obtained from STAR. Thirty-nine contracts were eliminated by this procedure.

Routine service and technical support contracts were next eliminated. These included contracts for maintenance, blueprints, photography, engineering support services and the like. Eighty-three contracts were dropped in this step. Once again, the SCAG and STAR descriptions were the basis for the screening.

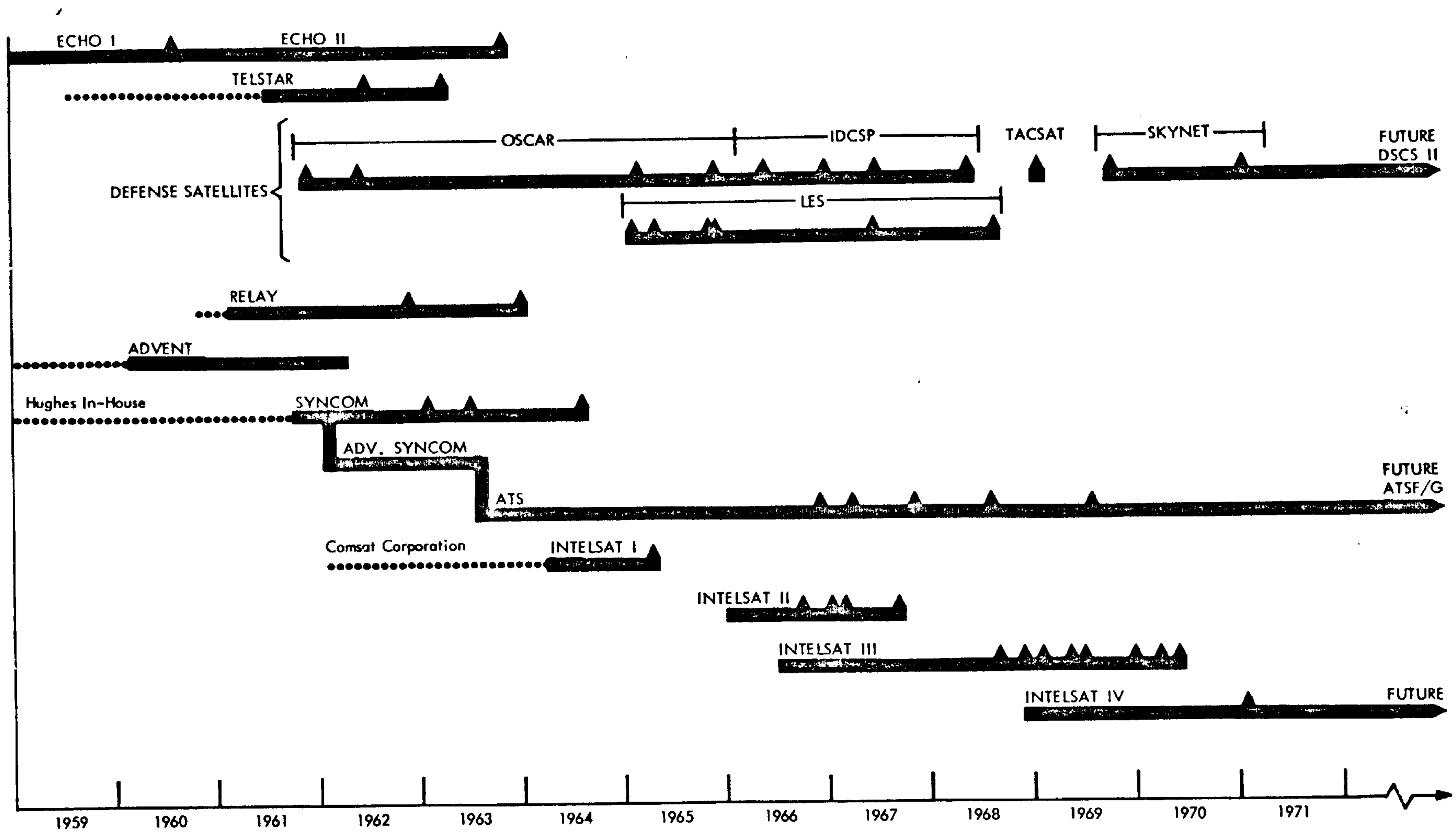
The fourth screening was based on a comparison of the portion of total contract value which was assigned by NASA to the three UPN's 627, 629, and 630. Many of the contracts seemed to be "blanket" contracts of which only a fraction was directly related to synchronous communications satellites. All contracts which had less than 10 percent of their effort in the three UPN's were discarded. Forty-six contracts were so eliminated.

At the completion of the fourth screening a total of 76 prime contracts were still under consideration. The information available from SCAG and STAR was not sufficiently precise to justify further deletions from the list. An intensive effort to obtain more complete descriptions was undertaken. This effort had a twofold purpose: (1) to permit further screening and (2) to provide guidance for our interviewers in preparation for the visits to the contractors ultimately selected for case study. All NASA sources which might shed any additional light were approached including: Research and Technology Resumes (NASA Form 1122), contracting officers, knowledgeable NASA program officers, Program Planning Documents, etc. In spite of very active cooperation by all NASA people contacted, the capability of the information systems to produce the desired information was spotty. However, we were able to screen out an additional 22 contracts using the same criteria that had been applied before.

At this point in the screening process 54 prime contracts performed by 27 companies remained under consideration.

This list was further reduced by 13 companies as the interview phase was carried out. In some cases the persons involved in the NASA contract work on communications satellites were no longer with the company or that particular division of the firm had been disbanded, dispersed or absorbed by other groups. After preliminary contact with some of the firms, it was ascertained that their involvement was not oriented in a direction suitable for our interrogation. Only one company declined to participate in the study.

Two companies which did not perform work on the NASA synchronous communications satellite programs were added during the course of the project. Both firms were spin-offs from companies which had participated in the programs, and were contacted to insure representation of the spin-off mode in the study. Thus, the final sample was composed of 16 companies.



Appendix B1 - Milestones in Communications Satellite Technology

U.S. APPLICATIONS SATELLITES 1958-1970
(Communications)

Date	Name	Remarks
18 December 1958	SCORE	First Comsat, carried taped messages.
12 August 1960	ECHO I	One-hundred foot balloon served as first passive Comsat, relayed voice and TV signals.
4 October 1960	COURIER IB	First active-repeater Comsat.
30 March 1961	LOFTI I	Low-frequency experiment; failed to separate from rest of payload.
21 October 1961	WESTFORD I	First attempt to establish filament belt around earth; failed to disperse as planned.
12 December 1961	OSCAR I	First amateur radio "ham" satellite.
2 June 1962	OSCAR II	
10 July 1962	TELSTAR I	Industry-furnished spacecraft in near-earth orbit.
13 December 1962	RELAY I	Active-repeater Comsat.
14 February 1963	SYNCOM I	Successfully injected into near-synchronous orbit but communication system failed at orbital injection.
7 May 1963	TELSTAR II	
9 May 1963	WESTFORD II	Filaments formed reflective belt around earth as planned for emergency communications experiment.
26 July 1963	SYNCOM II	First successful synchronous orbit active-repeater Comsat. After experimental phase, used operationally by DoD.
21 January 1964	RELAY II	
25 January 1964	ECHO II	One-hundred thirty-five foot balloon, passive Comsat, first joint use by United States and U.S.S.R.
19 August 1964	SYNCOM III	Synchronous-orbit Comsat; after experimental phase, used operationally by DoD.
11 February 1965	LES I	Experimental payload did not reach intended apogee.
9 March 1965	OSCAR III	
6 April 1965	INTELSAT I (Early Bird)	First Intelsat (Comsat Corporation) spacecraft, 240 two-way voice circuits; commercial trans-Atlantic communication service initiated 28 June 1965.
6 May 1965	LES II	All solid state advanced experiment.
21 December 1965	LES III	All solid state, UHF signal generator.
	LES IV	All solid state SHF or X band experiment.
	OSCAR IV	
16 June 1966	IDCSP 1-7	Initial defense communication satellites program (IDCSP)-active-repeater spacecraft in near-synchronous orbit, random spaced.
26 October 1966	INTELSAT II-F1	First in INTELSAT II series spacecraft; 240 two-way voice circuits or one color TV channel. Orbit achieved not adequate for commercial operation.
3 November 1966	OV 4-1T, OV 4-1R	Transmitter and receiver for low-power satellite-to-satellite F layer experiments.
7 December 1966	ATS-I	Multipurpose, including VHF exchange of signals with aircraft.
11 January 1967	INTELSAT II-F2	Trans-Pacific commercial communication service initiated 11 January 1967.
18 January 1967	IDCSP 8-15	
22 March 1967	INTELSAT II-F3	Positioned to carry trans-Atlantic commercial communication traffic.
6 April 1967	ATS-II	Multipurpose, but did not attain planned orbit.
1 July 1967	IDCSP 16-18	
	LES V	Tactical military communications tests with aircraft, ships, and mobile land stations from near synchronous orbit.
	DATS	Electronically despun antenna experiment.
	DODGE	Multipurpose, gravity stabilized.
27 September 1967	INTELSAT II-F4	Positioned to carry commercial trans-Pacific communication traffic.
5 November 1967	ATS-III	Multipurpose including communications.
13 June 1968	IDCSP 19-26	
10 August 1968	ATS-IV	Multipurpose; failed to separate from Centaur, did not reach planned orbit.
26 September 1968	LES 6	Continued military tactical communications experiments.
18 December 1968	INTELSAT III (F-2)	First in INTELSAT III series of spacecraft, 1,200 two-way voice circuits or four color TV channels. Positioned over Atlantic to carry traffic between North America, South America, Africa, and Europe. Entered commercial service on 24 December 1968.
6 February 1969	INTELSAT III (F-3)	Stationed over Pacific to carry commercial traffic between the United States, Far East, and Australia.
9 February 1969	TACSAT I	Demonstrated feasibility of using a spaceborne repeater to satisfy selected communications needs of DoD mobile forces.
22 May 1969	INTELSAT III (F-4)	Stationed over Pacific to replace F-3 which was moved westward to the Indian Ocean. Completes global coverage.
26 July 1969	INTELSAT III (F-5)	Spacecraft failed to achieve the proper orbit. Not usable.
12 August 1969	ATS-V	Multipurpose; for millimeter and L band communications; entered flat spin.
22 November 1969	SKYNET I (IDCSP-A)	Launched for the United Kingdom in response to an agreement to augment the IDCSP program.
15 January 1970	INTELSAT III (F-6)	Stationed over Atlantic to carry commercial traffic between the United States, Europe, Latin America, and the Middle East.
23 January 1970	OSCAR V (Australis)	Ham radio satellite built by amateur radio operators at Melbourne University, Melbourne, Australia.
20 March 1970	NATOSAT-I (NATO-A)	First NATO satellite, stationed over Atlantic to carry military traffic between the United States and other NATO countries.
23 April 1970	INTELSAT III (F-7)	Stationed over Atlantic to carry commercial traffic between the United States, Europe, North Africa, and the Middle East.
23 July 1970	INTELSAT III (F-8)	Spacecraft failed to achieve the proper orbit. Not usable. Last launch of INTELSAT III series.
22 August 1970	SKYNET II (IDCSP-B)	Launched for the United Kingdom in response to an agreement to augment the IDCSP program. Spacecraft failed to achieve the proper orbit.