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SATELLITE COMMUNICATIONS:
Six Years of Achievement
1958 through 1964

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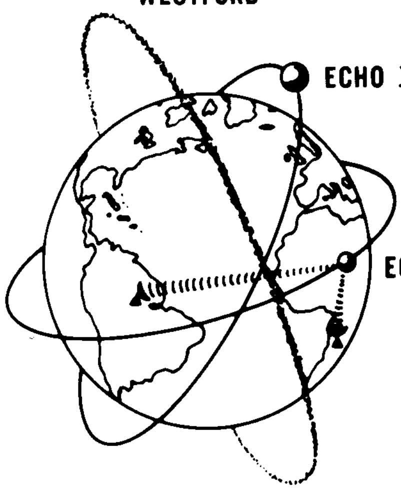
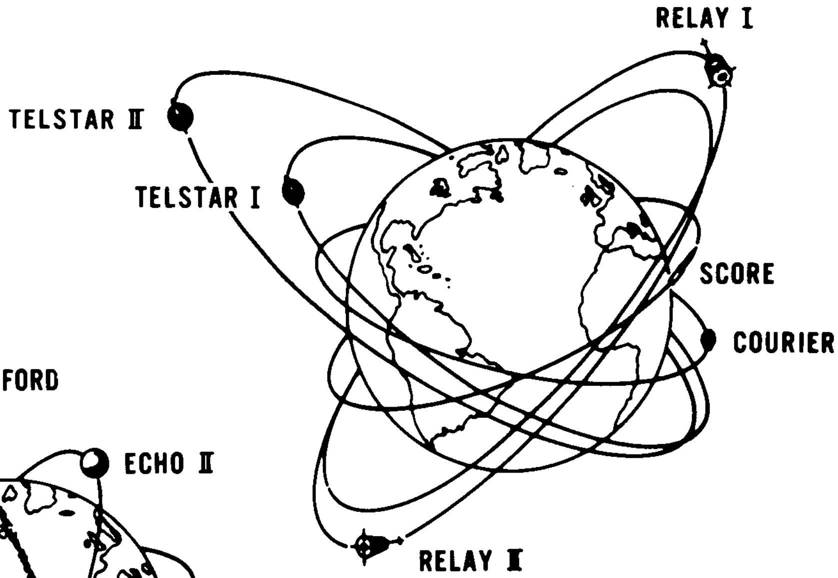
COMMUNICATION SATELLITES



PASSIVE

- LONG-LIFE
- MULTIPLE ACCESS

- LARGE ANTENNAS
- LARGE TRANSMITTERS
- LOW ALTITUDES
- LARGE NUMBERS
- CAPACITY LOW



ACTIVE (LOW & MED. ALTITUDES)

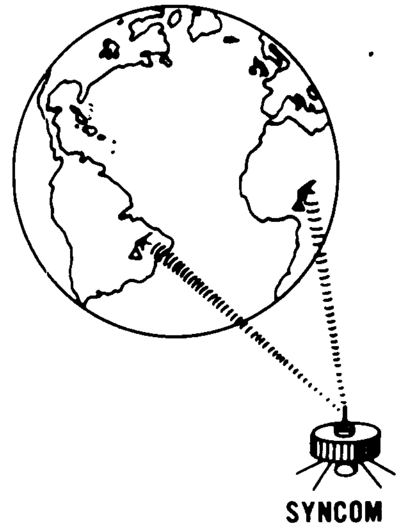
- SIMPLEST ACTIVE
- CAPACITY HIGH

- GROUND STATION COMPLEXITY
- LARGE NUMBERS (MULTIPLE LAUNCH)
- TRAFFIC MANAGEMENT COMPLEX

ACTIVE (SYNCHRONOUS)

- SMALL NUMBERS
- SIMPLE GROUND STATIONS
- CAPACITY HIGH
- TRAFFIC MANAGEMENT SIMPLER

- COMPLEX SPACECRAFT
- STATION KEEPING
- COMPLEX LAUNCH



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SIGNIFICANT ACHIEVEMENTS DURING SIX YEARS OF SPACE RESEARCH AND APPLICATIONS IN COMMUNICATIONS SATELLITES

I

Abstract

It was recognized, as early as 1945, that the world's expanding need for more channels of long distance communications could be alleviated by the communications satellite, provided the requisite technology was made available to the designers of operational systems. This became the aim of a NASA program which, from a modest start in 1959, had achieved significant technological gains by 1964.

Early efforts in the United States were those by the Services of the Department of Defense and consisted of Moon Relay, Score, Courier, and, later, West Ford. NASA's experimental activity in communications satellites began with Echo I in 1960. Notable technological progress was made between July 1962 and August 1964 as the result of experience gained from six successful, and two partially successful, launches of a spectrum of satellite types, altitudes, and orbits:

Telstar I and II
Relay I and II
Syncom I, II and III
Echo II

This effort culminated in the achievement of geostationary orbit by Syncom III in late summer, 1964. Chart SD64-1156 summarizes these satellites and their characteristics.

The objectives of this experimental satellite program were directed toward developing reliable active and passive satellites, both narrow and wideband in communications capacity, and demonstrating their feasibility in the low, elliptical medium altitude, inclined synchronous and geostationary orbits. Ground station experience confirmed the validity of critical design equations, explored alternate methods of satellite acquisition and tracking, and demonstrated experimentally the utility of the communications satellite and its potential in future communications systems.

Much of the technology necessary to the establishment of early international operational systems was thus made available to countries whose desire it would be, using the words of the President of the United States, to "grasp the advantages presented to us by the communications satellites ... to insure greater understanding among the peoples of the world." NASA will, however, continue to search for breakthroughs and to expand the state of the art in communications satellites.

II

PREFACE

Albert Camus, whose life spans The Great War to the Space Age writes: "Great ideas --- come into the world as gently as doves. If we listen attentively we shall hear in this faint flutter of wings a gentle stirring of life and hope that is awakened, revived, and nourished by millions of solitary individuals whose deeds and works every day negate frontiers and the crudest implications of history".

The communications satellite was, in the realm of technology, such an idea, and entered "on the wings of a dove" in 1945. During the years through 1964 the idea was translated into experimental reality by countless individuals members of the international technical community: scientific and engineering. It is in recognition of their efforts that this paper is published, at a time marking the end of the first generation NASA program to achieve that reality, and at the commencement of the period marking initial operational communications satellite systems.

The need for the communications satellite developed as a result of increasing world requirements for long distance real-time communications. Many ways of achieving a satisfactory technical solution to this need had been exploited by 1957, but all represented compromise of some form, and most were limited by their very terrestrial nature.

What was needed was a very high altitude relay station, higher than could be supported by any practical structure.

Arthur C. Clarke proposed the solution in 1945, a relay station in orbit as an Earth satellite.

Now the Moon is a natural Earth satellite, capable of passively reflecting signals over the Earth's curvature; in fact, the U.S. Navy "CMR" system operationally demonstrated Moon relay. But by 1960 it had also demonstrated that the Moon, although an extremely high altitude natural Earth satellite, had some limitations as a communications relay facility. The need, therefore, to develop and prove the feasibility of artificial Earth satellites, at altitudes optimum for their missions, became increasingly urgent.

Such satellites could be either of two types, passive or active. The passive satellite acts like a mirror, as did the Moon, retransmitting no more than that energy it intercepts. The active satellite on the other hand, receives and amplifies a signal before retransmitting it to the ground.

This report briefly reccounts the significant achievements in early experimental communications satellites, during the years 1958 through 1964. A selected bibliography has been included, and highlights of these achievements are summarized below.

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These efforts consisted of the following projects:

From 1954 to 1959 the Navy translated the Army's achievement (Project Diana, radar contact with the Moon, a form of passive reflection) into what has been called "the world's first operational Space Communications System": Communication by Moon Relay, or "CMR".

Score, built by the Army and launched by the Air Force on December 18, 1958, became the world's first artificial active communications satellite experiment.

In October, 1960, the Army Signal Corps' Courier I-B demonstrated the possibility of using active repeaters for both real-time and delayed transmission of high data rate messages.

In the early summer of 1963 the U.S. Air Force launched West Ford, a passive satellite system, a belt of orbiting reflective needles. It was demonstrated that this method of dispensing a belt of millions of tiny fine wires was workable and that predictions on non-interference with radio astronomy were valid.

NASA's experimental communications satellite program began in 1959.

Echo I, a passive reflector balloon, was launched August 12, 1960. This satellite has been called one of the best ambassadors the United States ever had inasmuch as it has been clearly visible to millions of people throughout the world.

Between July 1962 and August 1964 NASA's program resulted in the successful launches of two AT&T Telstars (Jul 10, 1962 and May 7, 1963), two Relays (December 13, 1962 and January 21, 1964), another Echo (January 25, 1964), and three Syncoms (February 14, 1963, July 26, 1963, and August 19, 1964).

Ground diagnosis of a malfunctioning communications satellite was successfully attempted for the first time when Telstar I was commanded on again January 4, 1963.

Relay I provided the first satellite communications link between North and South America. With a history of 81 TV demonstrations, Relay I has operated through twice its designed lifetime.

Syncom II, also operating beyond its designed life, has made outstanding contributions to our knowledge of gravitational anomalies. Syncom II has recorded more satellite communications "ON" time, 4800 hours of experiments and tests, than all other communications satellites combined.

Relay II, though only a year old, has successfully conducted 27 TV demonstrations.

Syncom III was the first satellite to be successfully boosted, attitude controlled, injected and maneuvered into a pre-selected station in geostationary orbit, requiring most precise control to accomplish.

Syncom III demonstrations have shown the feasibility and value of a communications satellite in geostationary orbit to provide multichannel voice communications, multichannel teletype, and TV, with and without simultaneous voice.

Syncom III successfully relayed the Olympics from Japan to the United States in October, 1964.

The first phase of cooperative US-USSR experiments in communications satellites was executed in 1964 using Echo II.

Of the nine orbital communications satellite flights attempted by NASA since 1960, only one passive satellite, Echo A-10 failed to achieve orbit, and only one active satellite, Syncom I, has failed to provide the relay capability for which it was designed. There have been, at times, several active repeater spacecraft in operation at one time (Chart ST65-3595-9.64) and Echo I has been available continuously, although gently degrading, since August, 1960.

Ground station experience has confirmed the validity of critical design equations, explored alternate methods of satellite acquisition and tracking, and demonstrated experimentally the utility of the communications satellite and its potential in future communications systems.

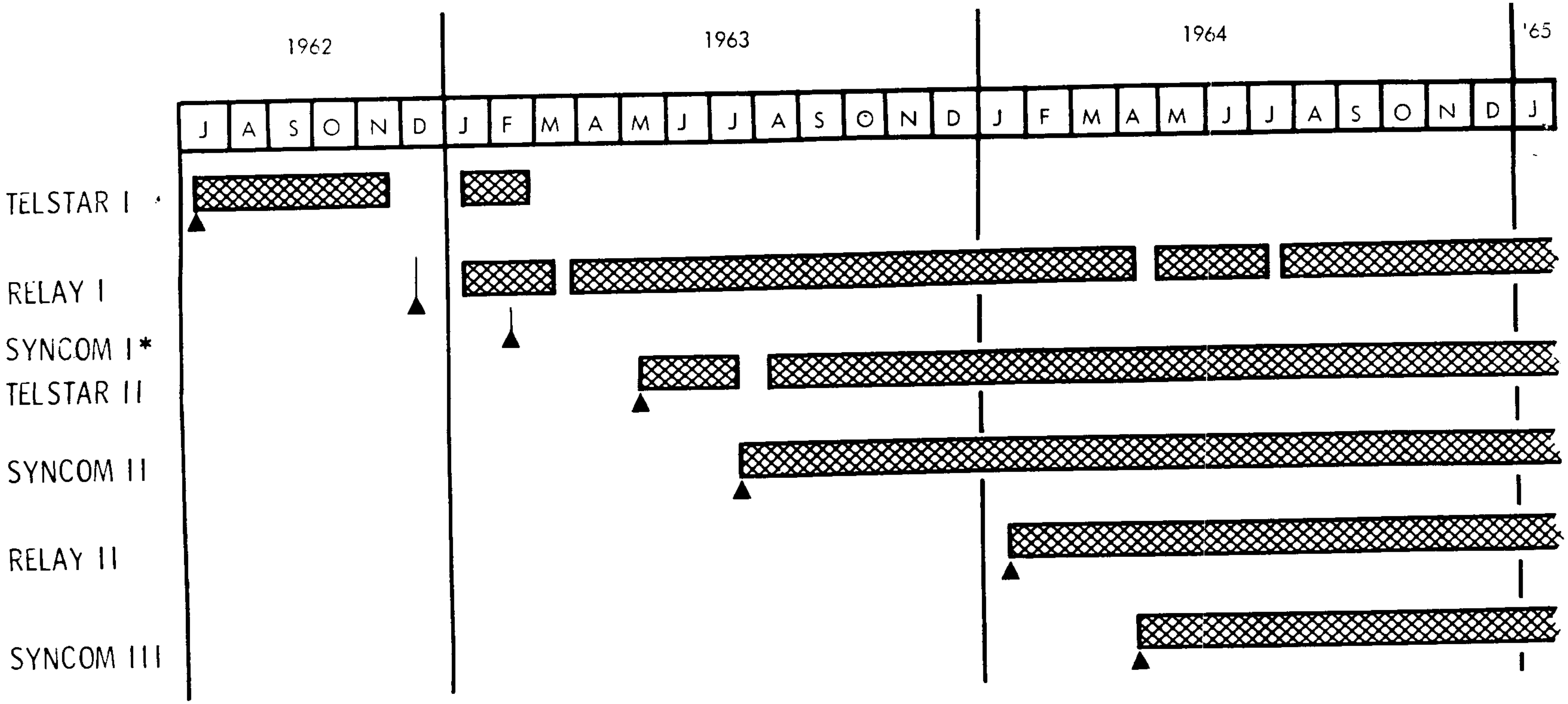
The success of NASA's experimental communications satellite program is clearly established by its numerous and varied accomplishments. The plans of a consortium of twenty nations, together with the United States Communications Satellite Corporation, to establish an international operational system in 1965 is clear evidence of the impact of this program.

The technical concept of the communications satellite, translated to the realm of economics and sociology, will, with little doubt, have a profound influence upon civilization which can only be imagined today.

Some young people in school today will, provided we solve both the technical and non-technical problems associated with high power satellites, see their own children informed, educated, and entertained by broadcasts received directly from space.

ACTIVE COMMUNICATION SATELLITES

OPERATING HISTORY



* SUCCESSFULLY ACHIEVED SYNCHRONOUS ORBIT;
SPACECRAFT DID NOT FUNCTION ELECTRONICALLY

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REV. 2-15-65

III

Introduction

A. Why Communications by Satellite? - A Historical Summary of the Development of the Requirement.

The objective of the United States' participation in satellite communications activities was voiced by the President of the United States in a public statement in 1962 in which he said: "There is no more important field at the present time than communications, and we must grasp the advantages presented to us by the communications satellite to use this medium wisely and effectively to insure greater understanding among the peoples of the world."

The history of civilization is a history of man's understanding of his environment and his interactions with other people in his attempts to master it. These attempts may take the form of trade, travel, exploration, education, or military operations, and each of them requires rapid communications to be effective.

For many millenia, man's communication of information was limited to spoken, written, pictured, or printed words, and the physical delivery of that information over long distances. Man had no real-time means of long distance communications. Real-time communications were limited to the use of smoke signals, flags, shapes, the heliograph, voice and the primitive tom-tom. All of these were distance-limited either to a line of sight or to the range of sound.

Telegraph and Telephone: Wire and Cable: Morse and Bell

When, in 1844, Samuel F. B. Morse demonstrated the telegraph, mankind had already witnessed the tragedies that can result from an unfulfilled need for communications: men died in the Battle of New Orleans in 1815 two weeks after the Treaty of Ghent.

The problem of spanning the world's oceans always has been a principal challenge in man's efforts to improve his means of communications. In 1866 transoceanic electrical communications began, with the completion of the first trans-Atlantic telegraph cable installation providing virtually instantaneous telegraph communication between North America and Europe. In 1861 Reis demonstrated the magneto-telephone by which it became possible to translate the human voice into wire-transportable electrical signals. Long distance communications achieved the real-time reality of human conversation after Bell, in 1876, developed a practical telephone and patented it for commercial use.

"Hertzian Waves"

Communications were still limited by man's ability to string wire or cable, however, until James Clerk Maxwell postulated[1], and Hertz (about 1885) demonstrated, the existence of electromagnetic wave radiation. If this radiation could be modulated in accordance with some intelligence, it could provide real-time communications not relying on wires or cables: wireless radio, telegraphie sans fils (TSF).

Countless investigators searched for practical methods to achieve this; but one man stands out, Guglielmo Marconi. His experiments prior to the turn of the century are calculated to have been at microwave line-of-sight frequencies, and he had successfully demonstrated short range communications by 1896. It is a tribute to his intellectual courage that he planned, and executed, a notable communications experiment: trans-Atlantic low frequency radio from Poldhu, Cornwall to St. Johns, Newfoundland, in 1901.

Reflecting long after this experiment, on his early years, Marconi himself said: "The idea of transmitting messages through space came to me suddenly as a result of having read in an Italian electrical journal about the work and experiments of Hertz. My chief trouble was that the idea was so elementary, so simple in logic, that it seemed difficult to me to believe no one else had thought of putting it into practice."

Marconi felt that the future of wireless telegraphy could only be assured by a convincing and dramatic demonstration of its potentialities for long distance communication. He decided that nothing less than bridging the Atlantic would meet the situation!

Cornwall, in the southwest of England, quickly suggested itself as a transmitting location, and a satisfactory site was found at Poldhu Point. On December 12, 1901, on a

Newfoundland hilltop, Marconi heard a radio signal that had spanned the Atlantic, travelling nearly 2100 miles from the Poldhu transmitting station.

It is worthy of note that the Goonhilly station in England which later received Telstar and Relay signals is within a stone's throw of Poldhu, and that the intellectual courage demonstrated by Marconi characterized many of the men associated with the achievements of the communications satellite sixty years later.

Exploitation of Terrestrial Relay

These next sixty years saw a succession of attempts to improve real-time wireless communications at long distances. Among these were:

a. Ionospheric relay using high frequency "short waves" relayed by ionospheric reflection. By 1927, trans-Atlantic telephone communications began, first at longer wavelengths, and, in the 1930's, at high frequencies, "short waves".

b. Underseas high quality cable. In 1956 a newly developed type of cable was laid that provided 36 high quality trans-Atlantic telephone circuits. By 1965, approximately 400 telephone channels had been established across the North Atlantic using such cables.

c. Microwave ground relays became a common sight from U.S. highways in the 1950's. Expanding telephone and TV traffic requirements on overland routes were met through the use of such microwave repeater systems. Terrestrial line of sight repeaters, however, must be spaced at intervals averaging only twenty to thirty miles. To extend this interval, one may increase the height of the towers on which the antennas were mounted -- but a single mid-Atlantic tower supported relay station would require a structure more than 400 miles high!

d. By the early 1960's tropospheric scatter, called "White Alice" was in common use initially in far North military Early Warning Networks. It later linked the U.S. and Cuba for TV and "island-hopped" the Atlantic and Pacific for defense traffic.

e. Airplane broadcast was profitably used for a number of years for mid-western educational TV broadcasting. Certain military over-the-horizon tactical links were established in the same way.

f. Ionospheric scatter relay was proven feasible as early as 1951, and some operational transoceanic circuits were established.

g. Meteor scatter, called "Juliet" in Canada, had been of interest to both military and civilian system designers.

h. And finally, knife-edge diffraction of micro-wave transmissions had carried telephone traffic over the Andean Mountains from Chile.

Artificial Satellites

But the real solution, for which all those listed above were mere substitutes, would be an orbiting satellite, for an orbiting satellite reduces the number of engineering or geographic compromises that must be made.

B. <u>1957: The Dilemma Confronting the Communications Engineer</u>

The dilemma of the communications engineer in 1957 was this:

Using low frequency long waves he could propagate signals that followed the curvature of the earth, and even penetrated sea water to submarines. This was Marconi's technique. Still widely used, these very low frequencies require large and expensive antennas and transmitters and are limited in the amount of information they can carry. As a medium for voice, TV, or data communications, very low frequencies fail.

The higher frequencies corresponding to the "short wave"-lengths provided a form of overseas voice communications, but were limited in circuit reliability by the vagaries of the ionosphere. They were limited too in spectrum width, particularly during periods of low sunspot numbers when the frequency range reflectible by the ionosphere was reduced to its minimum: a dozen megacycles.

Only microwave frequencies were ideally suited to carrying the tremendous communication loads of the then not-too-distant future, but microwave frequencies were limited to line-of-sight by their straight line propagation characteristic. A high altitude relay was the obvious solution, but all the compromises noted above were altitude limited by their very terrestrial nature.

Moon Relay[2]

On January 11, 1946, the U.S. Army Signal Corps' Project Diana was successful in its objective; radar contact with the moon, a natural Earth satellite. Radar contact is a form of passive reflection. From 1954 to 1959, the Navy therefore translated the Army achievement into what has been called "the world's first operational Space Communications System." An actual link between Washington and Hawaii via Moon Relay was operational from 1959 to 1963.

C. Description of Material in this Report

The Moon, although an extremely high altitude Earth satellite, has many limitations. It would be desirable to orbit an artificial Earth's satellite at an altitude optimum for its mission.

Such satellites were considered as being of two types: passive or active. The passive satellite, acting like a mirror, would retransmit no more than that energy it intercepted. It appeared that it must be physically large to be efficient. Proposed by Pierce in 1955[3] and O'Sullivan in 1956, the launching of such a satellite therefore had to await, until 1960, the solution of the engineering problem of erecting a large structure in space. An active satellite relay was first written about by Arthur C. Clarke in 1945[4]. Technical detail was added, by J. R. Pierce in 1954, and by others soon after.

For the purposes of citing their history, we shall recount the achievements of the passive satellite first, then the active satellite.

IV

Passive Satellites

A. Echo I[5]

With the solution of the engineering problem of erecting a large balloon in space, Echo I here, in Chart S61-577, was launched into orbit by NASA on August 12, 1960. Although signals had previously been experimentally reflected from an orbiting Tiros weather satellite, Echo I was the relay medium for a large number of well planned communications experiments, transcontinental and intercontinental. Most important, Echo I proved that it is practical to use a man-made passive satellite to reflect two-way telephone conversations across the United States. A 100-foot inflated balloon made from aluminum-coated Mylar, it was large enough to be seen by the naked eye. People throughout the world have subsequently seen Echo I sail on schedule across the sky in its 1000-mile-high circular orbit. Four years later, although wrinkled and deflated, the balloon is still in orbit, with a predicted further life of at least two years.

Echo I provided data valuable to the work in satellite communications that followed; it confirmed, to a remarkable degree, the validity of calculations used for ground stations design - an achievement of no small importance. It also provided a mechanism for the measurement of solar pressure effects.[6]

Two-way conversations of good quality were sent between the Bell Laboratories Holmdel, New Jersey station and the

135 FOOT DIAMETER RIGIDIZED SPHERE WITH CANISTER

Jet Propulsion Laboratory in Goldstone, California and successful transmissions were made to other points in the United States and Europe, all relayed via Echo I. The Holmdel scaled-up horn-reflector antenna proved itself. A method of receiving microwave signals known as frequency modulation with feedback (FMFB)[7], originally described by J. G. Chaffee in 1939 but little used for two decades, performed very well, as did the use of phase lock loops within receivers. New types of low-noise amplifiers using solid-state masers gave excellent results. Tracking of the satellite by computer prediction, by radar, and by telescope, proved to be extremely reliable.

B. West Ford[8]

Conceived in 1959 under military auspices was a different form of passive satellite system, a belt of millions of hair-thin orbiting reflective "needles" (whence its original project name). Originated and prosecuted by the MIT Lincoln Laboratory, an experimental West Ford belt was authorized but placed under severe launch constraints by the President of the United States, upon advice of the National Academy of Sciences due to world-wide concern expressed by radio and optical astronomers. A limited-life belt was successfully launched by the United States Air Force in the early summer of 1963. Although its formation was at a slower rate than first anticipated, it demonstrated that predictions of non-interference with radio astronomy were valid, that the method of dispensing a belt of millions of tiny fine wires was workable, and that a few such belts could provide worldwide, reliable, low data rate communications almost immune from physical destruction.

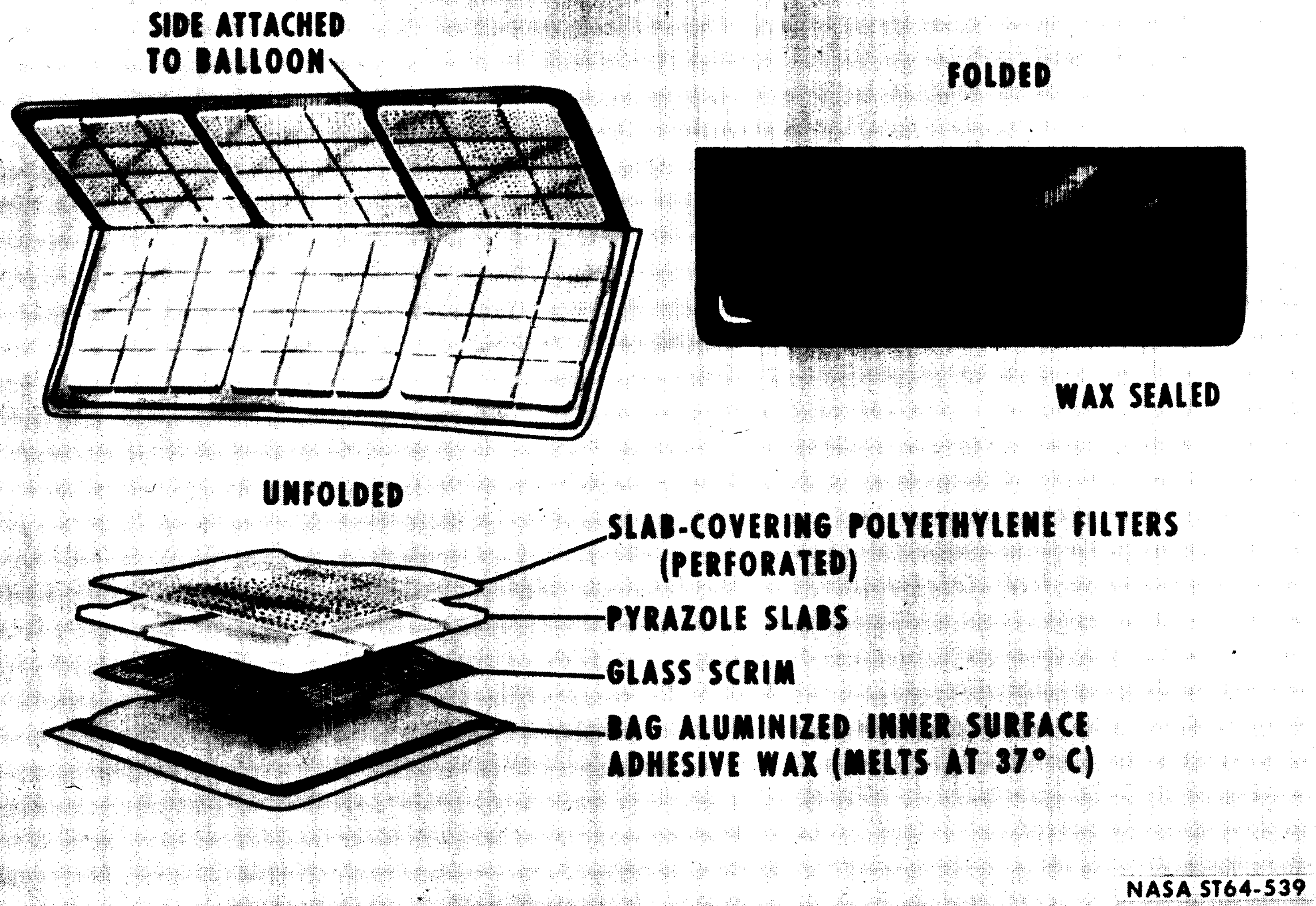
C. Echo II

On January 25, 1964, Echo II was successfully orbited by a Thor-Agena vehicle from the Pacific Missile Range. The satellite configuration deviated somewhat from that of Echo I since a careful review of radar data taken on two sub-orbital test flights in 1962 indicated that the balloons used had not been pressurized sufficiently to remove the wrinkles in their skin. As a result, an intensive program was initiated to develop a novel controlled inflation and pressurization system, and to study in greater detail the relationship between sphere pressurization and surface smoothness and sphericity. This involved static inflation tests in 1963 in a dirigible hangar at Lakehurst, New Jersey, and many precise measurements of surface condition at various pressure levels, using stereo-mapping techniques as well as near-field monostatic and bi-static radar observations.

It was definitely concluded after these tests that an increase in pressurization provided a marked improvement in balloon sphericity and RF reflectivity characteristics. As a result, the controlled inflation system was incorporated in the Echo II orbital payload. A number of bags, shown in the next chart (ST 64-539) each containing about one-half pound of cast pyrazole, were sealed closed with temperature sensitive wax and attached to the inside of the balloon prior

ECHO II

CONTROLLED INFLATION SYSTEM



to folding and packing in its canister for launch. After launch and canister opening, the sphere was initially inflated with only residual air (approximately 1mm of Mercury). This initially inflated the balloon to full extension, but did not pressurize it. As the sphere absorbed heat from the sun, the wax melted, allowing the bags to open and the pyrazole to gradually sublime and pressurize the sphere. In all, it took about 42 minutes after canister opening for the Echo II sphere to reach maximum pressurization of 218 microns, close to the design goal. The process is shown in Chart ST 64-710.

Echo II was intensively studied after launch by means of optical, radar, and telemetry measurements, and by analysis of communications experiments. In general, the behavior of Echo II was as expected.

In addition to experiments conducted in the United States to determine the condition of the satellite, a cooperative experimental program with the USSR was implemented. During early orbits of Echo II this program involved optical observation by stations in the USSR, and a series of communications experiments between the Jodrell Bank Radio Observatory of the University of Manchester, England operating on NASA's behalf, and the Zimenki Observatory of the Gorki State University, northeast of Moscow. Like all NASA experiments involving international cooperation, this one was based on a written agreement, in this case a Memorandum of Understanding implementing the Bilateral Space Agreement reached at Geneva on June 8, 1962, between the USSR Academy of Sciences and the National Aeronautics and Space Administration.

During the pre-launch and immediate post-launch phases of Echo II, the Academy of Sciences of the USSR was notified of nominal orbital elements and kept informed of launch rescheduling. The Astronomical Council of the USSR Academy of Sciences was notified of the launch scheduling information, as well as the type of optical observations of the early Echo II orbits that would be helpful in evaluating satellite inflation and pressurization. Confirmation of satellite inflation and preliminary orbital parameters were transmitted to Zimenki Cbservatory. The USSR supplied to the U.S. the results of their optical and photographic observations from various Soviet sites taken during the early life of the satellite.

US-USSR experiments with Echo II passive communications satellite involved receipt of 162 Mc/s transmissions at Zimenki. These transmissions originated at the University of Manchester station in the United Kingdom from which thirty-three communications experiments were conducted between February 21 and March 8, 1964.

V

Active Communications Satellites

A. Early Army Communications Satellites

1. Score[9] - the first active communications satellite experiment.

Most immediately feasible in 1958 was a battery-powered active relay satellite, one which amplified the signal

ECHO II

INFLATION IN ORBIT AS SEEN BY TV

CANISTER SEPARATION

INITIAL DEPLOYMENT

PARTIAL INFLATION

FULLY INFLATED

NASA ST64-710

it received before re-transmitting it to the ground. Score, meaning "Signal Communications by Orbiting Relay Equipment", was built by the Army laboratory at Fort Monmouth, New Jersey, and was launched by the Air Force on December 18, 1958, thus becoming the world's first artificial active communications satellite experiment. It was capable, as well, of real-time relay of voice, code and teletype and demonstrated its capability dramatically during its short life: twelve days. One of these demonstrations was Christmas Greetings from President Eisenhower. The repeated transmissions were triggered by ground command.

2. Courier[10]

On October 4, 1960 the Army Signal Corps' Courier I-B was launched into a 500-600 mile-high orbit. A sphere weighing 500 pounds and measuring 51 inches in diameter, the Philco Courier satellite was powered by 20,000 solar cells and contained four receivers, four transmitters, and five tape recorders. It was designed to demonstrate the possibility of using active repeaters for both real-time and delayed transmission of high data rate messages. Signals were received, stored on the tapes, and then retransmitted back to Earth when the satellite had moved on. After 18 days in orbit, technical difficulties ended Courier I-B's ability to send signals, but it received and retransmitted 118 million words during its active life.

B. Twenty-five Months of Intense Activity - July 1962 to Aug 1964

1. Telstar I[11]

The man in the street felt the personal impact of satellite communications in 1962. Proposed by the Bell System as early as July 6, 1960, and approved by the Federal Communications Commission on January 19, 1961, Telstar I, pictured in the next chart (ST 64-242) was successfully launched on July 10, 1962.

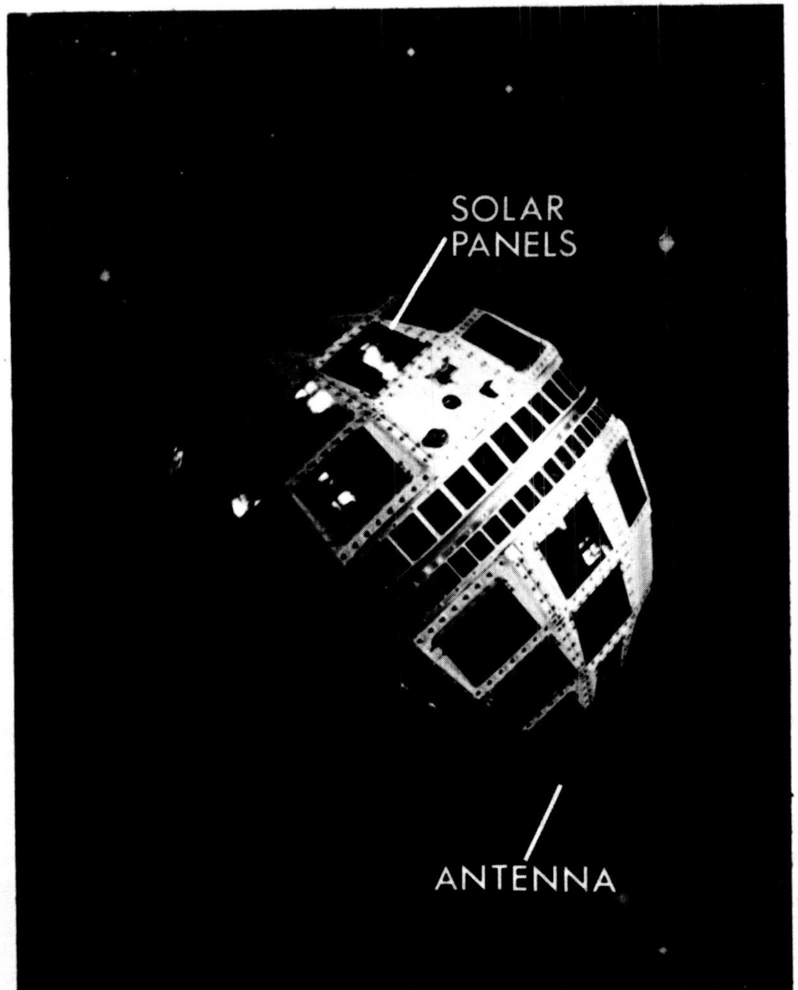
Project Telstar had these objectives:

- to prove that a broadband communications satellite could transmit telephone messages, data, and television;
- to test, under the stresses of an actual launch and the hazards of space, some of the electronic equipment that had been developed for satellite communications;
- to measure the radiation that a satellite would meet in space;
- to find out the best ways to track accurately a moving satellite;
- to provide a real-life test for the special satellite communications antennas and other ground station equipment.

For its early experiments* in satellite communications, Bell Laboratories built a large antenna of the type known as

*Much of the system technology incorporated in the Telstar project was developed or confirmed by work with Echo, discussed under Passive Satellites.

TELSTAR SPACECRAFT
ACTIVE COMMUNICATION SATELLITE



WEIGHT	175 LBS.	
DIAMETER	34 INCHES	
HEIGHT	34 INCHES	
ORBIT	APOGEE	PERIGEE
	(STATUTE MILES)	
TELSTAR I	3500	580
TELSTAR II	6700	600

STATUS

TELSTAR I LAUNCHED JULY 10, 1962

TELSTAR II LAUNCHED MAY 7, 1963

AGREEMENT BETWEEN NASA AND AT&T FOR TWO TELSTAR LAUNCHES HAS BEEN COMPLETED.

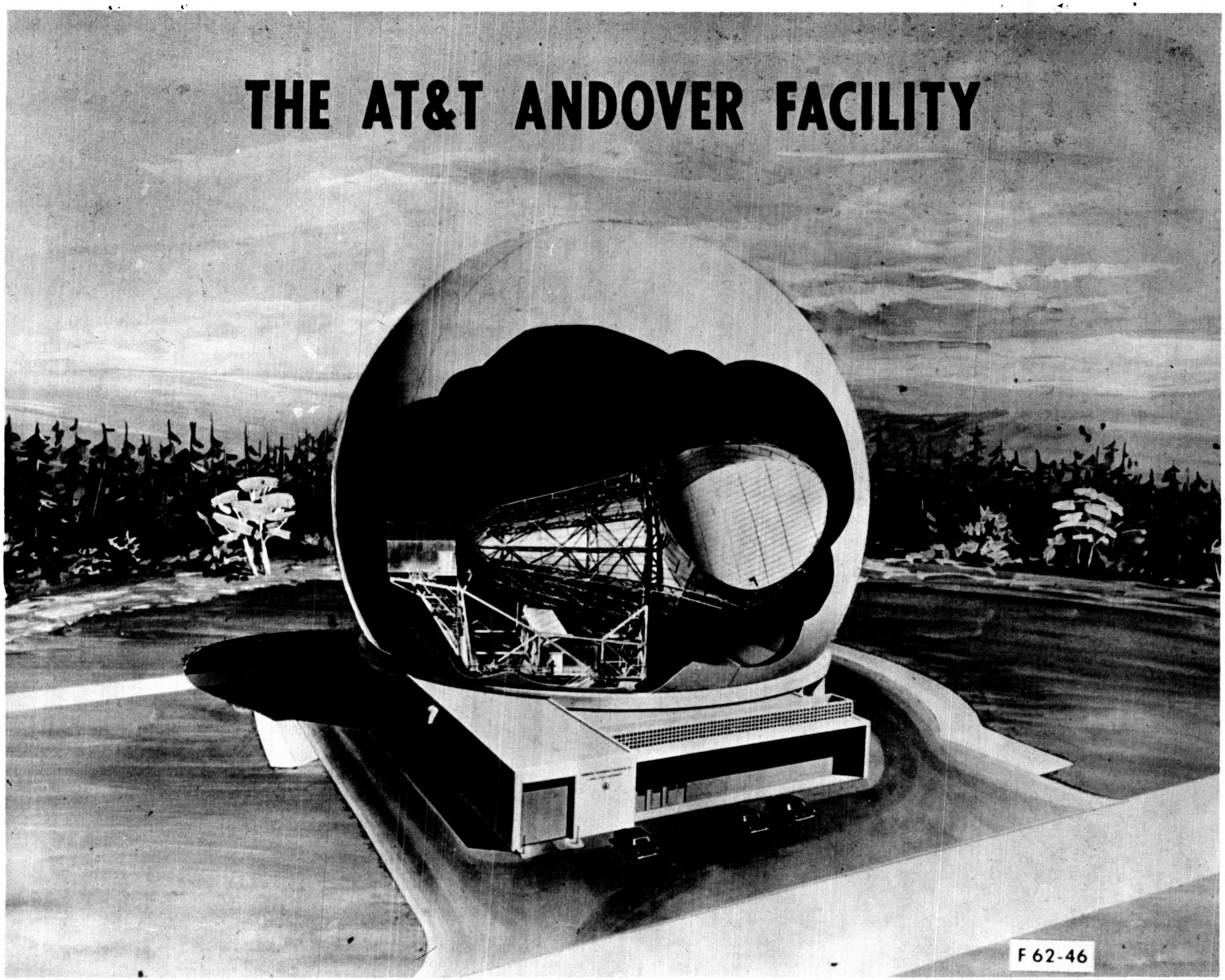
NASA ST64-242

a horn-reflector in Holmdel, New Jersey. For Project Telstar, a similar but larger antenna was designed[12]. It was located in a relatively isolated spot at Andover, in the western part of Maine, clear of microwave links with which it might interfere.

The giant Andover horn (Chart F62-46) is a steel and aluminum structure 177 feet long and 94 feet high that weighs 380 tons. At one end is a giant opening of 3600 square feet; from there the horn tapers down to a cab in which the very sensitive receiver and powerful transmitting equipment is located.

A ground station very similar to the Andover installation was built soon thereafter by the French National Center of Telecommunications Studies (CNET) at Pleumeur-Bodou in Brittany. The British General Post Office established its station[12] at Goonhilly, near Marconi's Poldhu site in Cornwall. It uses a large, deep parabolic dish rather than a horn-reflector antenna. Both the British and French stations participated in the first Telstar experiments. By late 1964 experimental Telstar satellite communications ground stations had been set up in Fucino, Italy; in Raisting, Germany; and near Tokyo, Japan. Chart ST65-687 shows the total complex of ground stations as they later came into being.

On Telstar's sixth orbit at 7:26 p.m. EDT, July 10, 1962 the first transmission to and from the satellite took place. During this pass telephone calls, TV, and photos were transmitted between Andover and Holmdel. Some of these


THE AT&T ANDOVER FACILITY
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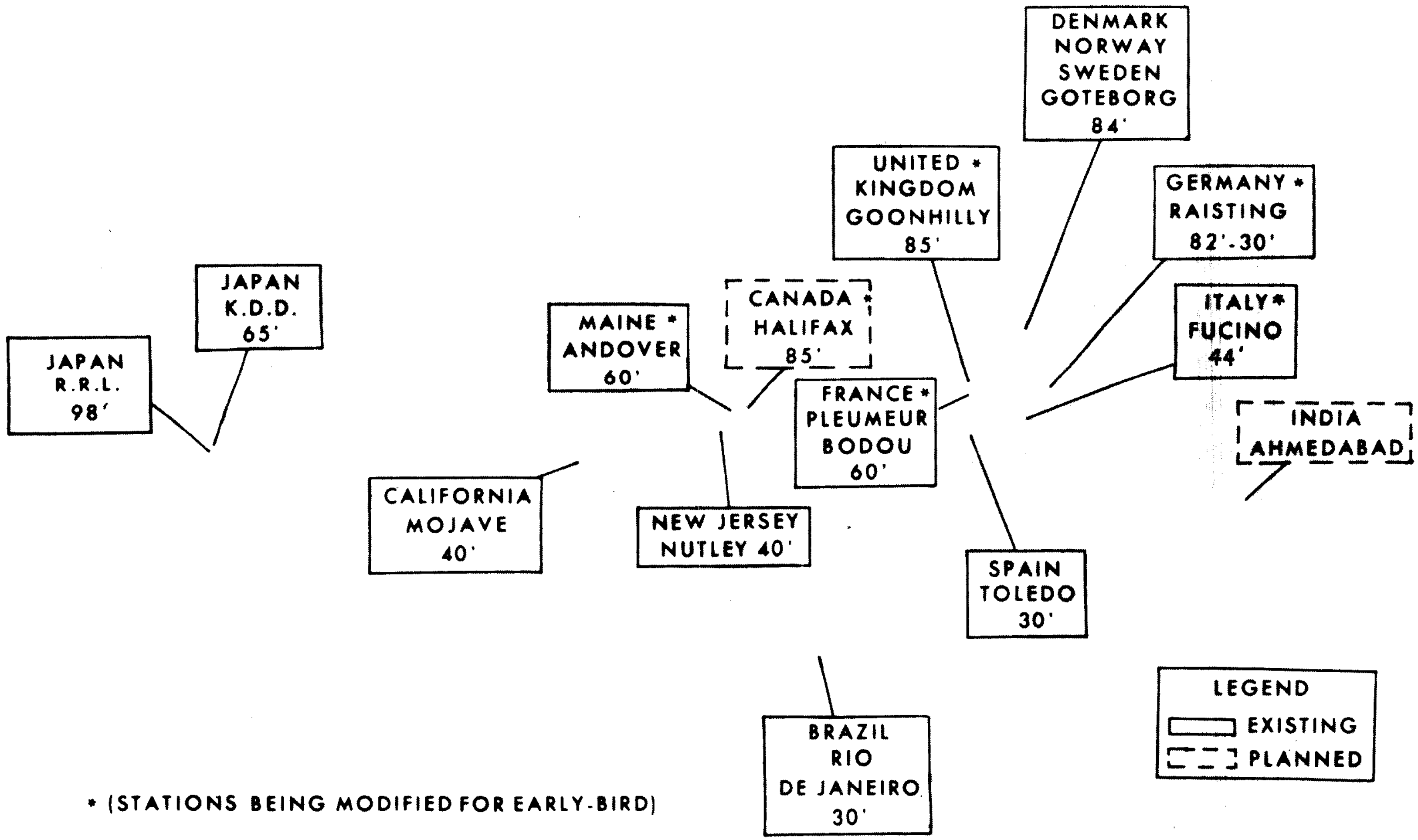
COMMUNICATIONS SATELLITE GROUND STATIONS



* (STATIONS BEING MODIFIED FOR EARLY-BIRD)

NASA ST 65-687
2-11-65

signals were also picked up in Europe. On the next day, a taped TV program was sent from France to the United States, and a live program came from England via Telstar.
During the next four months, more than 400 transmissions were handled by Telstar I - including 50 TV demonstrations (both black-and-white and color), the sending of telephone calls and data in both directions, and the relaying of facsimile and telephotos.

In addition, the satellite performed more than 300 valuable technical tests. Almost all of them showed remarkably successful results. Radio transmission was at least as good as expected. Telstar I's communications equipment worked exactly as it should, with no damage from the shock and vibration of the launch. Temperatures inside the satellite were within design range and the solar cells worked almost exactly as expected. The ground stations accurately tracked the fast-moving satellite, in almost routine fashion.

However, Telstar I unexpectedly encountered extreme man-made radiation levels in space, estimated to have been 100 times more potent than naturally expected. As a result, difficulties arose during November 1962 in some of the transistors in its command circuit. Ground diagnosis of a malfunctioning communications satellite was successfully attempted for the first time, and Telstar I was commanded on again on January 4, 1963. The satellite later failed to respond to commands from the ground, and on February 21 went silent.

2. Relay I[13]

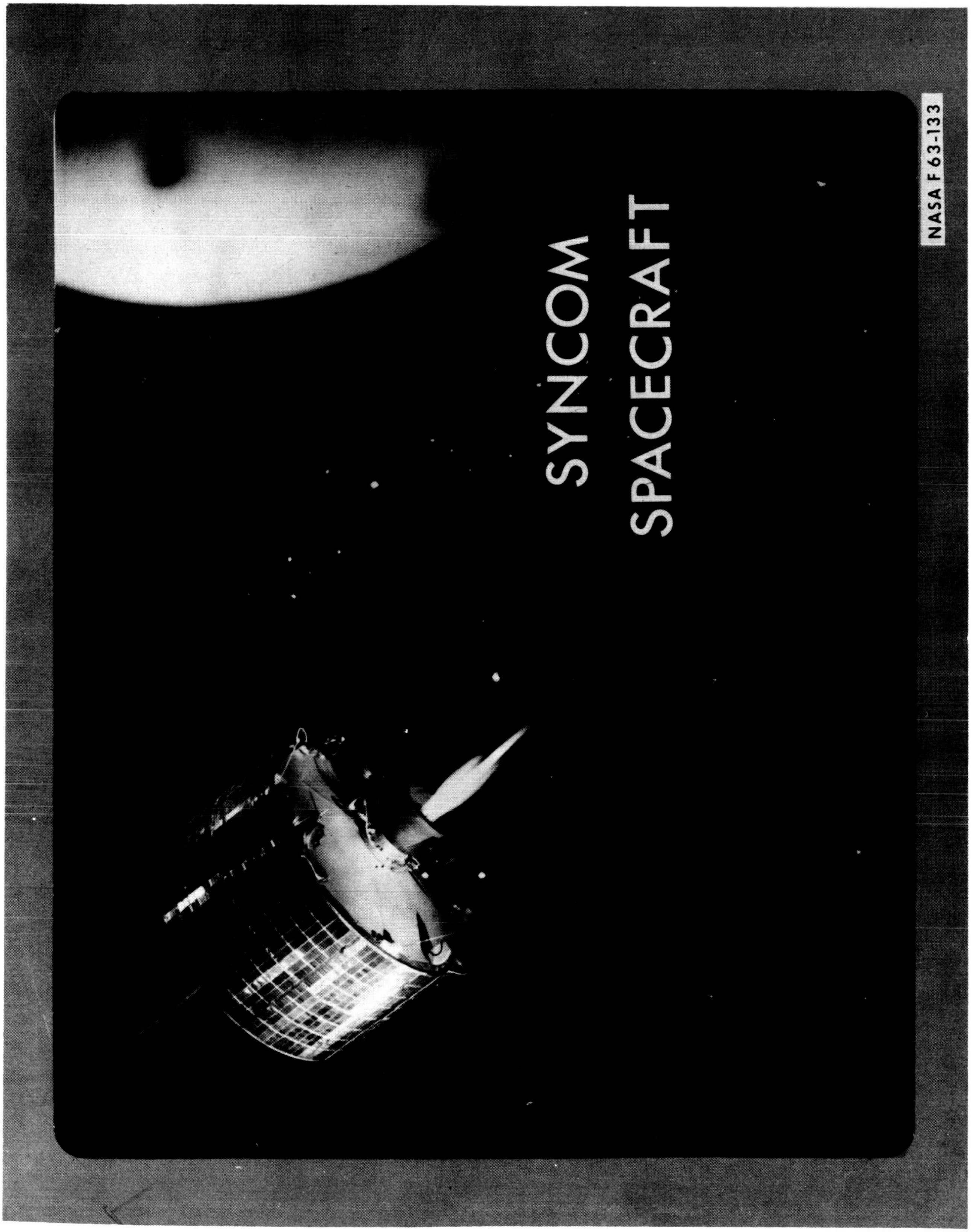
NASA launched Relay I (Chart ST 64-531) on December 13, 1962, an active repeater that received telephone, TV and other electronic signals and retransmitted them to a distant point. Relay I provided the first satellite communications link between the U.S. and South America with Japan, and with Germany and Scandinavia. Relay satellites are 33 inches long and weigh 172 pounds. A mast-like antenna at one end is used to receive and transmit a single TV broadcast or 12 simultaneous two-way telephone conversations. Four whip antennas at the other end of the prism handle control, tracking, and telemetry - turning experiments on and off and sending information on the behavior of its components and on the amount of radiation it encounters in space. Relay satellites are powered by nickel-cadmium storage batteries that are charged by more than 8,000 solar cells mounted on its eight sides. They contain two identical receiving, amplifying, and transmitting systems, called transponders, each with an output of 10 watts.

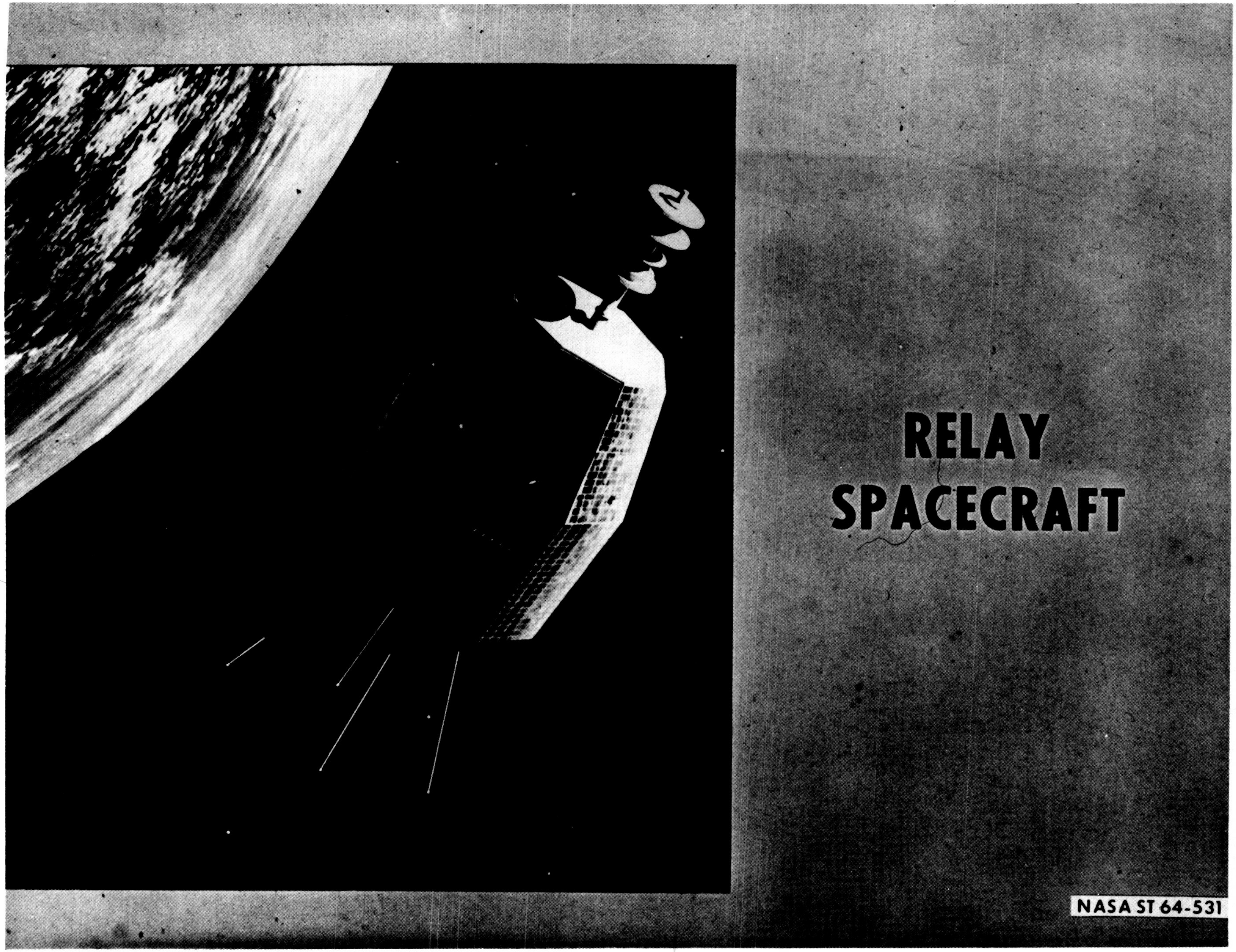
Relay I in 1965 is still traveling in an orbit that ranges from 820 to 4,630 miles high, circling the earth about every 185 minutes. Soon after launch, Relay I's telemetry reported trouble in the voltage regulator-switch for one of the transponders, which caused excessive power drain. On January 3, 1963, the alternate transponder was switched on, and a successful series of tests began - including live TV broadcasts between the United States and Europe. Relay I contained a built-in switch intended to terminate its usefulness automatically at the end of 1963, but fortunately the switch failed to function, and Relay I continued to be operational, although gracefully degrading, for several times its one-year design life.

3. Syncom I[14]

February 14, 1963 saw the first, but only partial, success in the Syncom Project, NASA's most ambitious undertaking in the field of active communications satellites, the objective of which was to place active repeater satellites into synchronous orbit. Syncom I was the first satellite to achieve a near-synchronous orbit (Chart F63-133).

There are two principal advantages in favor of a synchronous[15] satellite. One advantage of a synchronous orbit is a characteristic which allows few satellites to cover most of the earth's surface. A second advantage is that it will permit simpler ground stations, despite its greater distance from the earth. Low and intermediate altitude satellites move rapidly through the field of view of a given pair of ground stations, therefore at least two antennas are needed to maintain uninterrupted service. One antenna tracks the satellite until it leaves the field of view. Meanwhile, a second antenna must stand ready to acquire the next satellite as it comes into view. Message traffic must then be "handed over" from one to the other. When very large antennas are used to capture a signal


SYNCOM
SPACECRAFT
NASA F 63-133


RELAY
SPACECRAFT
NASA ST 64-531

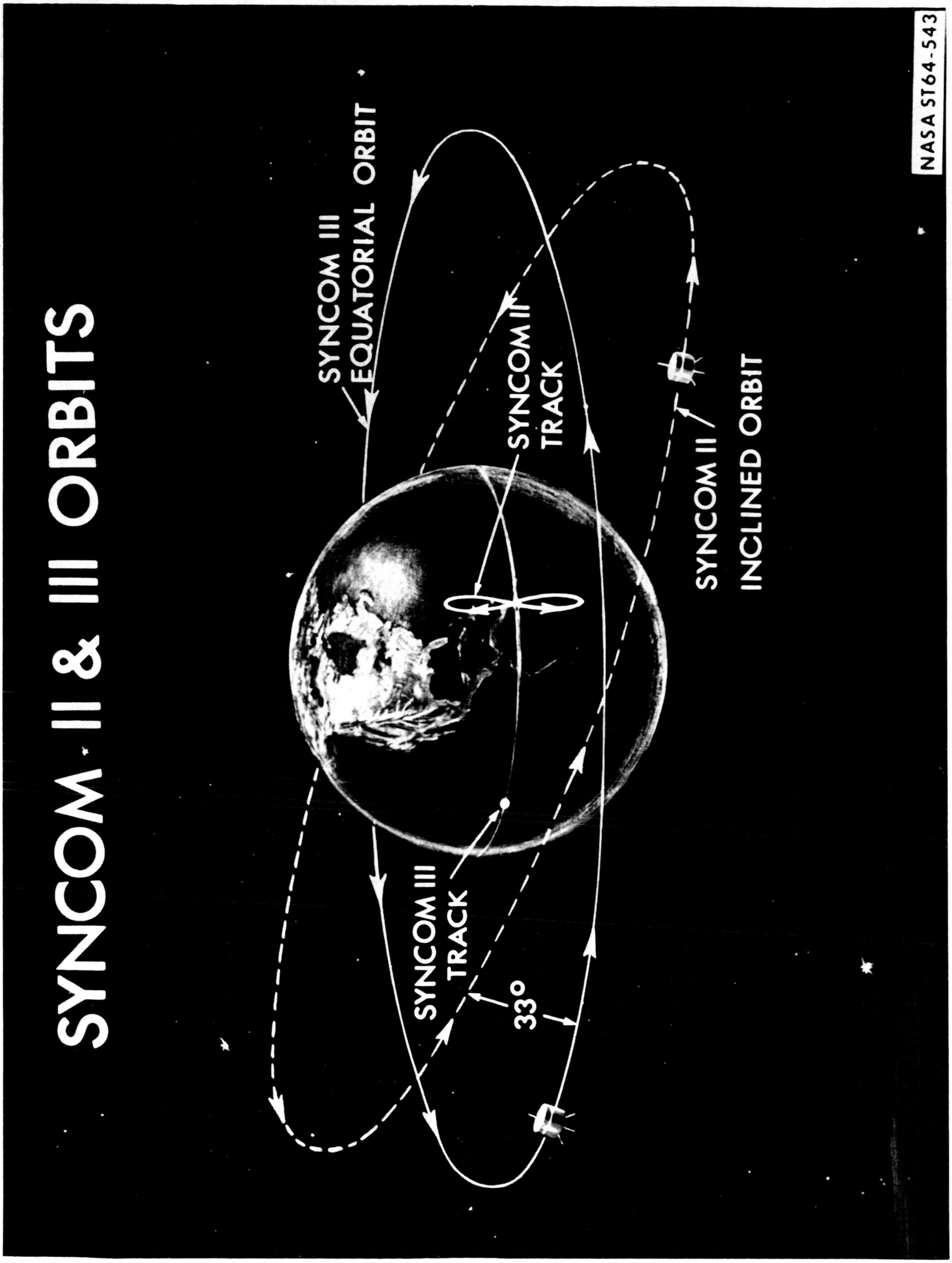
from a satellite their beamwidths are on the order of one-tenth of a degree. Pointing large antennas with such narrow beams at rapidly moving satellites is no easy task, and the equipment needed is expensive. Synchronous satellites, however, can be quite satisfactorily used with nearly fixed antennas. Of course, while they could be permanently pointed at one spot in space, some steerability must be included in order to track small motions of the satellite and to permit transferring operations to a second satellite in the event the first fails.

NASA's Project Syncom was a first step toward providing experience in the synchronous orbit. A distinguished feature of Syncom satellites was the fact that they carried within themselves an "apogee kick" rocket motor. Such a motor was required to supplement the capabilities of the existing launching vehicle to place the 75-pound satellite in a near synchronous orbit. Syncom satellites also carried a gas jet system for orienting the satellite in the proper direction with respect to the earth, and for maintaining the satellite's relatively stationary position with respect to points on the Earth's surface. One added complexity of a synchronous satellite over an intermediate altitude satellite stems from the fact that additional propulsion subsystems must work in order to complete the mission successfully.

The first experimental Syncom satellite, Syncom I, was launched from Cape Canaveral on February 14, 1963. The launch was near-perfect, and the satellite was placed in an elliptical orbit, the peak altitude of which was about 22,300 statute miles. At that point the on-board rocket was to be fired, adding the velocity necessary to sustain the satellite at synchronous altitude. During the five hours it took for Syncom I to reach this 22,300 mile altitude, its communications equipment was checked out by the USNS KINGSPORT[16] in Lagos, Nigeria; with satisfactory results. Approximately 20 seconds after the on-board rocket was fired, however, all signals from the spacecraft ceased, and Syncom I has been silent since. It was subsequently established, through telescopic observations, that Syncom I achieved a 33° inclined orbit with a period of nearly 24 hours. NASA had achieved a first by succeeding in placing a satellite into nearly synchronous orbit.

4. Telstar II

Competing for the stage among active satellites, with Relay I and Syncom I, in early 1963, was Telstar II. On May 7, Telstar II was launched into an elliptical orbit ranging from an apogee of 6697 miles to a perigee of 604 miles, with a period of 225 minutes. The higher altitude, almost twice that of Telstar I, provided Telstar II with longer periods of visibility at Andover and corresponding ground stations in Europe, and it kept Telstar II out of the high-radiation regions of space for a greater part of the time. The satellite itself was much the same as Telstar I, except for a few minor changes


SYNCOM II & III ORBITS
SYNCOM III EQUATORIAL ORBIT
SYNCOM II TRACK
SYNCOM III TRACK
33°
SYNCOM II INCLINED ORBIT
NASA ST64-543

that made its weight 175 rather than 170 pounds. Its radiation measuring devices had a greater range of sensitivity, and there were six new measurements to be reported back to earth. Telemetry could be sent on both the microwave beacon and, as before, on the 136-megacycle beacon. To help prevent the kind of damage that occurred in Telstar I's command decoder transistors, Telstar II used a different type of transistor, one from which the gases had been removed from the cap enclosures that surround the transistor elements. A simplified method of operating the giant Andover horn antenna was instituted with autotrack alone being used for precise tracking and pointing. Telstar II's first successful TV transmission took place on May 7, 1963 and a new series of technical tests, radiation measurements, and experiments in transoceanic communications began.

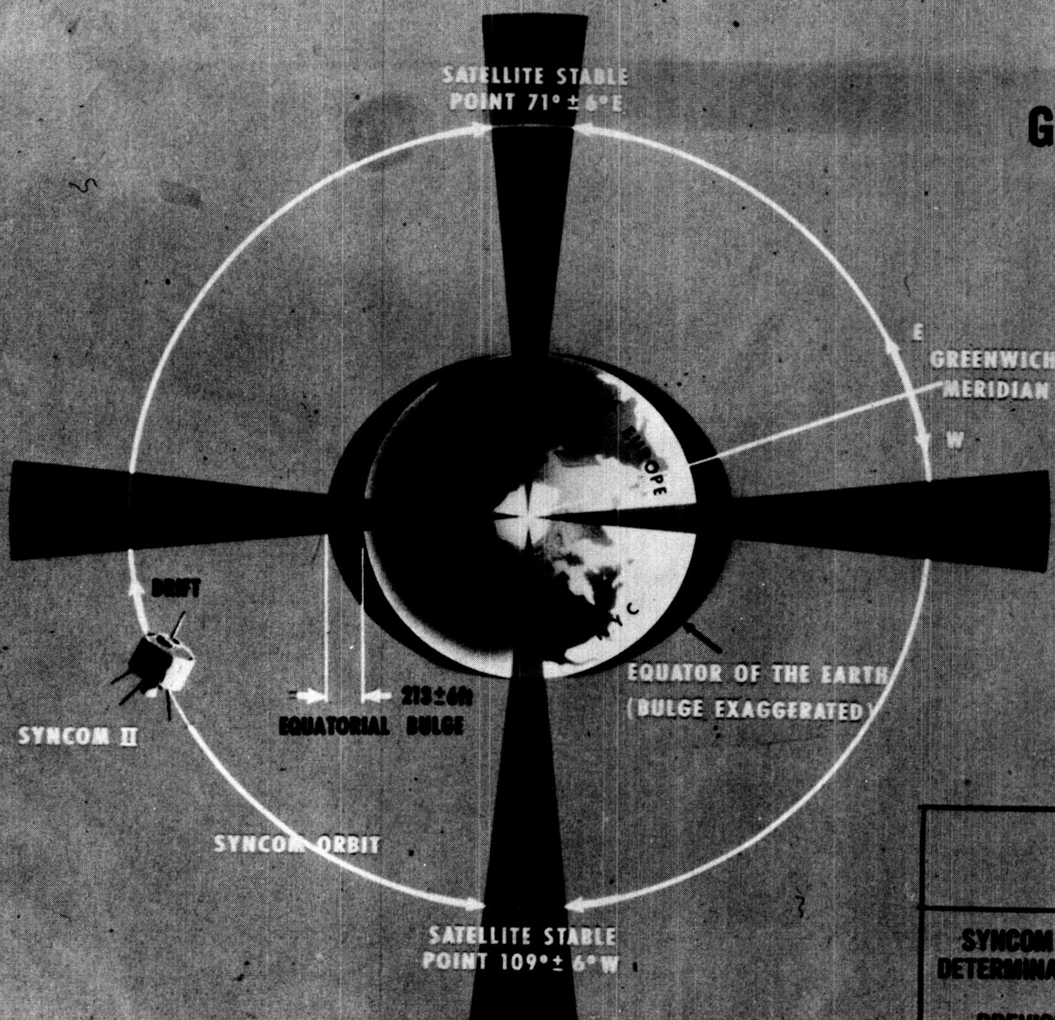
5. Syncom II

Syncom II was launched with complete success on July 26, 1963. The orbit of the very successful Syncom II is inclined about 33° to the Earth's equatorial plane. From the ground, a satellite in such an orbit appears to wander north and south at the longitude over which it is stationed. A truly stationary satellite, on the other hand, requires synchronous orbit and zero inclination, and the next chart (ST64-543) compares the inclined synchronous orbits of Syncom I and II with the geostationary orbit later achieved by Syncom III.

Syncom II achieved first successful synchronous orbit with full spacecraft capability. It provided first television, voice, and facsimile experience with a satellite in 24 hour orbit and became the first satellite maneuvered to a specific longitude (55^{o} West). Period and attitude control of a spinning satellite[15] was achieved for the first time in order to station Syncom II, and it provided the world many demonstrations between North America, Africa and Europe. It carried the world's first telephone conference between heads of state via satellite, between President Kennedy and Prime Minister Balewa of Nigeria. The first satellite communications press conference became a reality on the occasion of the successful conclusion of the 1963 Extraordinary Administrative Radio Conference on Space Communications in Geneva.

Syncom II made several contributions of data useful to scientific determination of the shape of the earth and to the drift behavior of synchronous satellites[17]. The Syncom orbits lend themselves particularly well to making accurate observations of anomalies in the earth's gravitational field. Because of their high altitude, effects of local uneveness of the Earth's topography are minimized. The accuracy of these observations was greatly enhanced by the Syncom range-and-range-rate system, capable of measuring range at synchronous altitude to less than 50 meters. Some very basic information resulted relating to the size and location of the bulges at the Earth's equator, as shown in the next chart (ST 64-1546), and it was concluded,

SYNCOM II
GEODETIC AND ORBITAL DETERMINATIONS



DATA SUMMARY

	MAX. DRIFT CORRECTION	MAJOR AXIS LONGITUDE	EQUATORIAL BULGE
SYNCOM II DETERMINATION	5.36 fps/yr.	19°W ± 6°	213 ft ± 6ft
PREVIOUS DATA (1959 -1964)	17.0 to 1.75 fps/yr.	38.5°W to 0°	671 ft to 69 ft

NASA ST64-1546
REV 8-20-64

in addition, that it takes considerably less energy to keep a synchronous satellite on station than was formerly believed.

6. Relay II

Relay II, containing modifications principally intended to increase its reliability and its resistance to radiation damage, was launched into a slightly higher orbit than Relay I, possible due to improved launch vehicle performance. It was successfully checked out on the first pass after launch on January 21, 1964, and worked well into 1965 at least. It added its capability to that of Relay I and Telstar II.

7. International Ground Station Cooperation[12]

International cooperation was necessary to fully exploit the experimental possibilities of Telstar, Relay and Syncom satellites. As a result, not the least of the beneficial results of these projects was the international cooperative experimentation demonstrated by the experimental ground stations of the United States, Great Britain, France, Brazil, Germany, Italy, Japan, Spain, Scandinavia and Canada. USSR participation in tests between the USSR and the United Kingdom involving the Echo II satellite was previously described.

8. Syncom III

Syncom III represented the first attempt to place a synchronous satellite into geostationary orbit. The ground track of a geostationary satellite is a point instead of a figure 8. Considerably more energy was required to achieve this orbit, than the 33° inclined orbits of Syncom I and II. Zero inclination of the Syncom III orbit became possible with the availability, in 1964, of the Thrust Augmented Delta (TAD), a more powerful X-258 third stage, and the added thrust of the second hydrogen peroxide (H_2O_2) spacecraft control system.

The launch maneuver to achieve geostationary orbit with the TAD vehicle required that the second and third Delta stages be yawed through an angle of about 38° so that firing of the third stage would result in reducing the inclination of the transfer orbit from 28° to 16°. The remaining inclination could then be removed by the firing of the apogee kick rocket motor in the spacecraft.

The orbital characteristics of the transfer orbit were determined during the first revolution of the satellite by using range-and-range-rate measurements from the communication ground stations at Clark Field in the Philippine Islands, and the USNS KINGSPORT, at Guam. The spacecraft was then precisely reoriented at the time of the second apogee so that the thrust of the apogee motor would cause injection into a synchronous orbit of a near-zero-degree inclination. The apogee motor was then fired by ground command at the time of the third apogee. Final orbital adjustments were made with the H_2O_2 control system and the satellite drifted to its station, near the International Date Line.

The TAD (Chart ST65-742) with its three TX 33 Thiokol rockets attached to the Thor, added 162,000 pounds of thrust to the Delta first stage and thus provided a part of the energy required to reduce orbital inclination to near zero degrees.

Experience showed that the nitrogen control system originally used in Syncom I and II for purposes of vernier adjustments was not required since the vernier function could be adequately handled by the H_2O_2 system. The addition of a second H_2O_2 system, in place of the N_2 system, considerably increased the capability of the spacecraft for maneuvering and station keeping, and N-on-P solar cells with 12 mil glass shielding gave significantly greater radiation protection and longer useful life expectancy.

9. Public Demonstrations via Active Satellite

In addition to scientific and engineering tests of spacecraft-to-ground station systems, arrangements were early made to transmit real traffic of different types. A broader based subjective appraisal of system performance could be made and the real status of the work could be demonstrated to the public, in the most understandable form. The number of these public demonstrations was substantial and virtually every type of telecommunications traffic was represented. Through July 1964, the total number of demonstrations carried by Relay I and II, Telstar I and II, and Syncom II were, respectively, 133, 358, and 110. All of the results of these demonstrations were interesting, and some were most instructive. One clear reaction from persons using the satellites was amazement at the high-quality of the voice circuit. A notable result of these demonstrations was that the availability of two to three working satellites created a substantial demand for trans-oceanic TV transmission services - a demand that most economic studies of the preceding few years predicted would be non-existent or trivial.

Following are illustrations of the practical uses of communications satellites which have been demonstrated:

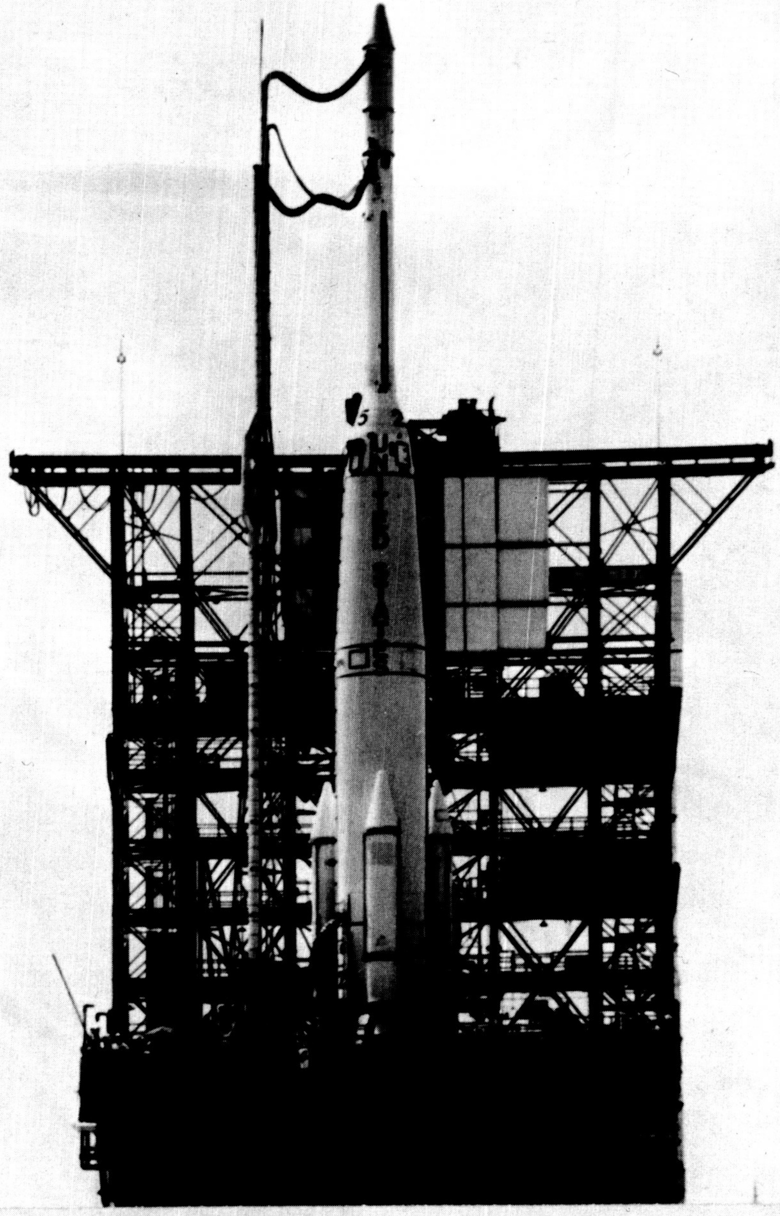
On April 25, 1963, Relay I transmitted an electro-encephalogram from the Burden Neorological Institute in Bristol, England, to the Mayo Clinic in Rochester, Minnesota. The electro-encephalogram was introduced into a computer, which printed out return data from which a diagnosis was made. The diagnosis was immediately sent back via satellite to the patient's doctors in England.

Similarly, on May 28, 1963, a fetal electrocardiogram was transmitted from Mount Sinai Hospital in Milwaukee, Wisconsin, to obstetricians in Paris, and two-way consultation took place.

An internationally televised explanation of a new medical procedure, hyperbaric pressurization, was carried on November 6, 1963 from the Royal College of Surgeons in England to the American Society of Anesthesiologists in convention at the Mayo Clinic in Rochester, Minnesota.

THRUST AUGMENTED DELTA

SYNCOM III LAUNCH



NASA ST 65-742
2-15-65

Consultation, diagnosis, prescription, and medical training on an international basis thus appear to be a benefit for exploitation by operational communications satellite systems of the future.

Communications satellites have also been used successfully to synchronize master time standards located in different continents. This was first accomplished in August 1962, between the United States and the United Kingdom via Telstar I[11]. An accuracy of 1 microsecond was achieved, compared to 2000 microsecond accuracies previously attainable. Further tests between the U.S. and Japan over Relay will extend this feasibility to another continent.

The wideband satellite, even though still in the experimental stage, provided solutions to many intercontinental time-lag problems of the news media. Relay I carried 76 network TV demonstrations, useful simulations of what might occur in a "real" system.

The skills and techniques developed to that point were dramatically employed in November 1963, when Relay I handled 11 TV spot newscasts, 8 between the United States and Europe, and 3 to Japan, in just three days at the time of President Kennedy's assassination. All the useful passes of the satellite were scheduled in order to bring to the world immediate coverage of the tragic events.

The United States' open attitude about its space program was clearly indicated to all who saw nearly real-time relaying of the Mercury flight of Astronaut Cooper, in May, 1963, and acknowledgement of this attitude was reflected by the return relaying of European reactions to the flight.

The peoples of Europe saw the American hospitality extended to the Russian Cosmonauts and to the Mona Lisa. The American people, in turn, saw the reception given to President Kennedy during his continental tour. Coverage of the last days of Pope John XXIII, his death and funeral, and the election and coronation of his successor, was of similar deep interest to people everywhere. Relay I later carried TV of the 1964 Winter Olympics from Europe to the United States.

The feasibility of comparing newly taken oceanographic data with known historical references to check quickly the accuracy of shipboard measurement equipment was demonstrated on September 19, 1963. The U.S. Bureau of Commercial Fisheries vessel, GERONIMO, was participating in Equilant II, an intensive survey of the tropical Atlantic in the Gulf of Guinea. GERONIMO encoded and transmitted its processed data to the USNS KINGSPORT at Lagos, Nigeria, for relay via the NASA Syncom II communications satellite to the National Oceanographic Data Center, NODC, Washington, D.C. At NODC the data were compared for consistency with available historical data from the 5° square within which the readings were made. Had those measurements been totally inconsistent with the others previously taken, oceanographers could have been alerted to an anomaly to be explained, confirmed, or corrected at minimum cost in time and money.

One of the most widely known communications satellite demonstrations was the international TV coverage of the Olympics from Japan in October 1964. TV programs were transmitted not only to the U.S., but to Europe as well. The European transmission marked the first time that two satellites had been employed in tandem for TV purposes. The programs were transmitted from Japan to the U.S. via Syncom III over the Pacific to Pt. Mugu, Calif. and retransmitted via Relay I over the Atlantic to Europe. Communications satellites are the only practical means of transmitting "live" TV programs over these distances.

In addition to U.S. viewers, more than 50 million Europeans behind the Iron Curtain viewed same-day transmission of the Tokyo Olympic games via U.S. satellites. The Tokyo Olympic coverage transmitted from Japan was received throughout Europe as far east as Poland.

In addition to transmission to Europe via Relay I, Tokyo Olympic pictures, sent from Pt. Mugu, California, by landlines, were videotaped in Montreal and flown to Europe for broadcast throughout the continent via the Eurovision network and behind the Iron Curtain by Intervision. Because of the time differential, European viewers saw Tokyo events on the evening of the same day they had taken place.

Total viewers in Spain, Italy and Portugal were estimated at 16 million; the United Kingdom counted an audience of approximately 13 million. From Warsaw, the American Embassy reported that 85 percent of Poland's 1,500,000 television receivers were tuned to the Olympic programs.

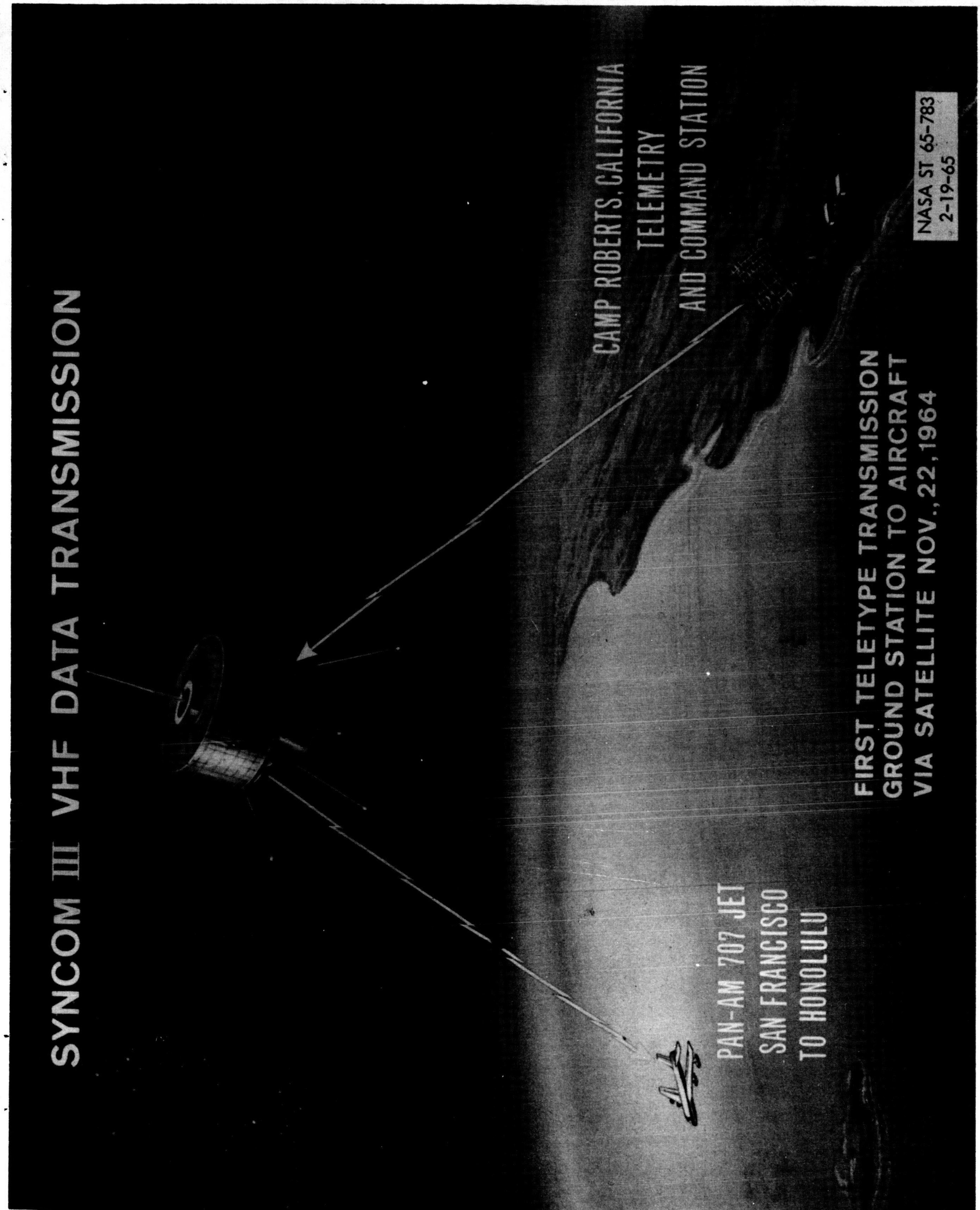
"Polish TV proudly credited the Syncom and Relay satellites," the Embassy reported. "There was considerable press comment about the special transmissions and the fact that these facilities were the result of American technology is widely, if not universally, known here."

In West Germany, where the audience is believed to have exceeded 20 million, the Olympic transmissions were credited with increasing the sale of television sets by more than 50,000 over the previous month's sales.

In a totally different kind of demonstration, NASA participated with the FAA, Air Transport Association, and private industry, in transmitting teletype test messages to a commercial aircraft, operating between Hawaii and California, via Syncom III on November 22, 1964. This was the first test demonstrating such feasibility, and has implications affecting the solution of communications, navigation, air-sea rescue, traffic control and small ground station problems. Chart ST65-783 pictures the test.

10. Experimental Conclusions

By the end of 1964 it was possible to conclude that Telstar I and II, Relay I and II, and Syncom II and III had demonstrated that:



SYNCOM III VHF DATA TRANSMISSION
CAMP ROBERTS, CALIFORNIA
TELEMETRY
AND COMMAND STATION
PAN-AM 707 JET
SAN FRANCISCO
TO HONOLULU
FIRST TELETYPE TRANSMISSION
GROUND STATION TO AIRCRAFT
VIA SATELLITE NOV., 22, 1964
NASA ST 65-783
2-19-65

- Communications quality via satellite relay was good out to at least 23,000 statute miles;
- Ground stations existed which operated routinely and effectively;
- Ground station technology was not limited to the U.S.;
- Accurate antenna pointing was practical;
- Orbital information could be routinely derived and disseminated;
- There had been no reported interference to surface microwave services;
- Control of a number of ground stations was feasible;
- <u>and that, therefore space communications technology was adequate for early communications satellite systems.</u>

VI

Technology Developed by the U.S. for Use By Designers of Early Systems

A. Certainty of Technical Feasibility

Surely it was in expectation of these communications satellite successes that the President of the United States stated in 1962 "our intensive research and development in the field of communications satellites have brought us to the point where we are now certain of the technical feasibility of transmitting messages to any part of the world by directing them to satellites....... The actual operation of such a system would provide a dramatic demonstration of our leadership in this area of space activity... The direct benefits -

economic, educational, and political - of this improved world-wide communication will be invaluable."

Even prior to this firm conviction, work had been begun in 1960 to bring about the legislation necessary to executing this leadership through a private corporate entity: the Communications Satellite Corporation.

B. Summary of the Communications Satellite Corporation's Formation and Plans

The Communications Satellite Corporation (Comsat) was authorized by Act of Congress on August 31, 1962, and incorporated on February 1, 1963[18]. The Act stipulated that NASA was to launch satellites for the privately-owned Corporation, furnish technical consultation, and cooperate with the Corporation in research and development. Comsat's first experimental/operational satellite was to be launched late in March, 1965, and plans called for deployment of a global commercial system beginning late in 1966.

The decision of Congress, to place commercial exploitation of communications satellites in the hands of a private Corporation, was preceded by more than two years of intensive study and discussion, in and out of Government, concerning operational use of satellites for international communications.

One of the earliest official actions directed specifically at operational use of communications satellites was a Notice of Inquiry[18] issued by the Federal Communications Commission (FCC) in May, 1960, concerning allocation of frequencies for space communications. This Inquiry prompted a joint industry-Government study which concluded, in March, 1961, that it was feasible for communications satellite systems to share frequencies with terrestrial microwave radio relay systems.

This and other studies formed the basis for U.S. proposals to the International Telecommunications Union that frequencies for communications satellite systems be allocated on a shared basis. Such allocations were made in November 1963[18, 19].

Meanwhile, the FCC instituted another Inquiry, in April 1961, into "the Administrative and Regulatory Problems Relating to the Authorization of Commercially Operable Space Communications Systems". This Inquiry prompted extensive discussion on the subject among Government agencies and communications carriers, separately and together. The U.S. Congress held hearings on various aspects of the establishment, ownership, operation and regulation of a communications satellite system, and in July 1961, the President issued a policy statement favoring private ownership of the U.S. portion of a world-wide communications satellite system.

At the opening of the 2nd session of the 87th U.S. Congress several bills were introduced, proposing both private and public ownership of communications satellite facilities. After considerable discussion and debate, an Act authorizing private ownership was passed on August 31, 1963, and the Communications Satellite Corporation (Comsat) was incorporated on February 1, 1963.

The new Corporation had two principal tasks before it; one was to define and develop a technically feasible and economically viable communications satellite system, and the other was to secure participation by foreign carriers. These two efforts proceeded concurrently.

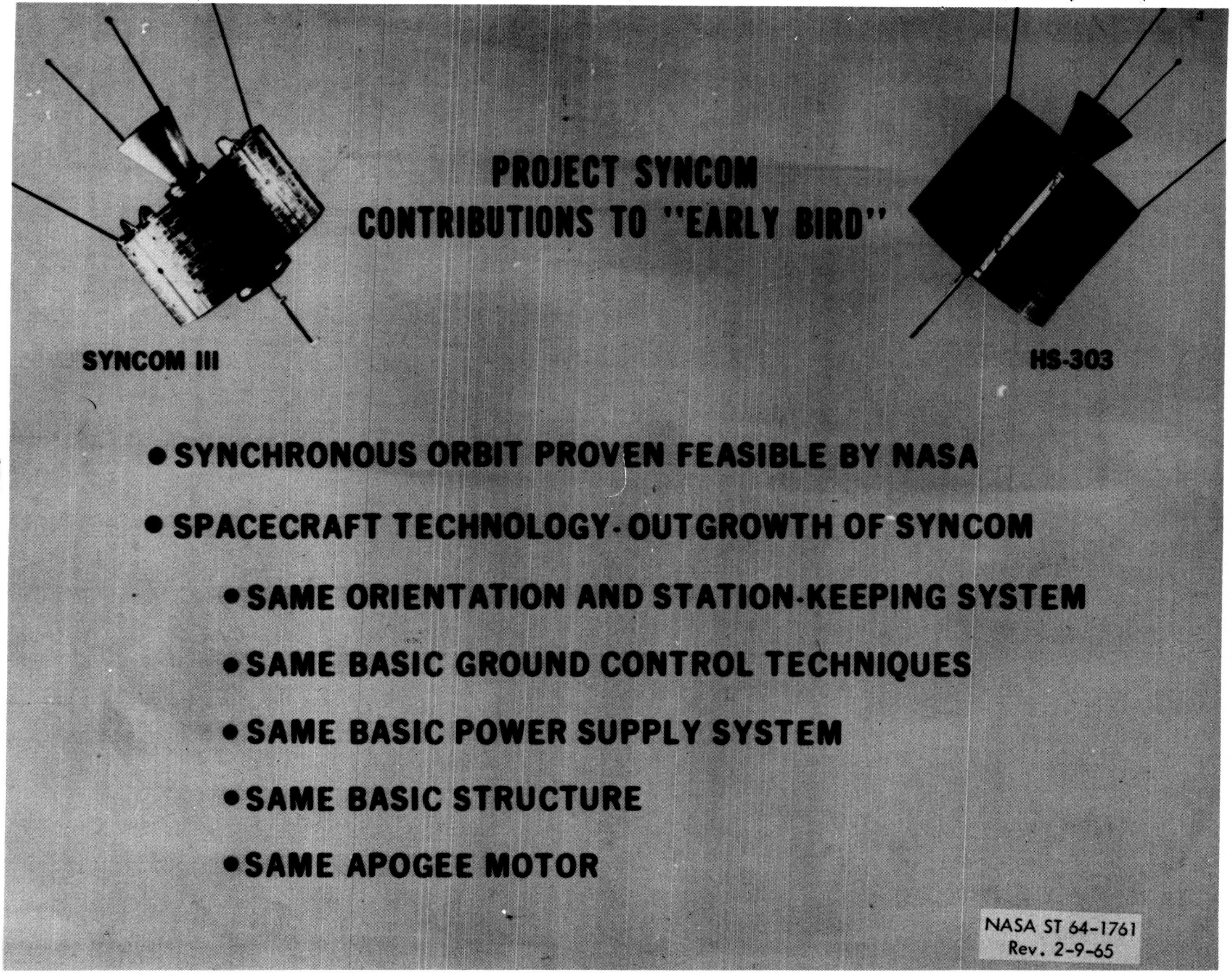
By the Summer of 1963, Corporation and State Department representatives were engaged in discussions with those European countries which by their possession of experimental ground stations, were obviously in a position to participate in an early operational system. These discussions were later broadened to include most of the countries in Western Europe, and Japan, Australia, and Canada. The discussions and negotiations culminated, in August 1964, in two multilateral Agreements, one a General Agreement among the Governments involved, the other a Special Agreement among the entities chosen to implement the global system[18]. As of February 20, 1965, the countries participating were:

Australia	Brazil
Austria	Jordan
Belgium	Kuwait
Canada	Sudan
Denmark	Lebanon
France	Libya
Germany	Syria
Ireland	Algeria
Israel	Tunisia
Italy	
Japan	
Netherlands	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	
United Kingdom	
United States	
Vatican City	

On the technical side, the Corporation's studies led them to choose a two-part program. The initial effort would be a synchronous altitude, low-inclination satellite, based on the NASA Syncom design, for service between North America and Europe. The later second phase was to be a truly global system.

In December, 1963, the Hughes Aircraft Co., designers of Syncom, submitted a proposal to the Communications Satellite Corporation for the initial satellite, known as HS-303 or "Early Bird." The relationship of HS-303 to Syncom is shown in Chart ST64-1761. Early in 1964 NASA agreed to launch one or more of these satellites, and to provide related services, on a reimbursable basis, as required under the Act. In December, 1964, NASA and the Corporation signed a formal Agreement detailing the services to be provided, the methods for determining costs, and related details. Under the Agreement, NASA was to procure and launch Thrust-augmented Thor-Delta vehicles, and provide related services. The specific NASA responsibilities are to:

- Procure and test launch vehicles
- Procure and test spacecraft apogee motors
- Manage launch vehicle-spacecraft integration
- Assure that launch vehicles are qualified for flight
- Manage and schedule launchings
- Provide tracking, orbital, pointing data and telemetry recordings during transfer orbit
- Provide camera coverage of apogee firing if feasible
- Perform other data, and communications services


PROJECT SYNCOM
CONTRIBUTIONS TO "EARLY BIRD"
SYNCOM III
HS-303
• SYNCHRONOUS ORBIT PROVEN FEASIBLE BY NASA
• SPACECRAFT TECHNOLOGY - OUTGROWTH OF SYNCOM
• SAME ORIENTATION AND STATION-KEEPING SYSTEM
• SAME BASIC GROUND CONTROL TECHNIQUES
• SAME BASIC POWER SUPPLY SYSTEM
• SAME BASIC STRUCTURE
• SAME APOGEE MOTOR
NASA ST 64-1761
Rev. 2-9-65

as requested by the Corporation and agreed to by NASA.

The launching requirements of the HS-303 program were as follows:

- Initial launch on or about March 23, 1965
- Backup, if necessary, 60-120 days later
- Optional launch during 2nd half of CY 1965
- Up to five optional launches between April 1, 1966 and March 31, 1967
- Replacement launches as necessary subsequent to March 31, 1967

Costs to the Corporation for HS-303 support were based on the principle of "identifiable additional cost", the principle advocated by NASA before Congress during testimony preceding adoption of the Act, and the basis for charging the American Telephone and Telegraph Company (AT&T) for services rendered by NASA in launching Telstar.

For the follow-on global system the Corporation had three separate design studies under way.

- One by Radio Corporation of America (RCA) and AT&T (Bell Telephone Laboratories) studied a system of randomly spaced medium altitude, spin-stabilized satellites at an altitude on the order of 6000 miles.
- Another with Space Technology Laboratories (STL) of Thompson Ramo Woolridge, considered a medium altitude system of "phased" satellites using gravity gradient attitute control.

- A third study, by Hughes Aircraft Company, on an improved synchronous, geostationary system.

The decision on which system to employ was to be made late in 1965, based on results of these design studies, experience with HS-303, and other factors.

C. Major Problems Ripe for Attack, NASA Near Term Plans 1965-1970

1. Applications Technology Satellite - The Technological Bridge to Future Promise

Constant increase in launch vehicle capability, and parallel improvement in space flight techniques, led naturally to the idea of an unmanned satellite performing several not necessarily related functions, or providing a capability for meeting several not necessarily related mission objectives. NASA initiated the Applications Technology Satellite (ATS) project in 1964 as a first step toward the idea of a multi-mission satellite for useful satellite applications.

The principal objectives of the ATS program at that time were to:

- Insure continuing availability of the spacecraft technology required for the useful application of satellites with particular emphasis on stabilization and orientation techniques;
- Provide means for conducting space experiments in various technological applications of satellites, with particular emphasis on the stationary orbit;

- Conduct a definitive experiment in gravity gradient stabilization, designed to provide basic information for use in design of stabilization systems.

The early history of this Program and these objectives are important, and let us digress for a moment and recount that history:

All of the experimental communications discussed thus far in this report radiated when transmitting, far more radio energy than was directed toward Earth. If, instead of a spinning satellite, one could be devised which would always keep one face pointed toward Earth, directive antennas could be used, and the energy incident on the Earth enhanced.

NASA has thus far, through 1964, demonstrated the useful application of satellites in meteorology and communications, using rather simple stabilization techniques. In order to provide for future growth, considerable spacecraft technology remained to be developed, with emphasis on spacecraft stabilization and orientation. This is particularly true in the higher altitude orbits. Many applications require Earth orientation of spacecraft in intermediate altitude orbits, and for very precise stabilization, orientation and station-keeping in the synchronous orbit. In order to reduce costs it became evident that a single spacecraft be developed capable of several different missions. Communications, meteorology, and navigation, for example, were a possible combination that could be accomplished from a single spacecraft in synchronous orbit.

One form of stabilization was recognized which required no on-board power. This "gravity gradient stabilization" is the mode of stabilization keeping the same face of the Moon always pointed toward Earth. Several tests of a gravity gradient attitude control system had been conducted earlier at low altitudes, but none at the higher altitudes of interest to communications satellites. NASA formulated plans, therefore, for a thorough technological test of gravity gradient stabilization at higher altitudes under its ATS Program.

A study effort conducted between 1962 and 1964, directed toward a large communications satellite, resulted in a systems concept and a subsystem and component engineering design, for a spin-stabilized synchronous satellite requiring an Atlas-Agena class launch vehicle plus a large "apogee kick" stage. The design of this satellite proved to be adaptable to other stabilization systems and to provide a capability to carry several types of functionally unrelated applications experiments. NASA proceeded therefore to a full flight project based on this spacecraft concept in order to test different types of stabilization technology and to provide a means for carrying out research in several engineering and technological disciplines on one spacecraft.

Plans for a five-flight program, beginning in 1966, and continuing through 1968, now include two spacecraft spin-stabilized in the synchronous orbit, a 6500-mile technological gravity gradient experiment, and two Earth-oriented in the synchronous orbit using a gravity gradient technique. In addition to the gravity gradient experiments, others in the areas of communications, meteorology, navigation, radiation detection, and radio propagation will undoubtedly be carried out. A picture of ATS-A as conceived in 1964 is shown in Chart ST65-642.

VII

Summary and Outlook

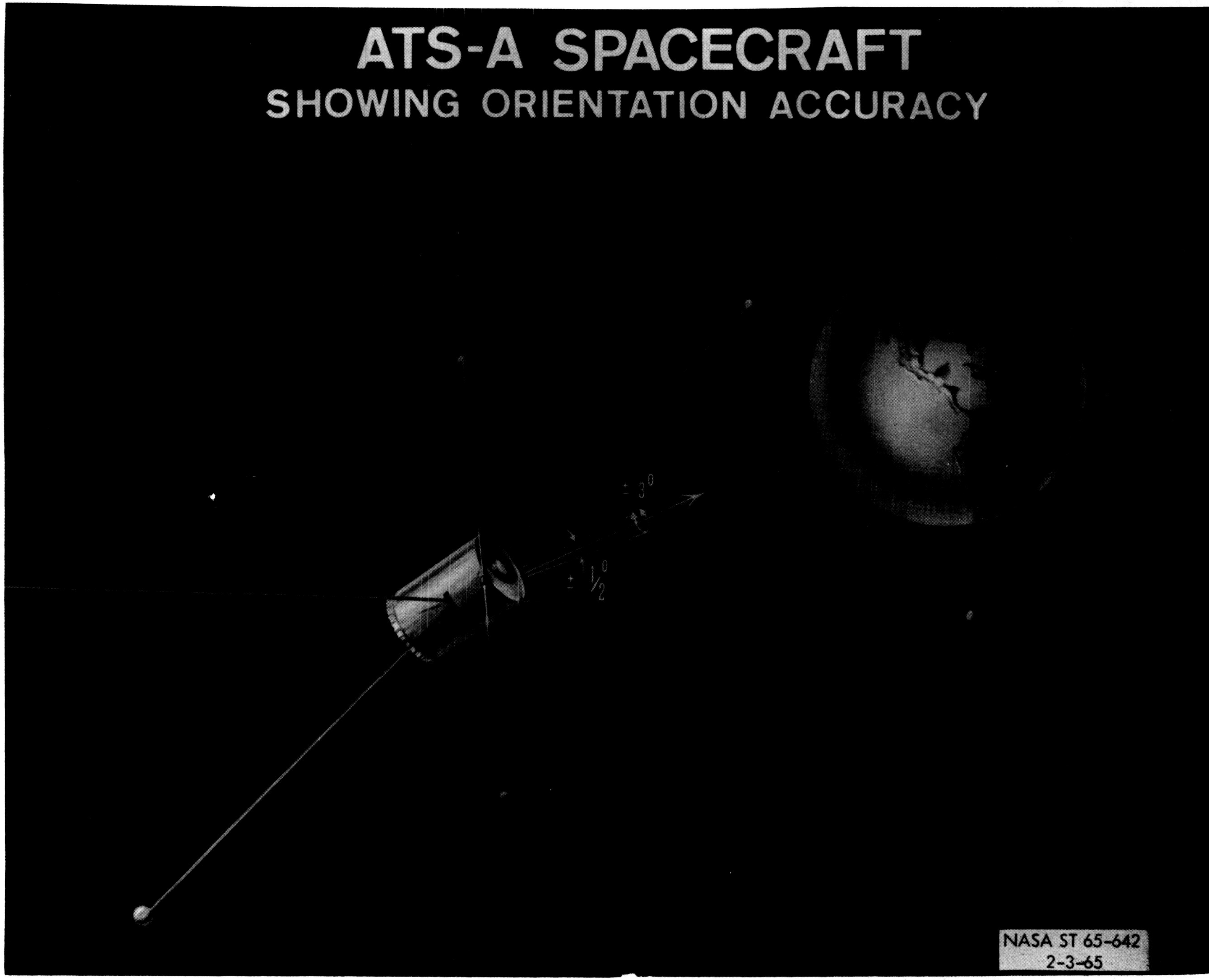
A. Achievements Specified

1. Technology of Communications Satellites[20, 21]

a. Passive

The erection in orbit, by inflation, of a large spherical passive reflector, was accomplished by the Echo Project[5]. Experience and experimentation resulted in improved materials and inflation systems. The large area to mass ratio of the Echo sphere provided data from which atmospheric density and solar pressure measurements have been extracted from Echo orbital observations[6]. Echo I, being initially of known size, smoothness and reflectivity permitted total communications system calculations that agreed with theory to within one decibel[5]. Future passive satellites have been well studied[22].

With Echo II, a long-lived, rigidized spherical passive satellite, the technology for erecting large structures strong enough to maintain themselves against the environment was demonstrated.


ATS-A SPACECRAFT
SHOWING ORIENTATION ACCURACY
± 3°
± 1/2°
NASA ST 65-642
2-3-65

b. Active

The communications capacity of spacecraft transponders was increased from narrowband (voice, teletype, and facsimile) to wideband, suitable for TV, or hundreds of telephone channels. Transponder design has been a fruitful arena for the application of a growing field within electronics: the design of reliable travelling wave tubes, components, circuits, and systems.

The effect of solar radiation on many spacecraft components, particularly solar cells[11], has been observed and improvements made[13]. The radiation environment and damage to the spacecraft components has been measured. The possibility of diagnosing the failure of a spacecraft and its reactivation from the ground, has been demonstrated[11].

2. Ground Station Design

Design parameters and system calculations have been confirmed by Echo I, and the value of noise reduction by application of cryogenic techniques (masers and parametric amplifiers) was confirmed as well. The lowering of the noise threshold at which a frequently modulated (FM) signal becomes readable, by use of FM with feedback (FMFB), has been amply demonstrated[7].

Propagation anomalies have been identified and are understood[23]. As a result, the utility of ground stations small enough to be transportable or shipborne[16] was experienced with Relay and Syncom ground stations. Tracking data have been generated which are sufficiently precise to provide accurate pointing information for communications antennas.

4. Orbital Characteristics - Effects on System Design

The limitations of the low altitude orbit for operational systems are known. The use of ellipticity at medium altitudes not only as a method of minimizing radiation damage to the spacecraft, but as a means of increasing or decreasing mutual visibility periods between certain ground stations at certain times, has been demonstrated.

Of great importance was Syncom III's achievement of geo-stationary orbit, with attitude and position control and full spacecraft communications capability.

Early, subjective, reactions to the fraction of a second time delay involved in communicating via synchronous satellite indicate a less serious problem than often predicted. System design considerations, more generally, have been thoroughly examined[24] and designers of future operational communications satellite systems now stand on more firm ground inasmuch as all orbit types have been proven feasible.

Computers have been used as an aid to optimization of system parameter trade-offs for given boundary conditions.

5. Impact on Operational Users by Public Acceptance of Demonstrations

A precedent for government licensing, and government launching of a privately-built satellite and system has been established by the Telstars. The Communications Satellite

Corporation has been established by the U.S. Congress, and a consortium formed. American and European audiences are conditioned and enthusiastic about intercontinental TV. The delivery of facsimile copy of "speedmail" letters by communications satellite has been demonstrated. Cooperative experimental programs, both inter-agency and international, have been proven feasible and valuable. Real-time reliable transmissions of conferences, both by the press and between heads of state, have been demonstrated.

6. Economic and Other Considerations

Problems of economics, and political considerations have been well examined[25].

7. Frequency Considerations

Frequency problems have undergone[19] sufficiently thorough examination to inspire reassurance that present assignments are adequate for a decade, and future changes will be made based on the sound base of a consensus of international experts in the CCIR and CCITT.

8. Typical Technical Results - Relay I

Typical of the technical results of each of the satellites described are those of Relay I, summarized here as an example.

The general conslusions drawn from Relay I were that the planned techniques of communications with a communications satellite resulted in a link of commercial CCIR quality. A low cost ground station with a smaller 30 foot antenna could be used successfully, furthermore, to work 12 telephony channels with a spacecraft of the Relay type.

Propagation and noise

In practically all cases, the measurements made of received carrier power agreed with predicted values within measurement error. The spin modulation of received carrier signal strength caused by the spacecraft antenna pattern was noticeable, but became objectionable only when the received signal was near FM threshold, where 3-cycle spin modulation carried it in and out of threshold. Signal strength at low elevation angles showed the same fluctuations due to ground propagation effects as observed on Telstar. Above 3^{o}, these effects were negligible.

Overall receiving system noise temperatures held quite well at each station over a period of time. At the Pleumeur-Bodou and Andover stations, rain actually caused system noise temperature to be worse at zenith than at low elevation angles. This was attributed to rain impinging more directly on the top than on the sides of the radome.

Measurements of continuous random noise - both wideband and narrowband - at all stations indicated that predicted values of noise were not quite being obtained. Departure from the predicted FM triangular noise spectrum had been observed at the lower base-band frequencies, but the increase was attributed to residual noise in the ground base-band equipment. The discrepancy between predicted and actual post-detection S/N was largely attributed to this, and other, extraneous noise sources in the base-band equipment. Representative values were as follows - predicted, 54 db; actual, 46 db (Pleumeur-Bodou); predicted, 45 db; actual 37 db (Goonhilly Downs).

Linear distortion

CCIR (Recommendation 267) standard video test signals and steady-state response measurements were both utilized to determine linear distortion of the system. Both methods indicated that the spacecraft caused little distortion of this type. The linear distortion noted was caused mainly by the ground base-band equipment. Measurements in the wideband mode of both video and audio steady-state response at base-band indicated that the Relay I objectives, based on the CCIR recommendations, were met. Representative values were: Video-flat within $\pm$0.3 db from 50 kc to 5 mc.; Audio - down 3 db at 50 cycles and at 8 kc. The general conclusion was that linear distortion did not offer a problem for communication spacecraft links of the Relay I type, over and above that inherent in ground microwave links.

Nonlinear distortion

Data obtained relative to nonlinear distortion indicated that the CCIR-oriented Relay I objectives for differential gain and phase across the r.f. and i.f. passband were not quite met at all times. Pre-emphasis at base-band was recommended to improve the differential gain characteristics, from early measured values of 2.8 db peak-to-peak, to the objectives of 2 db. Differential phase measurements as high as 45° were obtained, indicating that an objective of 5°, as required for color TV, was not attainable. Delay equalization and pre-emphasis was recommended as an aid in decreasing this phase shift.

It was tentatively concluded that nonlinear distortion in the Relay I system was completely within limits for black-and-white TV, but did not meet CCIR standards for color, even though it appeared adequate subjectively.

Multichannel telephony, intermodulation noise

Measurements made at the wideband stations of 300- and 600-channel intermodulation noise indicated that the objective (of 15,000 picowatts for the sum of thermal and intermodulation noise) was not always met. Equalization of delay in all the respective ground equipments was recommended. Representative values measured at Andover were 10,000 picowatts of thermal noise and 12,000 picowatts of intermodulation noise.

Narrowband measurements, mainly at the Nutley, New Jersey ITT station were made of envelope delay distortion, harmonic performance, and indirect measurements of intermodulation noise. Results indicated that the spacecraft met the Relay I objective of 7500 picowatts for intermodulation noise. Delay equalization in the ground equipments was again recommended to reduce intermodulation noise.

Envelope delay distortion and harmonic signal testing were pointed out as affording a means of measuring multichannel telephony interchannel noise indirectly.

Two-way (12-channel) telephony, intelligible crosstalk

AM-to-FM conversion in the spacecraft travelling wave tube appeared the cause for crosstalk from base-band of one carrier to the other. Complementary channel operation reduced this crosstalk to satisfactory levels.

Transmission Tests

Television tests involving the main wideband stations - Goonhilly, Pleumeur-Bodou, and Andover, were conducted numerous times. Relay I was used to transmit both video and audio through the spacecraft, obviating the need for any use of the transatlantic cable for sound transmission. Subjective performance of the TV link on Relay I proved excellent on many tests and demonstrations. Color television without sound was conducted through the spacecraft in loop configuration from Andover, with quality sufficient to put the program material on U.S. commercial network facilities.

B. Significant Technical Questions Undergoing Continuing Analysis

The technology represented by this early generation of flight tests is demonstrably adequate for the establishment of "first generation" operational communications satellite systems. A number of important technical questions still need to be answered, however, and are under intensive study. They are:

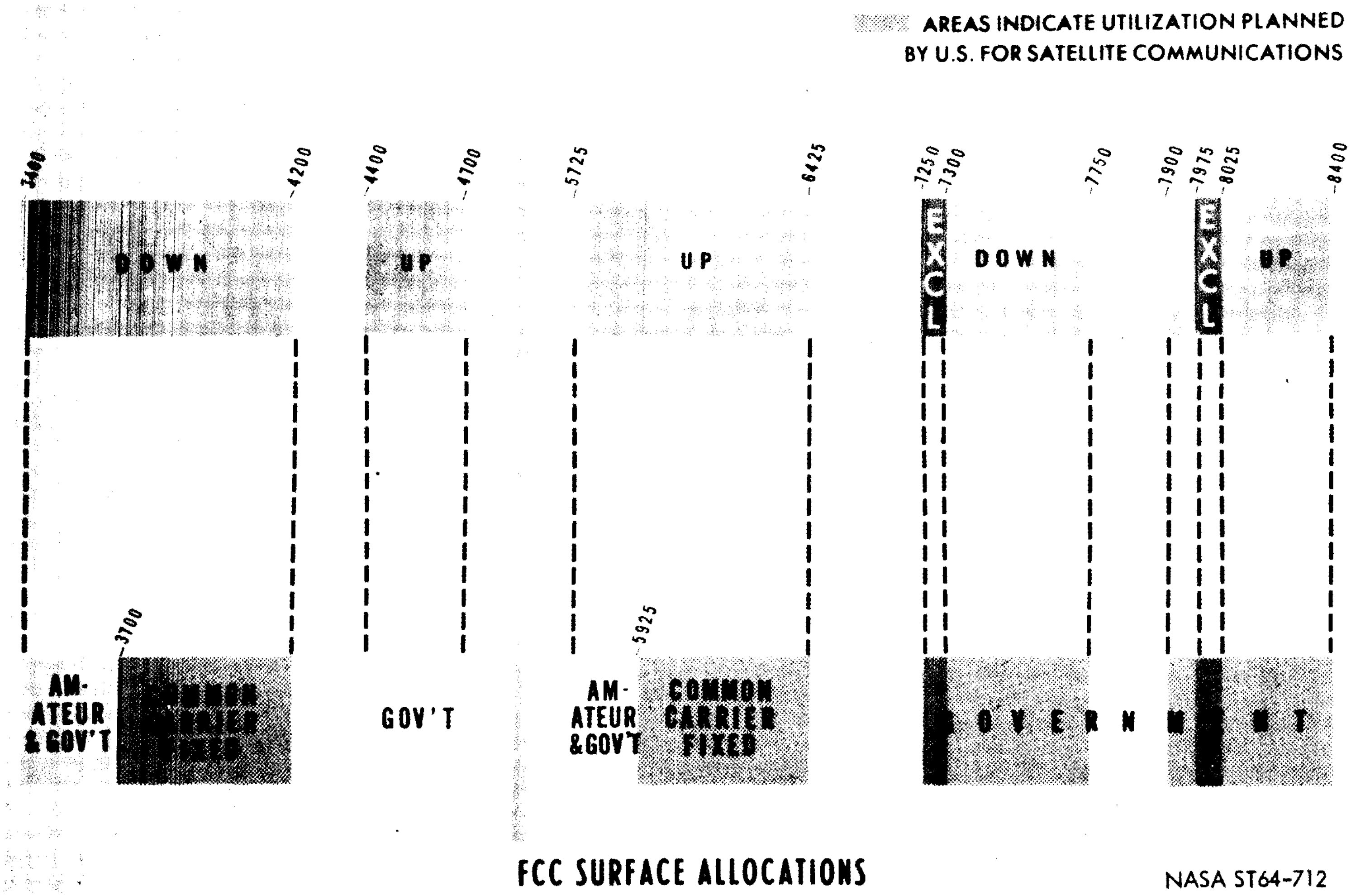
1. Frequency Allocations

It was apparent from the outset in 1959 that frequency-sharing with surface systems was mandatory for communications satellites, since the 1-10 Gc/s region, which is best suited for space communications, was already fully allocated to terrestrial services. Studies conducted in 1960-1962[19] concluded that frequency-sharing would be feasible. In November, 1963, the International Telecommunications Union allocated 2800 Mc/s of spectrum space for satellite communications systems on the basis of sharing with terrestrial systems (Chart ST64-712). Sharing criteria are very conservative, and further experience may well provide a basis for desirable relaxation, desirable since flux densities at the Earth's surface required for operation of small and inexpensive ground terminals are higher than allowed by the present criteria.

2. Time Delay and Echo[26]

A second important technical problem is the time delay inherent in synchronous altitude satellite systems in which the round trip delay is about 6/10 of a second. This delay by itself is not usually detectable by a telephone user. When terminations are imperfect, however, an echo occurs, and acceptability and usability of the circuit decreases rapidly with increasing echo amplitude. Echo suppressors are used to eliminate the echo, but echo suppressors are essentially voice-operated switches and they introduce undesirable side effects. The adverse effects of long-delayed echo led to a

ITU COMMUNICATIONS SATELLITE ALLOCATIONS



NASA ST64-712

1960 tentative international agreement that round-trip delays should not exceed 300 milliseconds, as recorded in the Annex to Question 6/XII in the CCITT "Red Book", 1960.

Additional laboratory and subjective tests of user reaction to time delays and echo were conducted for three years, 1962-1964, but with inconclusive results. The last in this group of tests was conducted by AT&T in collaboration with FCC, NASA, and the Communications Satellite Corporation. The most important results of these tests were submitted by the United States to the Plenary Assembly of the CCITT in Geneva in May, 1964. Based on these results and on information submitted by other administrations, particularly those of the United Kingdom, the CCITT provisionally recommended the following limitations on mean <u>one-way</u> propagation times when echo sources exist and echo suppressors are used.

a) Acceptable without reservation, 0 to 150 ms.

b) Provisionally acceptable, 150 to 400 ms. In this range, connections may be permitted; in particular, when compensating advantages are obtained.

c) Provisionally unacceptable, 400 ms and higher. Connections with these delays should not be used except under the most exceptional circumstances.

The problem of time delay and echo is not limited to voice communications. In fact, the conclusions may well be different when considered in connection with high speed data communications, particularly if automatic error detection, querying, and correction is included. Certain high speed automatic signalling and routing systems may be sensitive to the amount of delay.

3. Multiple Access

The successful application of satellite-borne repeaters for global telecommunications provides the potential for extending high quality telephone communications service to many points now served poorly or not at all. However, to fully realize this potential, a number of technical problems must be solved.

One of the most significant problems is called "multiple access", how to employ a single satellite-borne repeater simultaneously for communication among a number of ground stations, each communicating with one or more of the others.

Various methods of modulation and multiplexing can be employed to provide a multiple access capability. However, each scheme is sensitive to the configuration of the satellite system (medium or synchronous altitude), the number of participating ground stations, the traffic demands of each, the required flexibility of routing, etc.

Many papers[27] discuss the general attributes of the four principal categories of multiple access technology (multiple FM carriers, SSB in the up-link, time division multiplex, and common spectrum), and make an assessment of their relative merits.

Every evidence now exists that effort on this problem will continue to a successful resolution.

C. Outlook - The Near Future

1. Foundation Laid

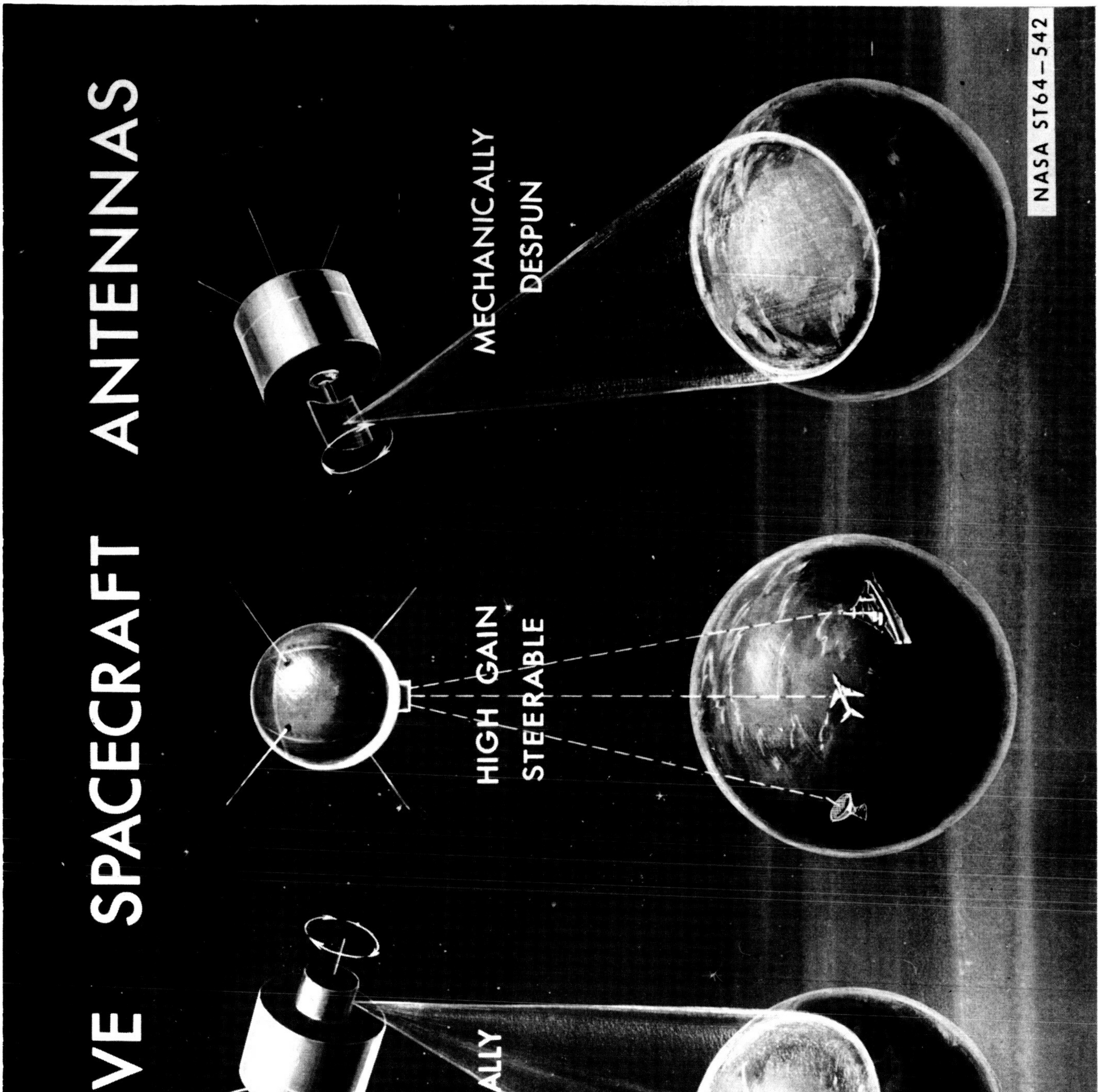
The first phase of the NASA Communication Satellite R&D Program was completed with the launch of Syncom III on August 19, 1964. This was the last scheduled launch directed exclusively toward developing the techniques and technology for high traffic density point-to-point communication satellite systems. The results of Telstar I and II, Relay I and II, and Syncom II and III have made adequate technology available for the development of the commercial communications satellite system which the Communications Satellite Corporation will establish, for example.

2. Bridge Built

The Applications Technology Satellites (ATS) Program, initiated early in 1964, will provide a spacecraft to be used for research, development and flight-testing common to a number of applications. The five ATS flights will develop the active and passive three-axis stabilization techniques for spacecraft in stationary orbit, and will attain further technological goals by performing critical experiments in communications, meteorology, and navigation.

3. The 1970's

The technology now available will permit establishment of early operational systems capable of heavy traffic densities, but only through the use of rather sophisticated and expensive ground terminals. Those services, which for many reasons require smaller terminals can only utilize satellites if the power flux at the surface of the earth could be increased several orders of magnitude above that produced by the first generation of communications satellites. Notable examples of such services would be air traffic control and navigation, broadcast services, mobile services and others. An increase in "effective radiated power" (ERP) from the spacecraft is required and attainable by increasing the spacecraft power output, by increasing spacecraft antenna gain (Chart ST64-542) requiring improved spacecraft stabilization, or by a combination of both. Any of these alternatives necessitate larger spacecraft than are required for systems using larger ground stations. Consideration should soon be given to flight projects directed toward higher power and improved stabilization and antenna gain, in the time period after the ATS A through E launches; i.e., during the early 1970's. System types which might be considered could be navigation and traffic control satellites, and radio and TV broadcast satellites, shown in Chart ST65-782. The interim period must be devoted to supporting research in components and techniques areas, directed toward technology for meeting requirements for higher spacecraft power and antenna gain, and improved spacecraft stabilization. Work on multiple access techniques, and on highly directional electronically steerable antennas must continue.


DIRECTIVE SPACECRAFT ANTENNAS
ELECTRONICALLY DESPUN
HIGH GAIN STEERABLE
MECHANICALLY DESPUN
NASA ST64-542


COMMUNICATION & NAVIGATION OPPORTUNITIES
AURAL BROADCAST SATELLITE
HF OR FM-RADIO
CONCEPT
MARS
PROBE
MOON
LASER
BEAMS
STABLE
POINT
MICROWAVES
INTERPLANETARY
EARTH
DIRECT BROADCAST SATELLITE
TV CONCEPT
COMMUNICATIONS/NAVIGATION SATELLITE
CN-3 CONCEPT
NASA ST 65-782
2-18-65

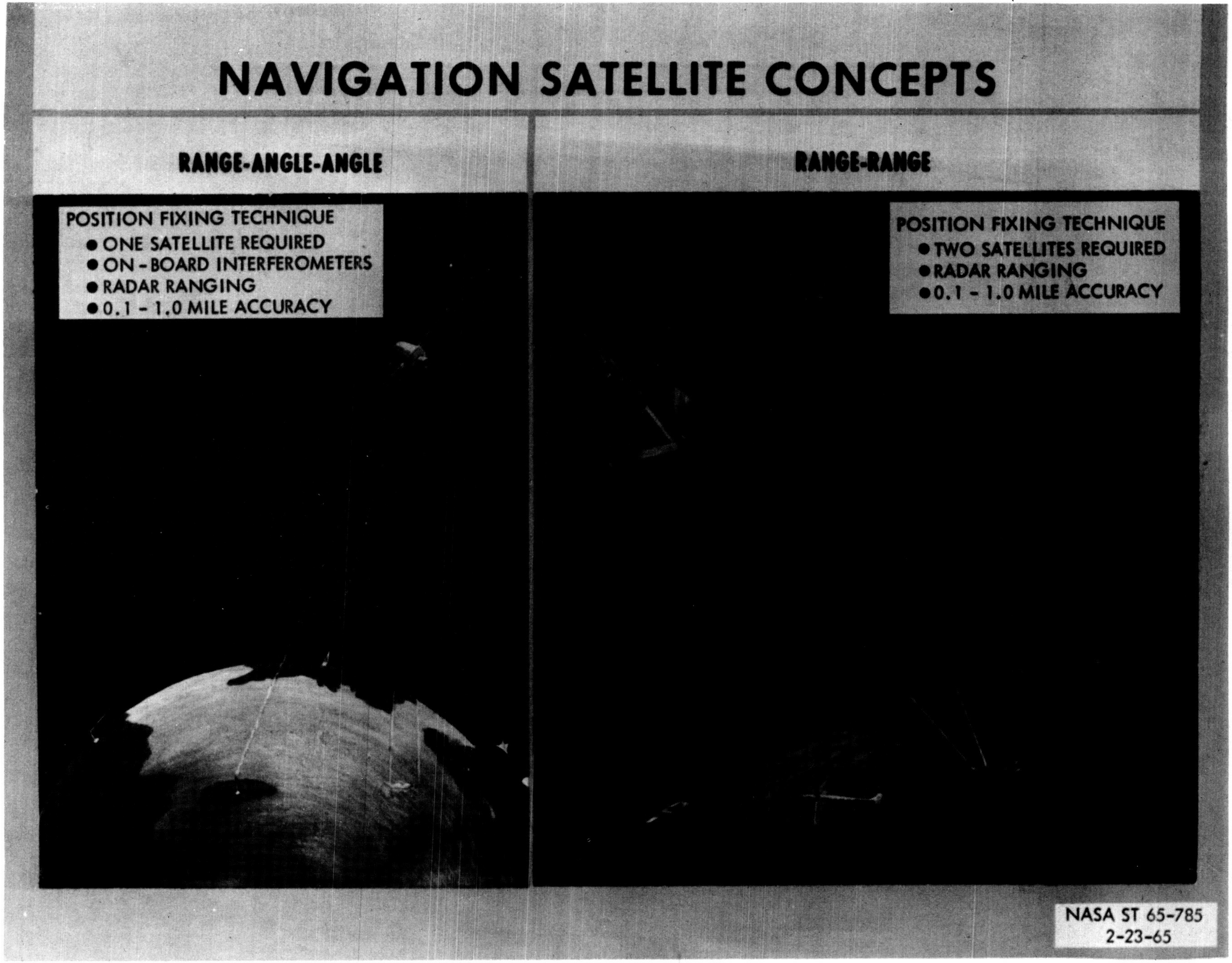
Under study at NASA are navigation satellites to meet these needs. These navigation spacecraft could determine the feasibility of satellite techniques as a navigational aid for ships and over-ocean aircraft, for air traffic control, for coordination of air-sea emergency and rescue, and for tracking other satellites and spacecraft as well as communications between small mobile terminals such as ships and airplanes. Two of the satellites under conceptual study (Chart ST65-785) utilize many of the technological advances of the synchronous altitude Applications Technology Satellite. One would weigh approximately 700 pounds, be placed in a 22,300 mile circular orbit by the Atlas-Agena, and be designed for a 3-year lifetime. The technology required for the successful accomplishment of this mission will become largely available from the ATS Program. In order to accomplish the 3-year lifetime however, advancements in spacecraft components will be required, as will technology for a precision spaceborne interferometer.

Such a mission would typically depend on the ATS Program for basic technology in the areas of spacecraft stabilization, component flight-testing and environmental data. No such missions will be attempted until these and other required technologies flow together, notably those of launch vehicles and spacecraft power sources.

Further advances in higher power communications satellites are ultimately foreseen. Called broadcast satellites[28], they could be capable of broadcasting either voice or television directly to the average home radio or television receivers of entire populations. Broadcast satellites should be placed in the synchronous orbit, so they will not move relative to the receivers in the homes. Having accomplished this, the simplest of receiving antennas could be used.

Broadcasting satellites can further provide for emergency and Civil Defense communications to an entire country. As an educational aid they can be used to bring the best of educational material to the remotest of communities. They can provide for global dissemination of information, and can ultimately serve to unite and elevate, educationally and culturally, the people of entire geographic areas more rapidly than would conventional techniques.

A broadcast satellite for television, however, would require ten's of kilowatts of radiated power to cover even limited areas on the earth. The development of nuclear reactors however could provide an initial capability perhaps by 1975. The problems of reliably handling large power levels in space are great; therefore, an intermediate step which uses a one to three kilowatt power supply to power an aural radio broadcast satellite in synchronous orbit appears desirable. Such satellites, perhaps by 1971, could provide voice broadcasts to home receivers over nearly an entire hemisphere, and provide the necessary experience with the problems of high power in space, as well.


NAVIGATION SATELLITE CONCEPTS
RANGE-ANGLE-ANGLE
POSITION FIXING TECHNIQUE
● ONE SATELLITE REQUIRED
● ON-BOARD INTERFEROMETERS
● RADAR RANGING
● 0.1 - 1.0 MILE ACCURACY
RANGE-RANGE
POSITION FIXING TECHNIQUE
● TWO SATELLITES REQUIRED
● RADAR RANGING
● 0.1 - 1.0 MILE ACCURACY
NASA ST 65-785
2-23-65

It is important to emphasize, however, that any concept of a broadcast satellite must include an assessment of the policy questions it raises, concurrent with the technical.

Resolution of those questions - legal, economic, and political - must be sought at a pace appropriate to that at which the technical question is resolved.

A hopeful sign of a tolerant and optimistic attitude toward broadcasting from satellites is contained in Recommendation Number 5A of the Extraordinary Administrative Radio Conference (EARC) held in Geneva in 1963[28]. The Conference recommended that the CCIR expedite its studies (of technical feasibility) and make early recommendations on technical characteristics of systems, and frequencies for operation.

It is significant to note, therefore, that there is heartening evidence that efforts to develop the technology of broadcast satellites can be matched by concurrent efforts to resolve those non-technical questions forming the keystone to their ultimate potential.

NASA, for its part will work to provide information on the technical feasibility, need, and economic justification of these higher powered satellites, as it becomes required to assist in the making of these decisions in a timely manner.

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