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HISTORIES OF

THE SPACE TRACKING AND DATA ACQUISITION NETWORK (STADAN),

THE MANNED SPACE FLIGHT NETWORK (MSFN),

AND THE NASA COMMUNICATIONS NETWORK (NASCOM)

by

William R. Corliss

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

People everywhere appreciate the fact that the U. S. was willing to share its program so effectively with them by means of modern communications. People of many countries have told me personally that they certainly appreciate not only our technology but also our intent in trying to build a better world through our space experiences. To those of you out there on the network who made all of the electrons go to the right places, at the right time ---and not only during Apollo XI----I would like to say thank you.

Remarks by Neil Armstrong to tracking network personnel on March 18, 1972.

FOREWORD

This is a partial history of the NASA tracking and data acquisition networks insofar as it does not include a major segment, the Deep Space Network (DSN), which is managed for NASA by the Jet Propulsion Laboratory. It is planned to incorporate the DSN into this document in the near future and publish a complete history of the tracking networks at that time.

In his remarks to the House of Representatives on the NASA appropriation bill, on June 3, 1971, Congressman Olin E. Teaque, now chairman of the House Committee on Science and Astronautics, commented: "The tracking and data acquisition program in NASA is one of the unsung heroes of our space program, and very little comes out in our reporting of this essential element of the space program." In this work, the author, Mr. William R. Corliss, recaptures and summarizes the events and decisions which led to these vital tracking and data acquisition networks and presents some of the highlights in their very successful support of the Mercury, Gemini, and Apollo missions. Many of you receiving this document have played roles in creating the networks, and I hope in reading it will recall, as I did, not only the problems but the many satisfactions that were experienced along the way.

Gerald M. Truszynski

PREFACE

Work on this historical monograph began in 1965, when the author was commissioned by Goddard Space Flight Center to prepare a short history of STADAN. Later, this historical work was expanded to include the MSFN through Apollo 8. In 1971, NASA Headquarters, after carefully reviewing the work done for Goddard, asked that the monograph be expanded further to include more emphasis on other NASA centers contributing to the MSFN. In addition, the histories of STADAN, the MSFN, and NASCOM were brought up to mid-1971. This latter work was done under NASA Contract NASW-2169.

In this history I have tried to satisfy both engineers and historians. Consequently, some portions may seem rather technical to historians, while other parts will dwell too much on politics and people for the liking of the engineers. I hope I have achieved a happy balance.

While I have made every effort to present the many facets surrounding these programs as accurately as possible, the very complexity of this effort has made me aware of the likelihood of error. Corrections and additions are invited.

William R. Corliss

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Chapter 1. INTRODUCTION

Every spacecraft that NASA launches becomes part of what has come to be called a *space data system*. From spacecraft sensor to data-processing computer, each component of a space data system plays a vital role in speeding data, voice conversations, and commands among the spacecraft and the mission controller and scientific experimenters on the ground. (Figure 1-1).

Spacecraft are no respecters of geographical boundaries, so NASA has had to build worldwide networks of Earth-based stations that can converse with a spacecraft overhead and accurately measure its position (the tracking function). Part of the history developed in subsequent chapters deals with the deployment of tracking and data acquisition stations around the globe; another part covers the linking of these dispersed stations to centralized control centers via cables, radio links, and communications satellites. Thus, as we view the total space data system, this history excludes the spacecraft and their sensors at one end and the data processing equipment and information displays at the other end. In between, however, are some two dozen Earth-based stations linked by more than two million miles of communications lines--more than ample substance for the historian of advanced technology.

NASA actually operates three major sets of tracking and data acquisition stations; each has a different mission:

STADAN:	the Space Tracking and Data Acquisition Network, which services scientific and applications satellites.[1]
MSFN:	the Manned Space Flight Network, which has been assigned to the Mercury, Gemini, Apollo, and other manned space ventures.
DSN:	the Deep Space Network, which handles unmanned lunar, interplanetary, and planetary spacecraft and backstops the Apollo manned lunar landing program.[2]

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[1]In late 1971, NASA initiated planning for the consolidation of the STADAN and the MSFN into a single network, the NASA Spaceflight Tracking and Data Network (STDN). This consolidation will proceed gradually, with full implementation expected by mid to late 1975.

[2]The historical development of the DSN is covered in a separate monograph prepared by the Jet Propulsion Laboratory.

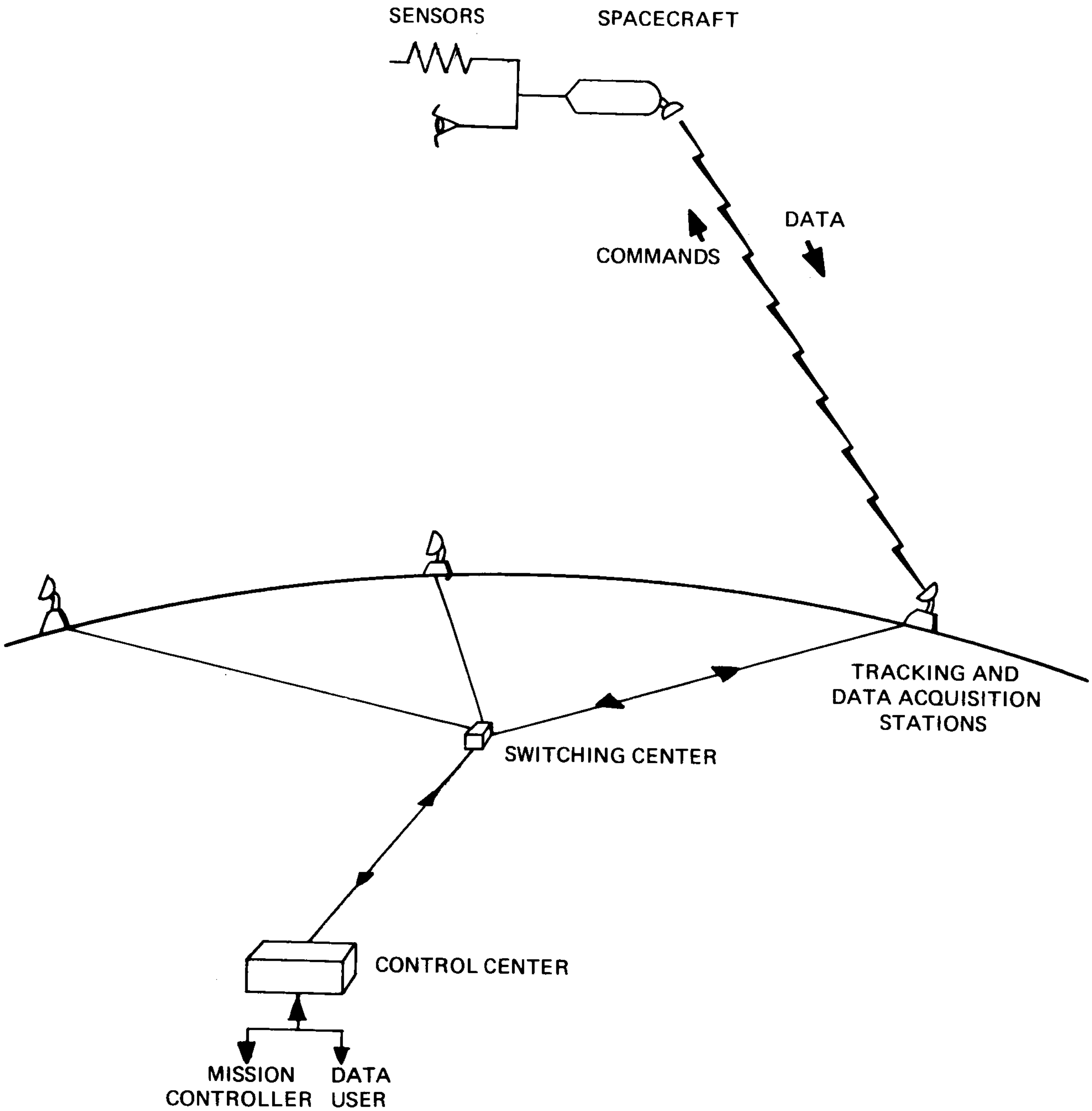

Figure 1-1. The space data system includes the spacecraft sensors (including man) and all communications and data handling equipment back to the data user. Tracking equipment adds data to the information stream at the tracking and data acquisition station. Data flow toward the control center, while commands flow in the opposite direction.

Each network started from a different point and has a history all of its own. Although the three networks were tied together in the early 1960s via NASA's worldwide, real-time communication system, NASCOM, it is only within recent years that technological and geographical convergence can be noticed with respect to the stations and their equipment.

Between 1958 and 1972, NASA invested roughly one billion dollars in tracking and data acquisition facilities. This investment has paid off handsomely, not only in terms of the many successes of America's space flight programs but also in two other kinds of coin: (1) the NASA stations are welcome emissaries of the United States in many foreign countries, and (2) NASCOM has become an important national asset, permitting near-instantaneous or *real-time* exchange of scientific data and voice messages between all continents save Asia and Antarctica.

The Minitrack Network, the progenitor of STADAN, was the first U.S. satellite tracking network to become operational (1957); so, our history begins here. However, before Minitrack evolved into STADAN, the Mercury Network became operational in 1961, and the foundations of the Apollo configurations of the MSFN were on the drawing boards. In the early 1960s, NASCOM, too, began to take shape. Thus, three slowly converging historical developments unfolded during NASA's first ten years of existence. So that the threads of the stories do not get too entangled, the three histories--STADAN, MSFN, and NASCOM--will be recounted separately, with cross references to the parallel chapters where appropriate.

Chapter 2. THE EVOLUTION OF STADAN

Purpose of STADAN

Scientific and applications satellites are information gatherers. Some radio back to Earth measurements of the Earth's magnetic field; others transmit TV images of the cloud cover below. The success of such operations depends, first, upon a communication link from satellite to Earth and, second, upon some means of fixing the satellite's position when it makes its measurements. These two functions, *data acquisition and tracking*,[1] are intrinsic to STADAN and form the basis for the acronym: STADAN = Space Tracking and Data Acquisition Network. Telemetry and tracking data are relayed to control centers where decisions are made concerning the operation and control of each spacecraft being "worked" by the network. Appropriate commands are then sent to network stations for relay to the spacecraft. Command and control constitute the third network function. A fourth function is that of terrestrial communication, in which data gathered from all over the globe are funnelled into the control center and data processing facilities. NASA's worldwide communication system is called NASCOM; it serves STADAN and two other NASA networks: the Manned Space Flight Network and the Deep Space Network. STADAN, therefore, is a worldwide complex of tracking equipment, data-receiving antennas, command antennas, and all the electronic gear associated with these functions. Under the overall direction of the Office of Tracking and Data Acquisition, NASA Headquarters, Goddard Space Flight Center has the operating responsibility for STADAN.

The records that arrive at Goddard carry not only data from the satellites' instruments and attitude sensors but also the tracking information acquired by the Earth-based station making the telemetry recording. It is of crucial importance that orbital position and satellite attitude be added to each record made by a satellite scientific instrument; because, if the scientist conducting the experiment does not know where the satellite is and which way his instrument is pointing, he cannot properly interpret his data. Worldwide STADAN thus is essential to the success of weather satellites, earth resources satellites, geodetic satellites, solar observatories, and the many other diverse instrument carriers orbited by NASA.

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[1]The "tracking function" is understood to involve the obtaining of *metric data*; i.e., range, range rate, angular bearing, etc.

STADAN is not used for all spacecraft. The Deep Space Network (operated by JPL) is used primarily for unmanned, deepspace probes, while spacecraft in the Mercury, Gemini, and Apollo programs have been tracked by the Manned Space Flight Network. However, the boundaries or "interfaces" between the three NASA networks have never been firm. There has been considerable cross-use of facilities.

Similar interfaces exist between STADAN, the farflung tracking networks maintained by the Department of Defense for military satellites, and the facilities of France, Italy, and ESRO (European Space Research Organization). There is constant interchange of information between all networks on scientific projects.[2]

One final point remains in connection with other satellite radio tracking networks, particularly SPASUR and ESTRACK; many networks have adopted radio interferometry for satellite tracking, a technique pioneered by the U.S. Naval Research Laboratory (NRL) during the International Geophysical Year (IGY) on Project Vanguard. STADAN itself has evolved directly from the NRL Minitrack network as new stations and equipment have been added to the basic core of IGY Minitrack stations. As this history will show, however, present-day STADAN equipment and configuration bear little resemblance to the simple "fence" of interferometers originally erected along the 75th meridian.

Another interface must be defined--the boundary between STADAN and the Smithsonian Astrophysical Observatory (SAO) network of satellite-tracking Baker-Nunn cameras. This network is financially supported by NASA, but it is not part of STADAN. The next section will discuss the fascinating confrontation between optical and electronic tracking prior to the IGY.

With the functions of STADAN established and its interfaces with other satellite networks summarized in Figure 2-1, what is the best way to organize an expedition into the past to dig out its history? Unlike the vicissitude-ridden story of America's early satellite efforts,[3] STADAN's history

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[2]For descriptions of SPASUR and ESTRACK and the other acronym-bearing satellite networks, see William R. Corliss, *Scientific Satellites* (Washington: NASA SP-133, 1967).

[3]R. Cargill Hall, "Early U.S. Satellite Proposals," *Technology and Culture*, Vol. IV, Fall 1963, p. 410.

is a rather orderly, cause-and-effect tale that logically breaks down into five phases:

1. Pre-IGY tracking developments
2. The IGY phase; from satellite proposals to satellites in orbit, 1955-1958
3. Minitrack operations, 1958-1962
4. Minitrack evolves into STADAN, 1960-1966
5. STADAN consolidation and integration with the MSFN, 1965-1972.

The temporal boundaries between these phases are not hard and fast; the phases overlapped.

A key feature of Minitrack and STADAN development had been the anticipation of satellite requirements--by several years in some instances--and the construction of equipment and deployment of stations to handle new satellites from the day they are launched. Just as obviously, STADAN cannot be static today. Tomorrow will bring new tracking techniques and new satellite programs may call for new stations in far-off places. At the moment, however, STADAN has reached a temporary plateau of development which is adequate for the present state of America's scientific and application satellite programs. Thus we have a propitious period of relative quiet in which to look back and see how STADAN became what it is today.

Pre-IGY Tracking Developments

STADAN has three functions: spacecraft tracking, data acquisition, and command; each of which has a historical trail leading back many decades, even into the 19th Century. Data acquisition via a radio link goes back at least to 1925, when the Russian scientist Pyotr A. Moltchanoff received telemetry signals from instruments he had installed on a balloon launched in Siberia. The function of remote command, where unmanned machines are controlled by radio signals, goes back to the 1920s, when many tinkerers built remote-control boats and aircraft. Weather stations and astronomical observatories have had centralized data-collecting facilities for centuries. Fascinating as the histories of such activities may be, it is the tracking function that leads us directly to the early Minitrack network, the precursor of NASA's STADAN. Even more specifically, radio interferometer tracking has done the most to shape the present STADAN network, although optical tracking and Doppler

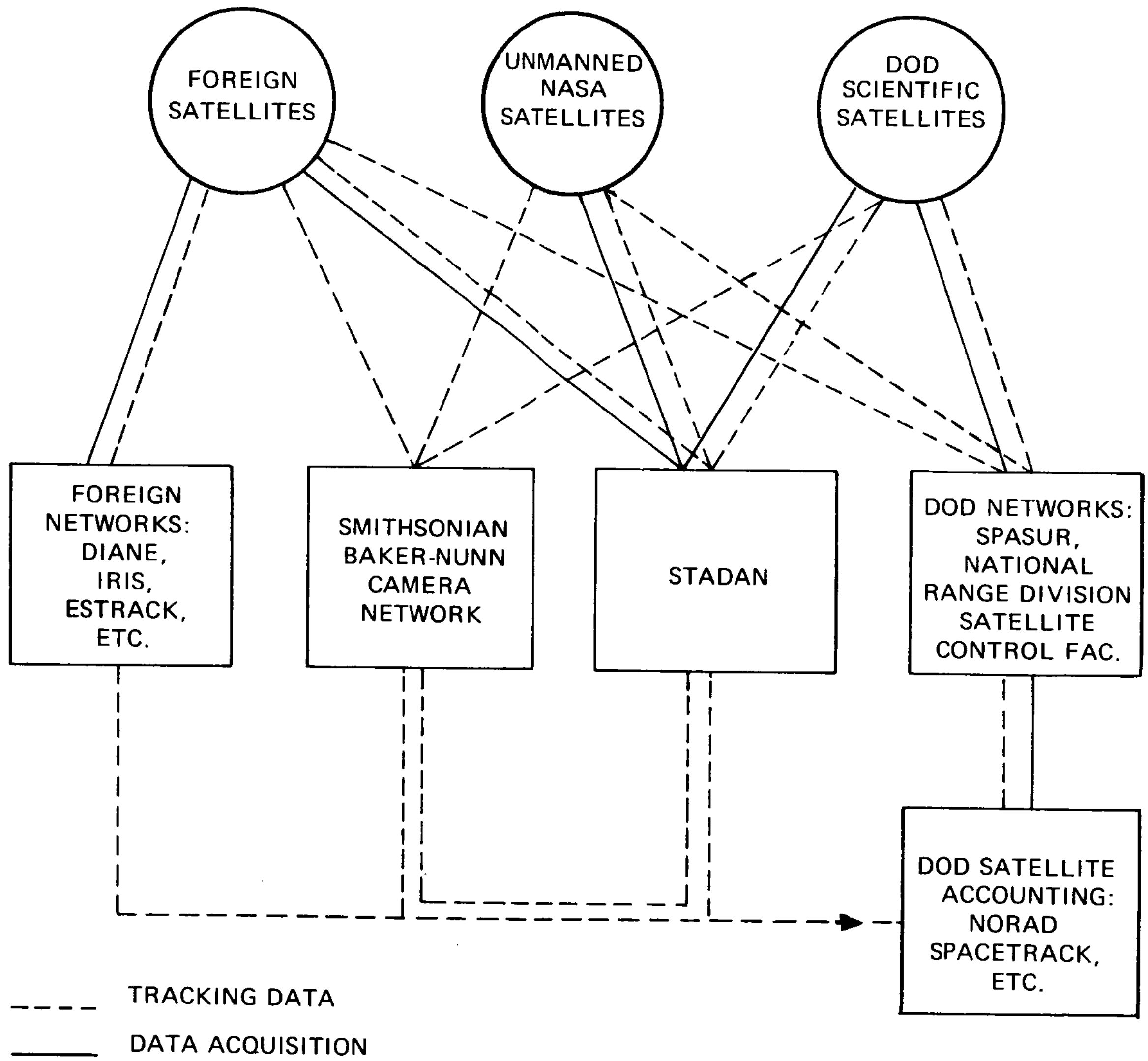

Figure 2-1. Summary of STADAN interfaces with other networks.

tracking have all contributed.

Antiquity of Optical Tracking. Tracking means measuring the position and possibly the velocity of a moving object. Today astronomers track the stars with telescopes driven by clock-controlled motors. Before such refinements, Tycho Brahe, in the 16th century, Ptolemy, in the 2nd, and their predecessors in earlier centuries had manually followed the stars and planets with astrolabes and other sighting devices. The point is that optical tracking is a venerable, well-proven part of our technical repertoire. When faced with the problem of tracking an artificial celestial object, it was logical to think first of optical techniques. This is precisely what happened with the artificial satellite.

As a matter of fact, the first allusion to the optical tracking of man-made satellites came via the fictional route, in 1869, when Edward Everett Hale published his precocious tale "The Brick Moon" in the *Atlantic Monthly*.[4] Hale envisaged flinging a large, inert mass into orbit along the Greenwich meridian with a large, water-powered flywheel. The satellite would be visible to mariners through their sextants, making the computation of their ship's longitude easier. In truth, of course, Hale was suggesting terrestrial navigation via optical observations of a man-made satellite in a known orbit rather than the reverse problem of tracking a known satellite of unknown position from ground stations whose locations are precisely known. The idea of visually following a satellite made visible by sunlight was a key concept, however.

Optical tracking of the V-2 and early U.S. missiles at White Sands during the late 1940s and early 1950s seemed to confirm the value of optics in this embryonic space work. Most intriguing, though, is the blank spot that existed in the plans of the early satellite thinkers during the same period. Although V-2s, Vikings, and other rockets were being regularly tracked, no one seems to have been concerned about tracking the satellites which were constantly in the backs of the minds of these missile pioneers. No one seemed

[4]The story is also available in a collection of Hale's works, *The Brick Moon & Other Stories* (Boston: Little, Brown, 1890). Hale also wrote the better-known "The Man Without a Country."

to have thought much about how to confirm that a satellite was actually in orbit or how to measure the orbital elements once the satellite was located in the sky. This oversight probably had its roots in the fact that the satellite pioneers were missile and rocket men, not astronomers. Their thoughts gravitated to the brute-force construction of a successful launch vehicle instead of the delicate problem of finding and tracking the few pounds of payload it carried.

The first serious U.S. satellite study confirms this statement through omission - the omission of any mention of satellite tracking at all. The study referred to is the landmark report: *Preliminary Design of an Experimental World-Circling Spaceship*, written by the Rand Corporation, then a part of Douglas Aircraft Co., and published on May 2, 1946, as Douglas Report SM-11827. The only STADAN function mentioned in the report was that of data acquisition; a set of equatorial telemetry-receiving stations was proposed. Naturally the report was written mainly by rocket and aircraft engineers who had never really had the problem of locating a small object lost in the immensity of space. The significance of this oversight became obvious nine years later when various satellite proposals were being evaluated for the U.S. IGY effort.

The first clear statement of the tracking problem came, as we should expect, from an astronomer. In an article, "The Heavens Open," in *Colliers*, in 1952, Fred L. Whipple of Harvard said:

> Predicting the position and motion of the space station itself will be one of the most difficult problems ever encountered in celestial mechanics, or the science of predicting the positions of astronomical objects.

Whipple went on to become the major proponent of optical satellite tracking during the IGY days and was one of the few recognized scientists who helped "sell" the IGY satellite idea to the rather reluctant political and scientific communities.

<u>Recent Vintage of Radio Tracking.</u> To recapitulate developments in radio tracking and bring its history up to the confrontation with optical tracking in the middle 1950s, there is no need to reach back to the ancient civilizations. Hertz did not discover radio waves until 1888, and Marconi's experiments did not begin until the 1890s. Radio tracking of moving, astronomical signal sources began when a Bell

Laboratories engineer, Karl Jansky, discovered and followed celestial radio noise sources across the sky with directional antennas in 1932.[5] Grote Reber followed up Jansky's work, building the first paraboloidal radio telescope in his backyard in 1937. Reber was preceded by developments in radar, which employs artificial "illumination" of the target. Sir Robert Watson-Watt was tracking aircraft in Great Britain with primitive radar as early as 1935. Radio echoes had been noted decades earlier.[6]

By the time Grote Reber had finished making his backyard radio dish, there were four radio tracking schemes in being that had some potential for tracking satellites:

- Radar, which required no signal source on the satellite.
- Dish tracking à la Reber, which necessitated a satellite-borne transmitter or *beacon*.
- Triangulation using radio-direction finders, which also required a signal source on the satellite.
- Doppler analysis of the radio signals received from a moving source. This technique was recognized in 1937 and soon incorporated into radars, but its value in tracking satellite beacons was not appreciated until twenty years later.

Still a fifth technique was potentially available - that of radio interferometry. The basic idea here was the use of two receiving points, as shown in Figure 2-2, and the comparison of the phases of the signals received separately by each. Physicists have long used optical interferometers in experiments, such as Albert Michelson's first attempt to detect the motion of the postulated ether past the Earth in 1881. The first use of radio guidance (not tracking) seems to have been by German engineers at Peenemuende.[7] Here, VHF transmitters laid down a lobed antenna pattern to improve azimuth guidance during a few V-2 flight tests in the early 1940s. The technique, however, was not employed during operational use of the weapons; it bears only a superficial

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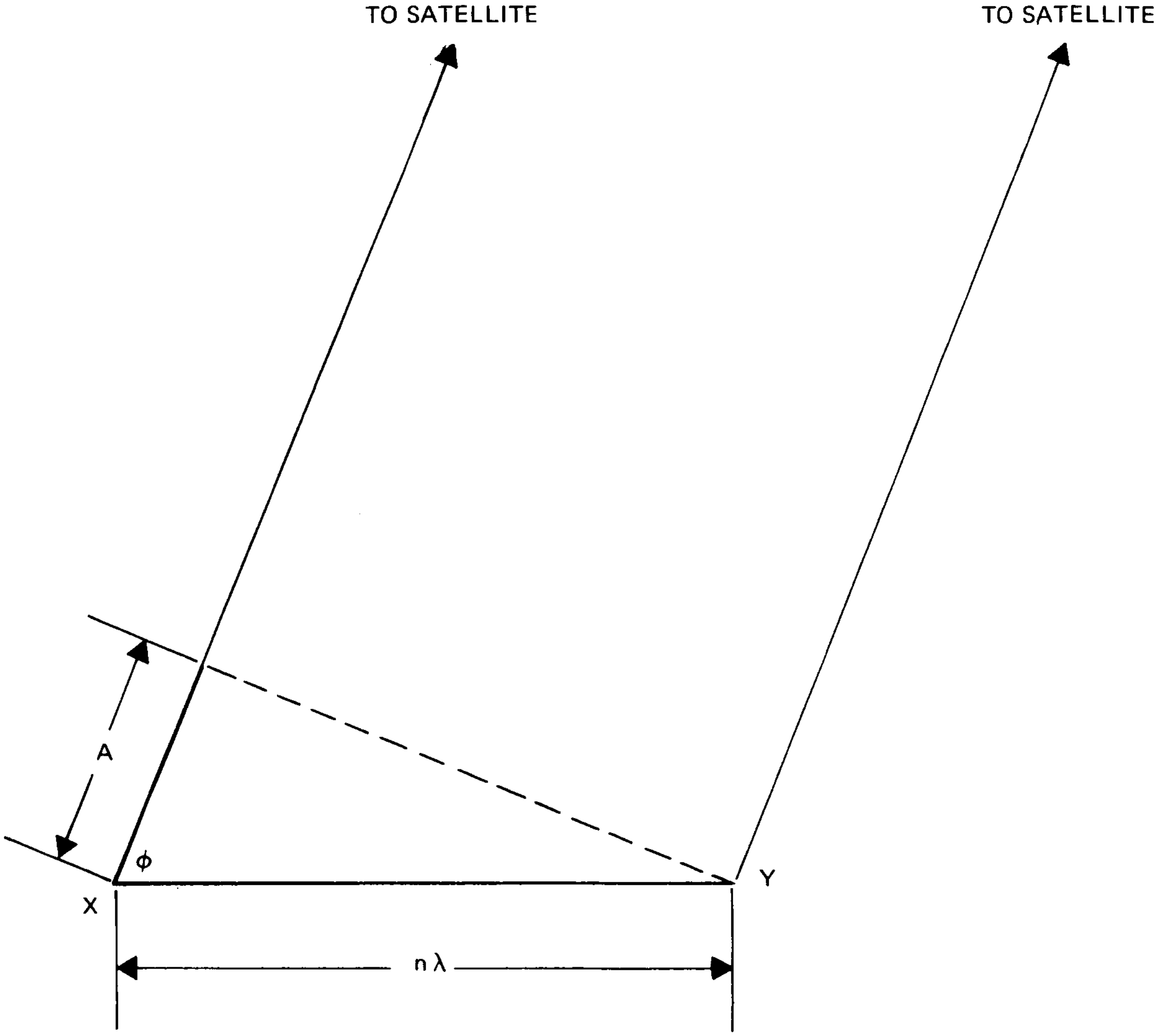
[5]Before this time radio direction finding was used by ships and aircraft as a navigation aid. During World War I, the American engineer Edwin H. Armstrong developed a radio-detection system that picked up and tracked the ignition noise of approaching aircraft.

[6]See Chapter 3 for more details on the development of radar.

[7]Personal communication from James W. Crooks, Jr., July 28, 1966.



$n\lambda$ = BASELINE IN WAVELENGTHS
A = TOTAL PHASE DIFFERENCE IN WAVELENGTHS
ϕ = ANGLE FROM BASELINE TO SATELLITE IN PLANE DEFINED BY ANTENNA X, ANTENNA Y, AND SATELLITE ANTENNA
BASIC INTERFEROMETER EQUATION: $\cos\phi = A/n\lambda$

Figure 2-2. The interferometer principle. The quantity A is measured electronically by phase comparison; then, the interferometer equation is used to find ϕ.

resemblance to later satellite-tracking interferometers.

In radio interferometry, we get on the main track leading directly to Project Vanguard's Minitrack and ultimately STADAN. Of course, no one knew this in 1940, or even 15 years later. Our hindsight, however, permits concentration on this tracking scheme in preference to the other radio and optical techniques.

The Crucial Viking Work. In the U.S. missile effort the path to Minitrack and STADAN becomes wide and straight. Radio interferometry has the advantage of yielding very accurate tracking angles when the target cooperates by emitting a radio signal. The angular precision of interferometry led to the development of the Azusa tracking system as part of the Army Air Corps MX-774 Project, forerunner of the Atlas ICBM program, at the Vultee Field Division of Consolidated Vultee Aircraft Corporation in Downey, California.[8] Two of the basic patents (2,972,047 and 3,025,520) in the field of interferometer tracking are shared by James Crooks, Jr., Robert C. Weaver, and Robert V. Werner, all members of the Azusa design team. By the spring of 1948, the Azusa team had built an interferometer operating at 148.58 MHz.[9] In a strange circle of history, the U.S. Naval Research Laboratory (NRL) was working on underwater sound interferometers at the time Convair was developing Azusa. Since the two groups were in close contact, there was considerable interchange of ideas.[10] The circle was completed in the early 1950s when the Navy picked up the Azusa interferometer work for its Viking project at White Sands, New Mexico. The Navy wanted to explore the possibility of converting the Viking or some derivative of it into a guided missile, and it needed an accurate guidance system. In an early report from this

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[8]Personal communication from James W. Crooks, Jr., July 28, 1966. The first formal report uncovered bears the title "A Precision Missile Tracking System," by James W. Crooks, Jr., Consolidated Vultee Aircraft Corp. (Convair) Report DEVF 4038, December 1946. Army Contract W33038-AC-14168.

[9]Robert C. Weaver, "Phase Comparison Angle Tracking System," Convair Report ZN-6002-017, March 2, 1948.

[10]Interview with Milton Rosen, May 18, 1966.

program,[11] NRL's J. Carl Seddon explained how the Viking would determine its position: "The Missile will detect its position relative to the hyperbolic guidance path by phase comparison of modulation waveforms derived from signals received from two pairs of stations." In this scheme, the missile would guide itself using onboard electronics and navigational signals received from the ground. This seems a far cry from Minitrack and satellite tracking, but phase comparison, the essence of Minitrack, is there.

Within a year, NRL reports from the Viking program were diagramming ground-based, tracking interferometers, which relieved the Viking of the burden of signal-processing equipment by computing the missile's position from the ground.[12] Two precursors of Minitrack are evident in the interferometer arrangement shown in Figure 2-3. First, only a tiny radio beacon needs to be carried on the Viking itself. This was to be an important feature of the Vanguard "Minitrack," in which the prefix "Mini" applies to the minimum-weight satellite transmitter. The second precursor is the "L" arrangement of the interferometer antennas which persisted in some early designs of Minitrack, although the final deployed version extended the bars of the "L".

<u>Pressures for a Satellite Program</u>. While NRL was flying and tracking Vikings at White Sands, pressure for a national satellite program was building up. Scientific instruments carried on captured V-2s, Aerobees, and Vikings whetted the appetite of the scientific community for a long-lived instrument platform above the atmosphere, where space phenomena could be measured directly over long periods of time. In 1952, V-2 experimenters such as James A. Van Allen pushed for a strong upper atmosphere rocket program. In 1954, the Ad Hoc Committee on Space Flight of the American Rocket Society (ARS) proposed to the National Science Foundation that the United States sponsor the construction of a small satel-

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[11] Milton W. Rosen, and J. Carl Seddon, "Rocket Research Report No. VI: Conversion of Viking into a Guided Missile." NRL Report No. 3829, April 1, 1951. (In NASA Historical Office Files). Both authors are now with NASA.

[12] John T. Mengel, and K. M. Uglow, Rocket Research Report No. XI, "A Phase-Comparison Guidance System for Viking," NRL Report 3982, May 5, 1952.

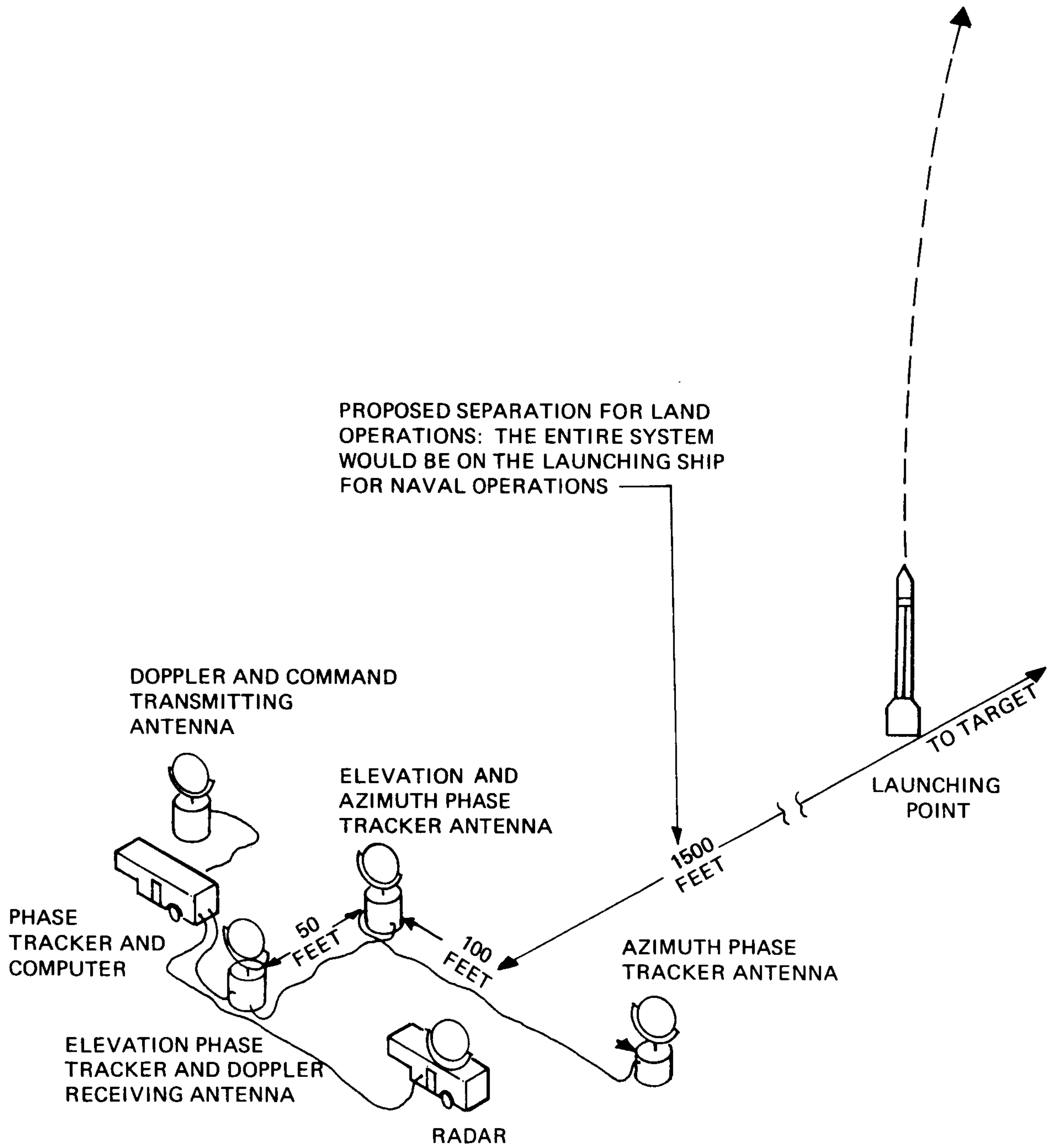

Figure 2-3. Viking White Sands radio interferometer proposed in NRL Report 3982, dated May 5, 1952. The L-shaped antenna layout and Doppler features were part of the original Vanguard Proposal in 1955.

lite to be launched by military rockets during the IGY.[13] In the fall of 1954, the U.S. Committee for the IGY formed a small study group, with Fred Whipple as chairman, to study the idea of a U.S. IGY satellite. Whipple's group reported on a "Long-Playing Rocket," or LPR, that would orbit a 5-kg white sphere that could be tracked optically from the Earth. Whipple's zeal and salesmanship undoubtedly did much to sell the satellite idea to the U.S. government. However, his astronomer's predilection for optical tracking was evident.

Whipple was also closely associated with "Project Orbiter," which was aimed at establishing the engineering feasibility of an Earth satellite. Project Orbiter pooled the talents of the Office of Naval Research,[14] the Army Ballistic Missile Agency (von Braun's group), the Jet Propulsion Laboratory (JPL) of the California Institute of Technology, and several industrial concerns. Commander George Hoover of the Office of Naval Research headed the Orbiter program. The plan of Orbiter was simple and straightforward: take one of von Braun's military rocket boosters, perhaps a modification of the Redstone, add solid-rocket upper stages built and proved by JPL, and propel a small satellite into orbit.[15] The concept was feasible and would represent a technical first for the United States. Tracking would be accomplished optically, but at this time this seemed secondary to getting something into orbit.

NRL was also interested in the idea of an Earth satellite and conducted a study independent of Orbiter during

[13]This ARS Committee was chaired by Milton Rosen, from the Naval Research Laboratory, who later helped put the Vanguard proposal together. For further details of the ARS recommendation see Rosen, "On the Utility of an Unmanned Earth Satellite," *Jet Prop.*, Vol. XXV, Feb. 1955, p. 71.

[14]The Naval Research Laboratory, which was to make the Vanguard proposal in 1955, was administratively attached to the Office of Naval Research, but was a much older organization with a long history of recognized scientific and engineering excellence.

[15]Von Braun frequently proposed such a combination of rockets for satellite launching. See: "A Minimum Satellite Vehicle," Redstone Arsenal Report, dated September 15, 1954.

1954 and early 1955.[16] The NRL feasibility study concluded that an Aerobee liquid rocket, plus a small solid third stage, on top of a Viking first stage could put a small payload into orbit. Satellite tracking was not considered in this propulsion study.

By the summer of 1955, the stage was set for concrete action on a U.S. satellite program.[17] The ingredients forcing such a decision were:

- The coming IGY and the manifest desirability of a small scientific satellite.
- The existence of a rocket technology capable of launching a small satellite.
- The cold-war pressure to produce a spectacular technical accomplishment.

Consequently, on July 29, 1955, President Eisenhower announced that the United States would launch "small, unmanned Earth-circling satellites as a part of the U.S. participation in the IGY." The Department of Defense was to be the launching agency.

By the time of the President's announcement, three major satellite proposals were on hand: the Orbiter proposal, using optical tracking; an NRL proposal, using a radio tracking scheme derived from its White Sands work; and a proposal based on the highly classified and very high priority Atlas program. To select the most appropriate program, a Committee on Special Capabilities, chaired by Homer J. Stewart, was convened by the Department of Defense. The NRL proposal was recommended for several reasons:

- NRL emphasized the scientific aspects of the program.

- The proposed launch vehicle did not entail the use of military rockets, a fact that made the program more palatable from the standpoint of

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[16]It is interesting to note that at the time of Orbiter, JPL engineers such as Henry Richter, Eberhardt Rechtin, William Sampson, and others were working on phase-locked electronic tracking systems, the forerunners of the Microlock Doppler-interferometer system.

[17]John P. Hagen, "The Viking and the Vanguard," *Technology and Culture*, Vol. IV, Fall 1963, p. 435.

> international relations and the IGY program. Furthermore, no U.S. military rocket program would be compromised.
>
> NRL had proposed a good tracking scheme that showed up some deficiencies in the Orbiter proposal.

Since radio tracking was important, though perhaps not the deciding factor, in the decision to adopt the NRL proposal, we should review briefly those few months in the spring of 1955 at NRL that led up to the successful proposal and the beginning of Vanguard.

Genesis of the NRL Vanguard Proposal. With so many years of experience with V-2s and Vikings at White Sands behind them, the NRL Rocket Development Branch, under Milton Rosen, could hardly be indifferent to all the talk of artificial scientific satellites making the rounds in early 1955. Rosen, as mentioned earlier, was Chairman of the ARS committee that made satellite recommendations to the National Science Foundation. Furthermore, NRL had refined the White Sands tracking interferometers described earlier. In early April 1955, Milton Rosen, John Mengel, and Roger Easton assembled informally at NRL and generated a document entitled, "Proposal for Minimum Trackable Satellite (Minitrack)." No date and no authors are listed on this key report; but, according to Rosen, it preceded only by a few days a more formal report with the title, "A Scientific Satellite Program," dated April 13, 1955, and written by the NRL Rocket Development Branch. Appendix B of this document was labeled, "The Minitrack System" and was nearly identical to its predecessor of a few days. The name "Minitrack" now appearing for the first time on paper, was coined by John Mengel. The radio interferometer concept advanced in these two reports differed only in the wavelength used from an X-band interferometer developed by NRL for submarine-based tracking of Viking test vehicles in pre-Polaris research. (Figure 2-4) The antenna geometry and supporting electronics were essentially identical.

The formal NRL proposal set before the Stewart Committee bears the date July 5, 1955. In content, it differed but little from the earlier informal documents.[18]

Why did NRL emphasize Minitrack in its proposal? Op-

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[18]The full reference for the NRL proposal is: "A Scientific Satellite Program," NRL Memo 487, July 5, 1955, with addendum letters S-7140-26255, Aug. 23, 1955, and C-711-14355, Sept. 3, 1955. A full history of Project Vanguard has been prepared for NASA by Constance McL. Green and Milton Lomask: "Vanguard--A History," (Washington: NASA SP-4202, 1970).

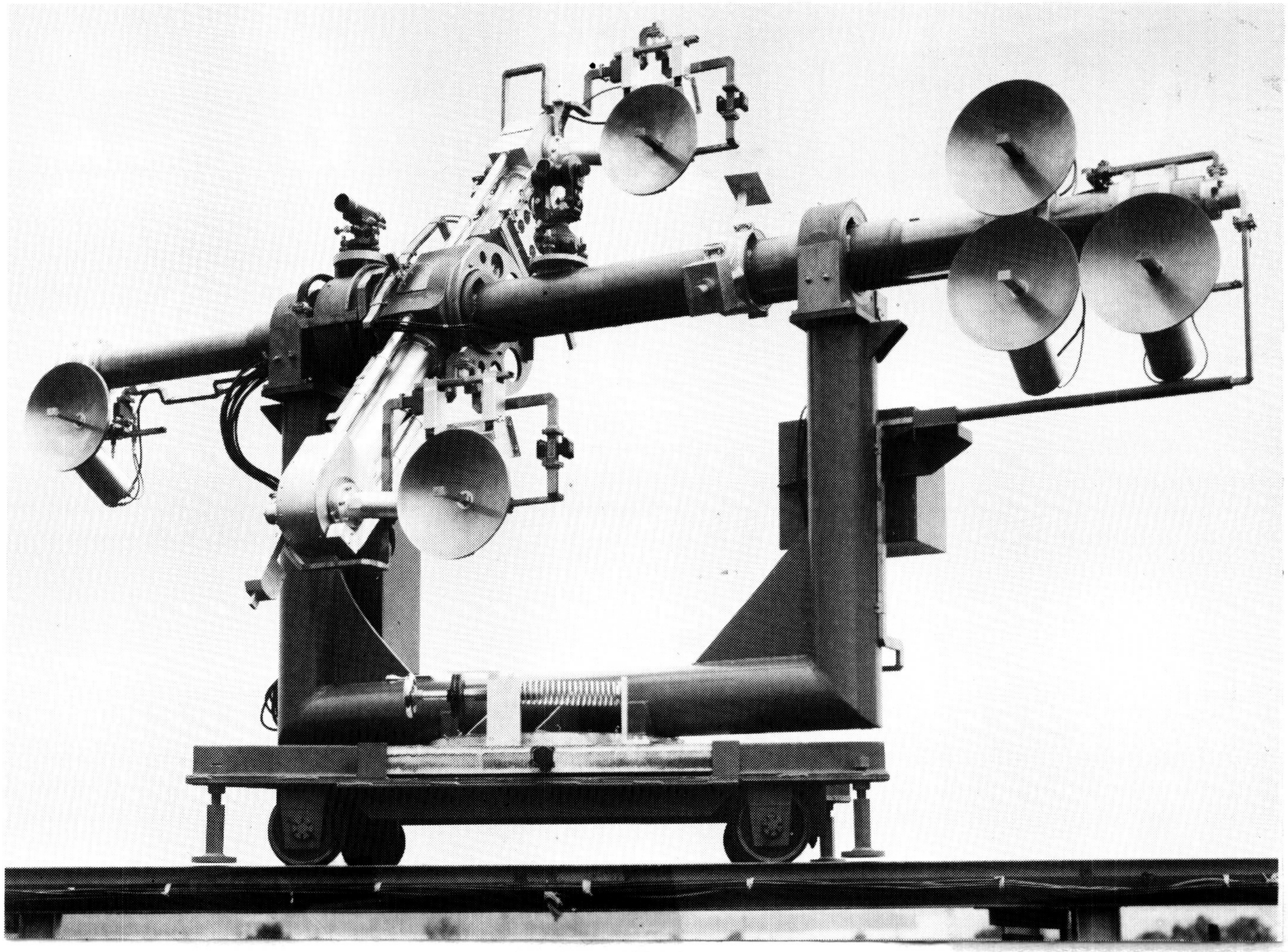

Figure 2-4. Photograph of the X-band interferometer that was constructed by NRL for possible use on submarines for tracking Vikings. The baseline was 4 m and the L-shaped antenna pattern was retained. Picture taken in early 1955. (Courtesy of Naval Research Laboratory).

tical tracking was the way to go, according to many experts. Fred Whipple, who had made many significant camera observations of meteorites entering the Earth's atmosphere, had proved analytically that a small payload of a few kilograms could be seen with terrestrial optical instruments. Rosen, at NRL, had doubts; and he asked Richard Tousey at NRL to check through the calculations in the spring of 1955. Tousey confirmed the visibility computations, but believed that there would only be a "million-in-one chance" of finding the satellite with optical equipment, given the uncertainties of a rocket launch, variable weather conditions, and the fact that the satellite would be visible only at dusk and dawn.[19] This factor--satellite acquisition--was the practical fact of life that made radio tracking desirable. What good was the precision of optical equipment if it could not find the satellite in the first place?

Tousey had found a weak spot in the Orbiter proposal, and Rosen pushed for the inclusion of radio tracking in the NRL satellite proposal. John Mengel and Roger Easton showed, in the NRL reports mentioned above, that radio interferometer tracking using a tiny satellite-borne transmitter was quite feasible, based upon White Sands experience.[20]

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[19] A. Boggess, III; J. E. Milligan; and R. Tousey; "Optical Acquisition and Tracking of the Satellite," NRL Memo Rpt. 560, 1956.

[20] We would expect NRL to adopt the system of radio tracking most familiar to them, but radar and Doppler tracking were also examined. Narrow beam radar was also plagued by the acquisition problem--you had to know where to look. (See Chapter 3.) Doppler tracking, as we shall see in the next section, was actually implicit in the first Minitrack proposal. NRL also looked at artificial satellite illumination using a searchlight; but, again, one had to know where to point the searchlights. (In a modern version of this pinpointing idea, lasers bounce light off satellites in known orbits to improve the precision of the orbital elements.)

Project Vanguard began at NRL on Sept. 9, 1955, when the Secretary of the Navy was authorized by the Department of Defense to proceed with the NRL proposal. Radio tracking was firmly established in the NRL Minitrack concept.

History, always retrospective, often makes things look too easy. Actually, because of Orbiter's momentum, the NRL proposal team believed that they stood little chance of winning the U.S. satellite program. According to John Mengel, the surprise announcement came as the NRL tracking team was checking out the second and last X-band interferometer. The X-band interferometer was quickly put in mothballs and work began on Minitrack, with its much longer wavelength and correspondingly larger baseline.

Minitrack through the IGY

When the Naval Research Laboratory was assigned the U.S. satellite program by the Secretary of the Navy on Sept. 9, 1955, one would expect that Minitrack would also become the "official" satellite tracking system. It is true that the Minitrack idea was turned into hardware and deployed in the first worldwide radio tracking net during the IGY; but this chapter must also deal with proliferations of the Minitrack concept as well as competing tracking schemes.

Perhaps it was just as well that Minitrack did not have a clear field; though it annoyed NRL personnel, the competition was stimulating.

This competition came primarily from two sources:

- The Orbiter program that lived on close to the surface at ABMA, ONR, and JPL. By now, the Orbiter proponents had adopted the JPL Microlock radio tracking concept to counter Minitrack. It was this "shadow" Army satellite program, of course, that ultimately launched the first U.S. satellite, *Explorer 1*.
- The SAO optical network, which was funded by the National Science Foundation as complementary to Minitrack. Deep in their hearts proponents of optics and radio each knew their system was better and would be the "prime" tracking system.

Two offshoots of Minitrack also deserve a few words: Minitrack II (or Mark II Minitrack), an amateur tracking program; and Active Minitrack, a military space surveillance system. First, though, let us see how the NRL proposal ideas of April 1955 were turned into an operational network.

Development and Deployment of Minitrack. The Minitrack network that became operational in October 1957 was substantially different from that proposed to the Stewart Committee in the summer of 1955. Here is what NRL originally proposed:

> The complete Minitrack System will consist of two comparison stations, the second identical to the one just described but located at a distance of 32 km on an E-W line to permit determination of satellite altitude to an accuracy of 0.8 km, and satellite velocity to an accuracy of better than 30 meters per second. Both of these stations will include a second ground station to permit the determination of the satellite position in a direction normal to its direction of travel, giving a complete 3-axis fix on the satellite as well as its velocity.[22]

In addition to angle-tracking interferometry of White Sands vintage, the above quotation implies distance (altitude) measurement through triangulation from a pair of stations and Doppler velocity measurements. Note that only a *single pair* of stations was anticipated, not a worldwide network.

Before the end of 1955, ideas changed drastically. First, it was realized that a single pair of stations would provide very limited geographical coverage, rendering data acquisition difficult and the accumulation of orbital data very slow. Four pairs of stations across the southern U.S. were next proposed. The idea of a "radio fence" was implicit in this suggestion; i.e., the creation of a long chain of overlapping antenna patterns that the satellite must intersect frequently. The trouble was that the planned orbital inclination of the Vanguard satellite would keep it away from the southern U.S. too much of the time. The next logical step was the construction of a long north-south fence that the satellite would pass through on almost every orbit. But the Vanguard program could not financially support a long chain of paired stations; besides, further thought soon showed that complete orbital data could be computed

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[22] "A Scientific Satellite Program," NRL Memo 487, July 5, 1955.

from angular (interferometric) tracking alone. These changes in thinking manifested themselves in a report describing a chain of nine single Minitrack stations strewn along the 75th meridian.[23] To the regret of some engineers, ranging and velocity-measuring capabilities were dropped.[24]

The technical desirability of Minitrack stations on foreign soil was one thing; more formidable were site negotiation, site preparation, and logistics. The situation was particularly acute in South American countries that were sensitive about U.S. bases and where transportation and communication facilities were primitive. Unfortunately, Minitrack stations required radio-quiet spots which are usually not coexistent with the also-desired communication links and supply facilities.[25]

Captain Winfred Berg, the Navy Senior Project Officer assigned to Vanguard, had the task of getting Minitrack stations into the South American countries. He was aided by two already-existing organizations: (1) The Inter-American Geodetic Survey (IAGS), in which the U.S. Army Map Service was very active, and (2) the international IGY committees that existed in most countries. As 1956 began, Berg and others realized that time was already growing short. The IGY was to end in less than two years, Vanguard was barely started, and the long slow process of site selection, negotiation, construction, and station checkout had not even begun. In early March, Captain Berg informed the Department of State that he was leaving on March 23 with a Site Selection Team to negotiate Minitrack sites in South America.[26]

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[23]Project Vanguard Report to Assistant Secretary of Defense (Research and Development), NRL Memo 548, Dec. 12, 1955. The suggested station locations were Washington, Jacksonville, Havana, Barbuda, Canal Zone, Quito, Huancayo, Tocopilla, and Santiago. (See Appendix A.)

[24]Rather ironically, ranging and Doppler capabilities were later added to STADAN as the Goddard Range and Range Rate equipment was deployed. The logically neat sequence of (1) requirement definition, (2) plan definition, and (3) equipment development was impossible at a time when engineers knew little about satellites and tracking.

[25]"Preliminary Specifications and Considerations - Minitrack Site Facilities," NRL document dated Feb. 27, 1956. No author or number. (In NASA Historical Office Vanguard files.)

[26]Captain Winfred Berg, personal interview, May 12, 1966.

Between March 23 and late April, Berg's team, which included NRL and Army personnel, toured South America, locating sites and drawing up the requisite agreements with the countries concerned. The Army Map Service saw to it that the Site Selection Team met the right people in the political and scientific spheres. With the cooperative feeling engendered by the IGY, (with its scientific and non-military features) and the good offices of the Army, the task was accomplished in only five weeks. Back in Washington, Berg informed the State Department that all countries concerned had agreed to a joint July 1, 1956, release of the news of the IGY tracking sites. With the formalities completed, Minitrack entered the deployment phase.

The Site Selection Team had picked six South American locations: Havana, Panama, Quito, Lima, Antofagasta, and Santiago; but who would undertake the imposing task of setting up stations outside the United States proper? The U.S. Army, by virtue of its IAGS experience, was the logical choice. In September 1956, the Army Chief of Engineers initiated construction at the six sites at the request of NRL.[27] More specifically, the task fell to the specially created Project Vanguard Task Force of the Army Map Service. It should be mentioned here that the South American sites, though near large cities, were generally some distance from modern facilities and their associated radio noise. The isolation and primitive conditions caused logistics and operator morale problems in early days.

The Minitrack sites in the continental U.S. were established with greater ease. The Navy set up and operated the Blossom Point and San Diego stations; the latter being at the Brown Naval Auxiliary Air Station, near Chula Vista, California, and operated by the Naval Electronics Laboratory. The stations downrange from Cape Canaveral were set up in cooperation with Great Britain and operated by the U.S. Navy and Air Force. After deliberation over tracking requirements, logistics, and support facilities, Antigua and Grand Turk were finally chosen for downrange stations instead of the initially planned Barbuda and Mayaguana. More details about the sites and the factors influencing their choice or rejection can be found in Appendix A.

The Blossom Point station, just 56 km southeast of

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[27]Ultimately the Panama site was abandoned (see Appendix A for details). The Army also handled construction at the Ft. Stewart, Fla., site. See: Smitherman,W.D.,"Army Participation in Project Vanguard," *IRE Trans.*, Vol. MIL-4, (June 1960), p. 323.

Washington, went into operation in July 1956, and was soon employed as a training headquarters for Minitrack operators and as a test facility for Minitrack equipment. During the IGY and after, many foreign nationals took the Minitrack course at Blossom Point. In fact, the willingness of NRL and NASA to employ and train foreign nationals at the Minitrack and STADAN stations greatly eased the task of placing U.S. facilities on foreign soil. Minitrack stations have "earned their keep" many times over as non-political, no-strings-attached representatives of the United States.[28]

The full Minitrack network of ten stations was placed in operation during October 1957, with the eleventh, at Woomera, Australia, added a month later. It should already be evident that the Minitrack network was not a static thing. Stations were added and subtracted as the space program required. Bigger satellites with more transmitter power made stations such as Antofagasta redundant. Political harassment in Cuba made it apparent as early as September 1957 that the Havana station would probably have to be moved.[29]

Simultaneous with the Minitrack station construction, NRL engineers were testing electronic equipment that would track and communicate with the satellite. Frequency selection was an early item on the agenda. The original NRL proposal had postulated 100 MHz as the interferometer frequency. At this frequency, the subminiature circuits needed for the tiny satellite transmitter would be reasonably efficient; the interferometer baseline of 100 wavelengths would be a practical 300 meters and the width of the fence projected up toward passing satellites would be adequate. A frequency of 108 MHz was finally agreed upon by the countries concerned on a local basis, but only for the duration of the IGY. Local interference proved a problem at 108 MHz; and Minitrack switched to the 136-to-137 MHz range in 1960 when the International Telecommunications Union (ITU) set aside this band for space research. For years, however, 108-MHz satellites were on the air (especially *Vanguard 1*), and conversion was not completed until three years later.

The Minitrack interferometer antenna layout, which had begun as a simple "L" at White Sands (Figure 2-3) became a cross, actually two crosses, because two separate inter-

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[28]Arnold Frutkin, *International Cooperation in Space*, (Englewood Cliffs, Prentice-Hall, 1965).

[29]NRL Memo 4130-417: JTM: Ids, Sept. 23, 1957. (In NASA Historical Office Vanguard files.) See Appendix A for details and chronology of station changes.

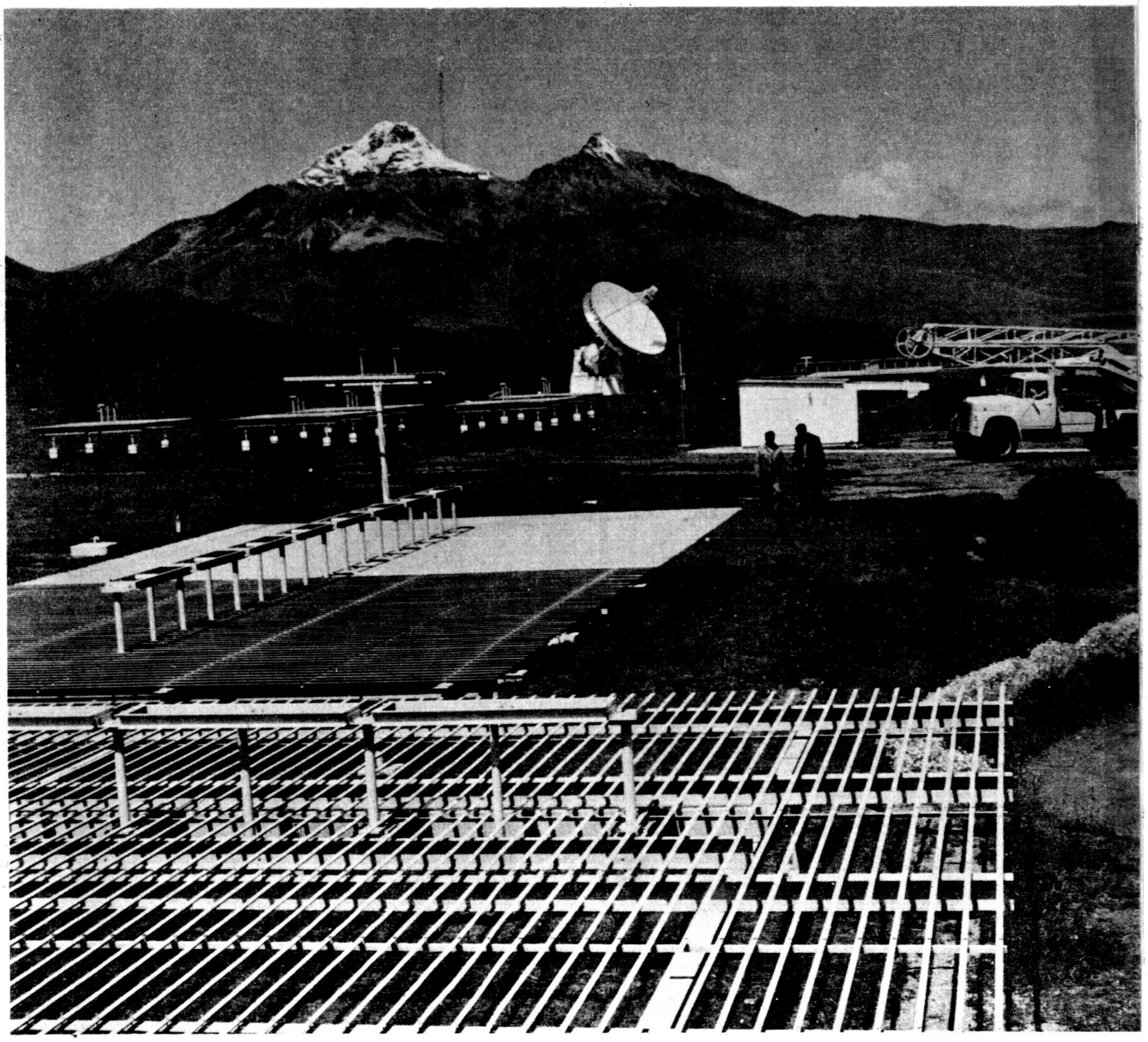

Figure 2-5. The 136-MHz Minitrack array at the STADAN Lima station.

ferometers with different baselines were needed to resolve an ambiguity in satellite direction inherent in a single interferometer. (Figure 2-5). These two interferometers were termed "fine" and "coarse."

In addition to the tracking function, each Minitrack station had to pick up and record the satellite's telemetry transmissions. The fixed, narrow, wedge-shaped interferometer antenna pattern was unsuited to this task. NRL had to design some sort of antenna that would follow the satellite from horizon to horizon. A Blossom Point experiment was carried out in 1956 with Yagi antennas fixed on a framework resembling a playground swing. The test emphasized the need for following the satellite with a directional antenna. A "seesaw" or "rockinghorse" antenna evolved. (Figure 2-6) This consisted of half a Minitrack antenna pivoted on a horizontal axle. As the satellite passed overhead the antennas were manually tilted from one extreme to the other, just like a seesaw. The experimental "seesaw" later gave way to a succession of more refined data-acquisition antennas that will be described later.

It is one thing to have an operating interferometer station and quite another to turn the received satellite signal into data that will be accepted by a computer and rendered as precision orbital elements. First, the centers of the Minitrack arrays had to be located accurately on a consistent, inter-connected system of geodetic coordinates. This task was easy on the North American continent, and, with the aid of the Army Map Service work in South America, it was eventually done for all stations within the Western Hemisphere. A special Vanguard Datum reference system came into being. The Woomera site in Australia was another matter, no one knew the distances between continents with real precision. One of the important accomplishments of satellites, of course, has been the tieing together of previously isolated continental geodetic grids with the help of satellite geodesy; thus, Woomera and other isolated stations were eventually tied into a unified, accurate reference system.

Figure 2-6. Photograph of the "rockinghorse" data-acquisition antenna deployed around the Minitrack network during the IGY. The antenna portion--the part that "teeters"--is just a section of the regular interferometer antenna. (Courtesy of W. Mitchell, GSFC)

A second Minitrack operational problem was calibration in terms of known signal sources. At first, it was suggested that one of the SAO Baker-Nunn cameras be located at the center of each Minitrack array so that airplane-borne radio-signal sources could be tracked electronically by Minitrack and, at the same time, against the known background of fixed stars by the Baker-Nunns. There were emotional and operational problems that prevented this fusion of optical and radio networks. Although it was publicly proclaimed that Minitrack and the Baker-Nunns were complementary, their proponents still believed in 1957 that their systems would be prime. There were practical reasons, too. Neither optical nor radio satellite tracking had yet proved itself, and it would be unwise to make the success of one dependent upon the success of the other. Furthermore, the Baker-Nunns needed much better seeing conditions than those available at the Minitrack sites, which had not been chosen with optical "seeing" criteria in mind. Furthermore, considerable difficulty was anticipated in mounting the camera focal plane coincident with that of the antenna array.[30]

Consequently, the Baker-Nunn cameras went to their own sites, and smaller, less costly astrographic calibration cameras were emplaced at the Minitrack stations.[31] High-flying aircraft, helicopters, and both free and tethered balloons carrying optical and radio signal sources calibrated the Minitrack interferometers.[32] By comparing light flashes

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[30]Personal communication from Chesley H. Looney, January 1968.

[31]An interesting technical aside: The Army had suggested in 1957 that the Minitrack sites be electronically calibrated through the use of radio signals bounced off the Moon, whose position, of course, was known as well as the stars. This technique was not employed for Minitrack calibrations because it would have required too much time to set up. Radio echoes from the Moon had been obtained in another Army program (at Evans Signal Laboratory) beginning in 1946.

[32]John H. Berbert, et al., "Minitrack Calibration System," *Photo Sci. Eng.*, Vol. VII, Mar.-April 1963, p. 78.

and star backgrounds from the camera plates with simultaneously received radio signals, the signals from real satellites could be more accurately interpreted. This calibration technique, however, did not account for the much greater refraction of radio waves in the ionosphere well above the calibrating source.

In addition to their geodetic ties, the Minitrack stations had to have coordinated "clocks" and communication lines back to the NRL Vanguard Control Center in Washington. Basic time referents came from standard frequency transmitters, such as station WWV. A Precision Time Standard Rack at each station was capable of an accuracy of one millisecond per day after calibration against WWV. The matter of communication was more difficult in remote, undeveloped areas. Again the Army experience and facilities in South America came to the rescue. The Map Service's Project Vanguard Task Force set up the rather impressive system of data links described in Chapter 6. Data converged on the NRL Vanguard Control Center and was transmitted from there to the Vanguard Computing Center in downtown Washington. IBM provided an IBM 704 computer, operating personnel, and analysis for orbit calculation.[33]

By October 1, 1957, Minitrack was complete except for the checkout of some teletype links and the calibration of some stations.[34] Three days later, *Sputnik 1* began crossing the Minitrack fence every 96 minutes; but it was transmitting at 20 and 40 MHz.[35] Minitrack operators knew *Sputnik 1*

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[33]IBM letter to NRL, dated April 23, 1956. IBM also supported the SAO in preparing satellite ephemerides from raw tracking data. In 1956, mathematical techniques and computer programs did not exist for handling raw tracking data. IBM donated considerable time and talent in helping astronomers and mathematicians to overcome this problem, which turned out to be quite different from the usual astronomer's job of computing star and planet positions.

[34]John T. Mengel and Paul Herget, "Tracking Satellites by Radio," *Sci. Amer.*, Vol. CXCVIII, Jan. 1958, p. 23. Mengel's coauthor on this paper, Paul Herget, was one of the astronomers who helped get the satellite orbit-computation problem under control.

[35]CSAGI Resolutions at Barcelona - Sept. 9-14, 1956. (Working Group on Satellite Launching, Tracking and Computation), Recommendation C. "Establishment in all countries of radio-observation stations for frequencies of 20 Mc/s and 40 Mc/s." According to Chesley H. Looney, these frequencies were re-

was passing overhead but could not track it with 108-MHz interferometers.

Sputnik 1 was transmitting in the amateur radio bands and getting good publicity as hams all over the world picked up the signals. Army radio engineers and many amateurs spent the night of October 4 building and modifying their equipment for Doppler tracking. Crude orbital data were available within a day. At NRL, the minitrack team had already begun to modify Minitrack for 40-MHz reception. Alerted by radio announcements of the Sputnik launching, they burned the midnight oil cutting 40-MHz dipoles and planning network modifications.[36] 40-MHz crosses were quickly installed at Blossom Point, San Diego, and Lima; and, later, at Santiago and Woomera. In several days, good tracking data were being received. *Sputnik 1* and *Sputnik 2*, in fact, gave Minitrack good shakedown runs.

When the Explorers and Vanguards came along a few months later, Minitrack was completely successful, fulfilling all expectations. The Minitrack interferometers are still the basic tracking equipment of STADAN.

Minitrack II. Minitrack II was a simplified version of the interferometer deployed at the prime Minitrack sites. Only four antennas were needed (two sufficed in the simplest design), but with the consequent loss of the ability to resolve the angle ambiguity mentioned earlier. A Minitrack II station could fix the time a satellite crossed its meridian with high precision by analysis of the nulls in the interference pattern. This information, as later proved by observations from the Sohio Minitrack II station, was sufficient to yield

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served for telemetry and Doppler tracking, while 108 MHz was assigned to interferometry. The Russians announced that they would be using the lower frequencies just a few days before the launch of *Sputnik 1*.

[36]The night of *Sputnik 1* will never be forgotten by any of the government and civilian engineers and scientists who rushed back to the lab to try and track that 84-kg sphere. The long-distance telephone calls and sense of comradeship in a common goal was perpetuated by scrolls (still hanging in some offices) dedicated to "The Royal Order of Sputnik Chasers."

accurate orbital elements with only a single station.[37]

Minitrack II, also called "Jiffytrack" and "Poor Man's Minitrack," was the brainchild of Roger Easton at NRL. Easton even suggested that Minitrack II be installed at the prime Minitrack sites, but this was vetoed in favor of the larger, more sophisticated ambiguity-resolving interferometers. Still, Minitrack II was simple to build - costing something around $1,000. Perhaps amateurs could build it and thus supplement observations from the prime Minitrack stations.[38] In cooperation with the American Radio Relay League, NRL started Project Moonbeam, the electronic cousin to the SAO amateur optical tracking activity, Project Moonwatch.

A thousand dollars plus was quite a sum for most radio amateurs and only a few stations were actually built.[39] The major Minitrack II station was built by amateurs associated with the Standard Oil Company of Ohio (Sohio). Sohio supplied some equipment, limited funding, and personnel to help reduce the data acquired.[40] The first version of the Sohio station went "on the air" at Burhan's home in Chagrin Falls, Ohio, on January 31, 1958, just in time for *Explorer 1*. A larger installation was next built at the Sohio Research Center, in Warrensville Heights, Ohio, a suburb of Cleveland. (Figure 2-7) The second Sohio station remained in operation for about five years. Some notable firsts recorded were: first station in the world to pick up *Explorer 4*; orbit confirmation for *Explorer 7*, *Echo 1*, and *Courier 1*; and the Doppler monitoring of the *Vostok 3*-*Vostok 4* separation.

NRL also built and installed Minitrack II equipment at Blossom Point (operational Jan. 23, 1957) and at Cape Canaveral for tracking operations with Vanguard TV-0.[41]

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[37]Letter from Ralph W. Burhans, May 21, 1966. Burhans was the Project Leader of the Sohio Station.

[38]Roger L. Easton, "Radio Tracking of the Earth Satellite," *QST*, Vol. XL, July 1956, p. 38

[39]See *QST*, Vol. XLII, Feb. 1958, p. 60, for a station list.

[40]Ralph W. Burhans, "Sohio Project Moonbeam," *Sky and Telescope*, Vol. XXV, March 1963, p. 1.

[41]See NRL Report 4880, Dec. 3, 1956. (In NASA Historical Office Vanguard files.)

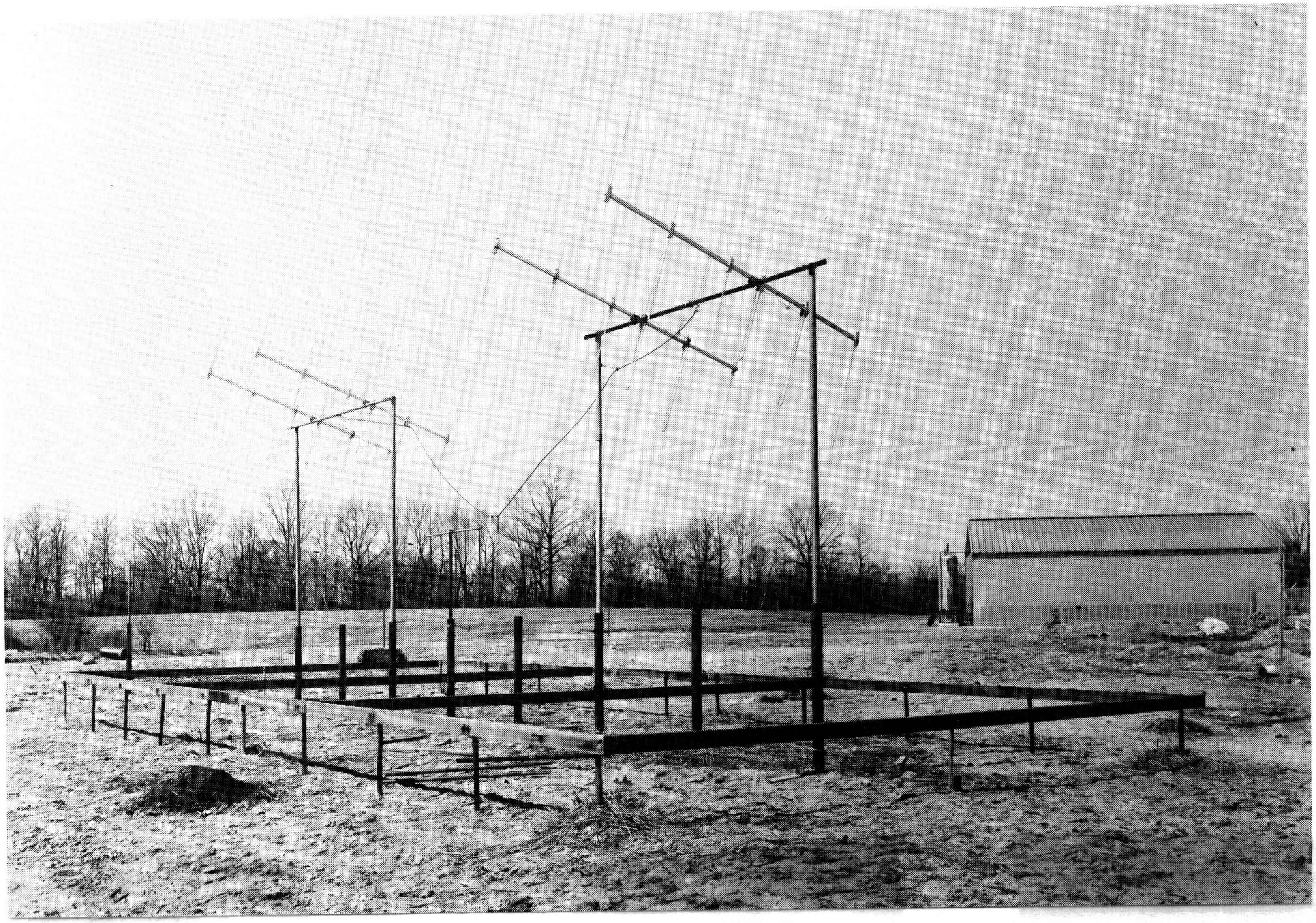

Figure 2-7. Photograph of the Sohio Minitrack II antenna. (Courtesy of R. W. Burhans)

Active Minitrack. *Sputnik 1* caused a major tremor in military circles. Did the Russians have other satellites already in orbit that did not advertise their presence via a tracking beacon? The specter of undetected reconnaissance satellites and weapons in orbit started a crash project aimed at detecting and tracking "dark" or "uncooperative" satellites. Obviously the target had to be illuminated with radio waves; and several proposals were submitted that required long chains of radar-type installations. In contrast to these billion-dollar programs, NRL, notably Roger Easton, suggested in May 1958 using Minitrack-type interferometers in an East-West chain across the U.S. Several powerful transmitters along the chain would project a wedge-shaped radio "fence," so that a satellite crossing it would announce its presence by reflecting radio waves into the interferometers waiting below. Easton's computations showed that it would be easy to detect an object with an effective reflection area of one square meter at 4800-km altitude. Furthermore, the whole job could be done for about $3.5 million. The NRL price was three orders of magnitude less than other proposals. The Secretary of Defense bought the NRL concept. In a Horatio Alger story of military radio tracking, Active Minitrack stations were quickly installed between Ft. Stewart, Georgia, and Brown Field, California, meeting all dollar, schedule, and performance goals. Active Minitrack was called SPASUR (for Space Surveillance System) and generated ephemerides for each of the several satellites and many pieces of space debris that crossed its fence each minute.

The impact of Active Minitrack on "passive" Minitrack was slight. The Ft. Stewart Minitrack station was turned over to SPASUR and replaced by the Ft. Myers (Florida) station that received the equipment withdrawn from Havana in 1959.

Microlock. Even after Vanguard became the "official" U.S. satellite program, Army engineers and scientists continued to push for an Army satellite effort based on ABMA/JPL (Army Ballistic Missile Agency/Jet Propulsion Laboratory) technology. Participants in Project Orbiter were particularly unhappy over the Stewart Committee selection. Realizing the weakness of the original Orbiter proposal in the tracking area, the JPL Microlock phase-comparison tracking system was added to the Army arsenal.

Technically, the Microlock (originally "Microtrack") system consisted of (1) a phase-locked receiver, with implicit Doppler-tracking capabilities, (2) interferometer receivers, and (3) auxiliaries, such as acquisition-control, recording, and timing equipment. The phase-lock and Doppler features were not part of Minitrack; but the Microlock interferometer receivers - usually just three or four separate antennas along the baseline - were similar in function to the Minitrack antenna arrays. Mobility was another important characteristic of Microlock units. Most field units were trailer-based.

The phase-lock feature of Microlock, in which the receiver automatically "locks on" to the signal phase (like radar "locks on" to a target) had been under study at JPL since the early 1950s.[42] A satellite-tracking-feasibility study was completed for the Army in September 1955 - too late for the first Orbiter proposal. The Army Ordnance Corps (supporting von Braun) ordered hardware development of Microlock. A prototype was completed in early 1956, with tests at Earthquake Valley, Calif., in May 1956. On September 20, 1956, the Grand Turk Microlock station downrange from Cape Canaveral tracked a Jupiter-C carrying a dummy fourth stage along a trajectory 4800 km long and 1110 km high. The Army believes that it could have put a satellite into orbit on that shot.

The primary Microlock station was the one at Earthquake Valley. Eventually, this station was moved to Goldstone Dry Lake (now the site of STADAN, MSFN, and DSN stations). The mobility of Microlock made the station list a fluid one. At one time or another there were additional stations at Ibadan, Nigeria; Cape Canaveral; Singapore; China Lake, Calif.; Aberdeen, Md.; and several other locations. Some of these stations deployed the interferometer antennas; others relied solely on Doppler measurements. The Sputniks and the Vanguard troubles gave Project Orbiter another chance; and, on November 8, 1957, the Secretary of Defense announced that the Army would also participate in the nation's satellite program. *Explorers 1, 2,* and *4* resulted from this decision. They were tracked by Microlock as well as Minitrack stations. For these satellites, three Microlock stations were employed in a network called "Spheredop."[43]

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[42]Robert C. Tausworthe, "Theory and Practical Design of Phase-Locked Receivers," Vol. I, NASA CR-70395, JPL TR-32-819, Feb. 15, 1966. The key JPL personnel on Microlock were Henry Richter, Eberhardt Rechtin, William Sampson, Walter Victor, and R. Jaffee.

[43]The stations were Earthquake Valley; China Lake (Naval Ordnance Test Station); and an amateur station run by the San Gabriel Valley Radio Club. Other amateur Microlock stations were at Cedar Rapids and White Sands. The Sohio Minitrack II station actually adopted the phase-lock and Doppler features of Microlock. See Henry L. Richter, William F. Sampson, and R. Stevens, "Microlock: A Minimum Weight Radio Instrumentation System for a Satellite," *Jet Prop.*, Vol. XXVIII, Aug. 1958, p. 232.

When NASA was formed on October 1, 1958, it phased out the Microlock stations. However, concepts applied to Microlock still survive in the space program. JPL phaselock techniques are central to the tracking of deep-space probes from the DSN as well as Apollo spacecraft from the MSFN (Chapter 5). In another interesting parallel between Minitrack and Microlock, history finds that an Active Microlock was also proposed for the tracking of dark satellites. Dr. L. G. deBey, at the Army Ballistic Research Laboratory, Aberdeen, Md., was the moving force behind this approach. Though it lost out to Active Minitrack, the Active Microlock idea became the military DOPLOC missile-tracking system.

The SAO Baker-Nunn Camera Network. The Smithsonian Astrophysical Observatory's Baker-Nunn satellite-tracking camera network is not officially considered part of STADAN; but, because of Minitrack's early confrontation with optical tracking in the pre-Vanguard days and the present complementary relationship of the two systems, a very brief recounting of the evolution of the SAO network seems proper here.[44]

Fred L. Whipple had suggested the use of three equatorial optical tracking stations as part of Project Orbiter in June of 1955. Prior to the fateful Stewart Committee decision against Orbiter in late summer 1955, the National Science Foundation budget had already set aside $10 million for ten satellites and five optical tracking stations placed along the equator - a fact attesting to Whipple's influence and reasoning before the Long Playing Rocket Committee of the U.S. National Committee for the IGY. When Orbiter fell before Vanguard, Whipple realized that optical tracking of the much smaller Vanguard satellite would require a camera with an extremely large aperture. In addition, he appreciated the satellite-acquisition problem and pushed "Project Moonwatch," a worldwide amateur effort that would help find the satellite and provide rough times of transit over the local meridians. From these data, the big, new cameras could acquire the satellite and generate precision tracking data. In late 1955, the National Academy of [redacted] and National Science Foundation, acting for the U.S. National Committee for the IGY, assigned optical tracking responsibility to the SAO. Money started flowing January 1, 1956.

The critical piece of hardware in the SAO program

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[44]See E. Nelson Hayes, *Trackers of the Skies*, (Cambridge, Doyle Press, 1968).

was, of course, the big camera. Whipple asked James G. Baker, a consultant to Perkin-Elmer of Norwalk, Conn., to design it. By February 1956, Whipple and Baker, joined by J. Allen Hynek, who had left Ohio State University to become associate director of the SAO tracking program, had laid out plans for the new tracking camera. They asked Joseph Nunn of Pasadena, Calif., to do the mechanical design work. By fall of 1956, the Baker-Nunn camera design had progressed to the point where hardware contracts were let. Perkin-Elmer built the optical system, while Boller & Chivens, South Pasadena, Calif., built the camera proper. The first camera was tested October 2 and 3, 1957, at South Pasadena. It was decided at that time to dismantle the camera for minor alterations and adjustments. A few hours later, *Sputnik 1* went into orbit. *Sputnik 1* accelerated the Baker-Nunn, just as it did all other U.S. satellite work. The first Baker-Nunn station became operational at Organ Pass, New Mexico, in November 1957, just a few weeks later.

The SAO Moonwatch program paralleled the Minitrack Moonbeam amateur effort. One might have expected there to be more amateur radio enthusiasts than astronomy enthusiasts. The Moonwatch Program, however, was well publicized and, under the direction of Leon Campbell, Jr., was sold all across the U.S. by SAO representatives. Through the astronomical fraternity, many international Moonwatch stations were set up. By October 1957, there were 80 registered Moonwatch teams in the U.S. and 84 in foreign countries. The night of October 4 caught Moonwatch by surprise just as it had the Minitrack group. Only two people were at the SAO Cambridge facility when the news of *Sputnik 1* came through. Others hurried back to help as they heard the news. By the dawn of October 5, over 100 Moonwatch teams were looking for *Sputnik 1* as it was lit by the morning Sun for the Moonwatchers still in darkness on the Earth below. Unfortunately, the attempt at camera acquisition of *Sputnik 1* was as futile as the attempts at reception of its signals by radio hams. The Baker-Nunn cameras were not completed and the Minitrack frequency was wrong.

Although no more will be said about the SAO optical network in this monograph, its twelve worldwide stations are an important adjunct to STADAN, particularly where precision tracking data is wanted for geodetic purposes.

Four Years of Stability; 1958-1962

The last prime IGY Minitrack station went operational at Woomera during October 1957. Outside of some minor shuffling and addition of sites and the rebuilding of temporary installations, no major changes were made to Minitrack until the big 26-m paraboloidal antenna was installed at the new Fairbanks site in May 1962. This section covers the four years of relative stability following the first Explorer and Vanguard satellites. During this period, the Minitrack network easily tracked the few, relatively simple scientific satellites that passed overhead. It was a time of intense planning, research, and development as the Nation planned space programs that would soon saturate Minitrack's capabilities. It was also a period of organizational flux as the government searched for the best way to prosecute a space effort that would surpass that of the U.S.S.R.

Organization of NASA. At first, the official U.S. IGY satellite program - Vanguard - was buried deeply within the country's military organization. The Army's successful Explorer satellites further split a satellite effort that Russian accomplishments quickly proved was far too weak in total. The National Aeronautics and Space Administration was created on October 1, 1958 to remedy these deficiencies by concentrating all peaceful space programs into a single organization.[45] Of this major realignment and upgrading of the national space program, only the fate of the tracking, data-acquisition, and other STADAN functions interests us here. Under Vanguard, tracking responsibility had been assigned to the NRL Radio Tracking Branch, under John T. Mengel. (Figure 2-8) When NASA was formed, the Vanguard group was transferred bodily to NASA.[46] The NRL Vanguard team became the nucleus of the Beltsville Center, which in May 1959 was renamed the Goddard Space Flight Center. In the tracking area, Mengel remained in charge of the Goddard work with the title of Assistant Director for Tracking and Data Systems, reporting to the Office of the Director of Goddard. Until the Goddard reorganization of July 25, 1967, the STADAN and MSFN tracking and data acquisition activities were both under the same directorate. The reorganization assigned the MSFN responsibilities to a new Manned Flight Support Directorate, under Ozro M. Covington. STADAN and data processing activities remained in Mengel's directorate.

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[45]Executive Order 10783 established NASA. A subsequent, separate agreement between NASA and DOD transferred the Minitrack network. See Robert Rosholt: *An Administrative History of NASA, 1958-1963.* (Washington: NASA SP-4101, 1966).

[46]The cohesiveness and permanence of the Vanguard Minitrack group over a period exceeding ten years is remarkable. In the transfer to NASA, only a few of the original Minitrack team, notably Roger Easton, remained behind at NRL.

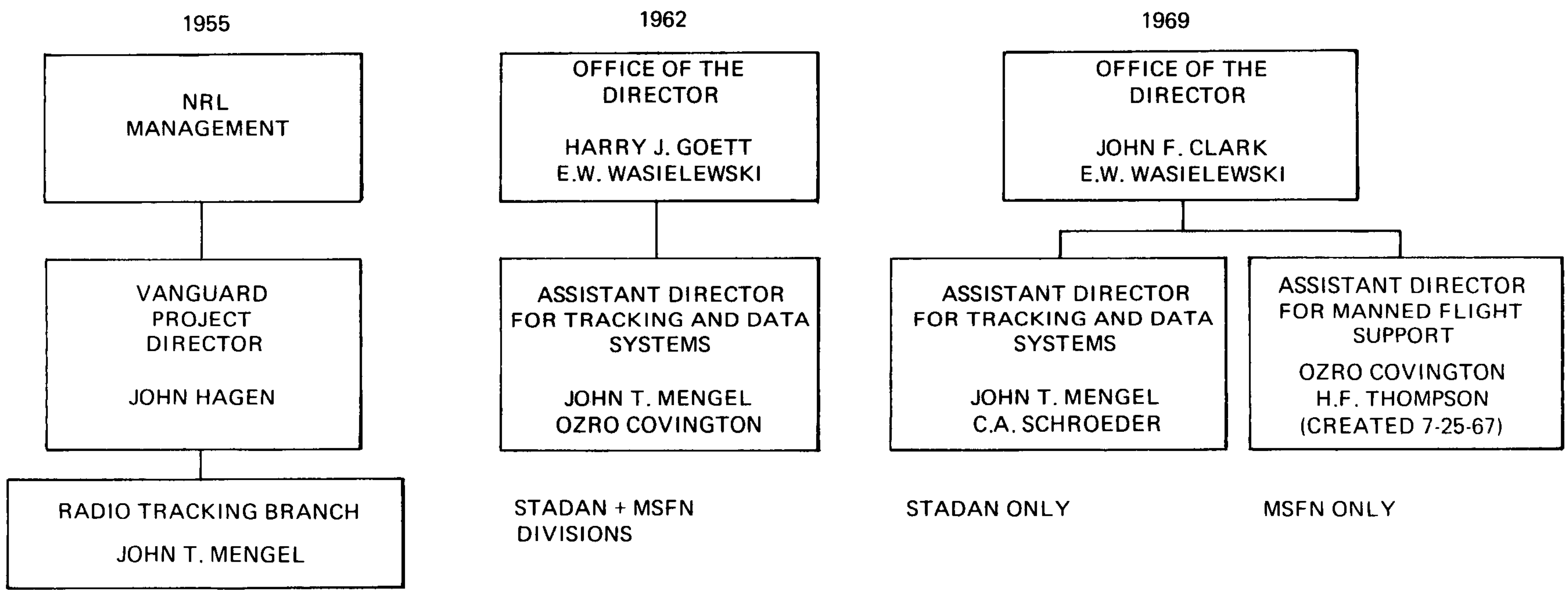

Figure 2-8. Sketch of Goddard management structure in tracking and data acquisition.

At NASA Headquarters, in Washington, where Agency-wide operations were to be coordinated, the tracking and data-acquisition functions were handled by the Assistant Administrator for Space Flight Operations in the person of Edmond C. Buckley, who reported to the Associate Administrator for Space Flight Programs. (Figure 2-9) With some minor changes in titles, this arrangement persisted until Nov. 1, 1961, when an Agency-wide Office of Tracking and Data Acquisition was established.[47] Edmond C. Buckley assumed the title Director, Office of Tracking and Data Acquisition, at this time; becoming, in 1966, Associate Administrator, Tracking and Data Acquisition. This organization was retained through 1967, when Buckley retired and his Deputy, Gerald M. Truszynski, assumed his position.

In comparison with industry and even other Government agencies, NASA's organization for managing the Minitrack and STADAN functions has been extraordinarily stable.

When NASA absorbed Minitrack and assumed the responsibility for tracking non-military satellites, it also inherited the problem of finding money for operating Minitrack and for financing the development and purchase of new equipment. During the Vanguard Program, money had been allocated to the National Science Foundation and then passed on to the Naval Research Laboratory. In the case of NASA, Congress appropriates money directly. NASA Headquarters assembles all the monetary requirements for new facilities, research and development, and operation of all its networks. These requirements are related to the total NASA program; a budget is prepared and presented to Congress. Funds appropriated for STADAN flowed originally through the Office of Space Flight Operations to Goddard Space Flight Center, the field center with the operating responsibility for STADAN. After the creation of the Office of Tracking and Data Acquisition in 1961, it has served as the source of STADAN funds within NASA.

DOD Interfaces and Coordination. After its formation, NASA moved rapidly to assimilate all nonmilitary space activities as well as military operations it deemed important to its mission, particularly von Braun's organization at Huntsville and the JPL team. With the acquisition of JPL, NASA had central control over all scientific satellite work and had absorbed the JPL Microlock stations. NASA also took over direct control of the South American Minitrack stations from the Army in early 1959.[48]

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[47]Robert Rosholt, *An Administrative History of NASA, 1958-1963*, (Washington: NASA SP-4101, 1966), p. 221.

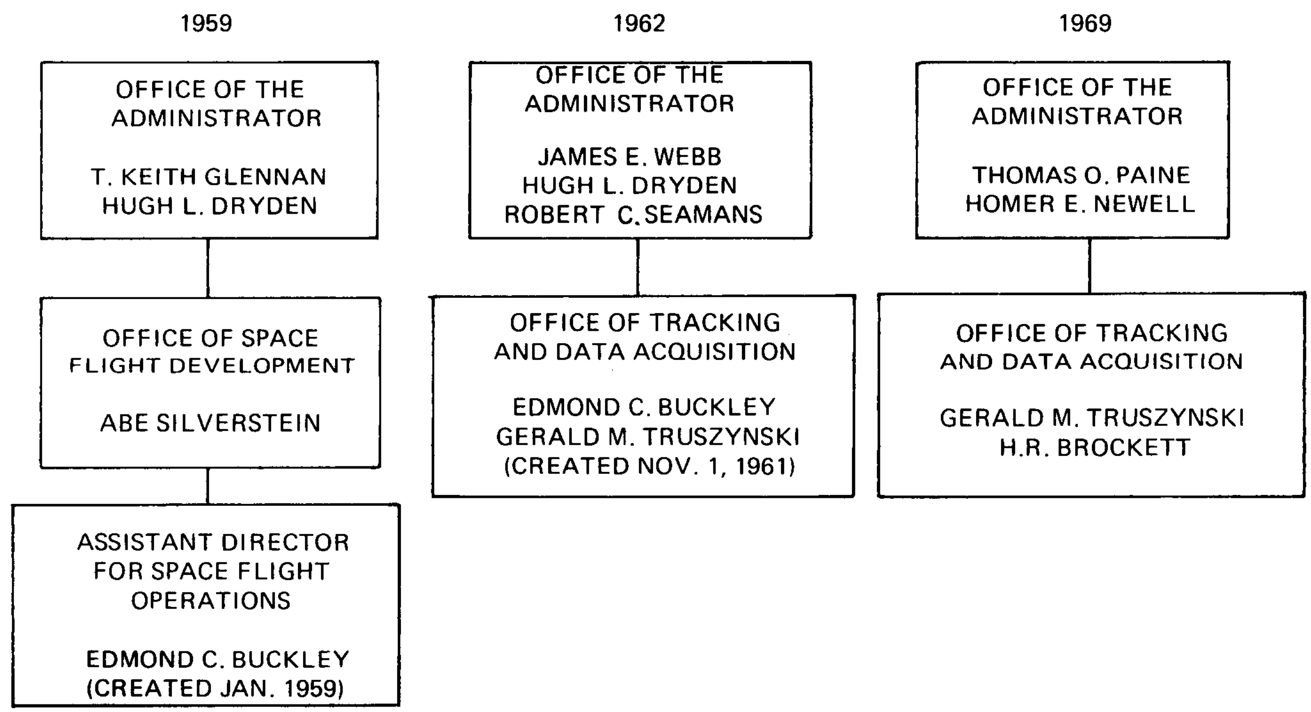

Figure 2-9. Sketch of Headquarters management structure in tracking and data acquisition. Gerald M. Truszynski became Associate Administrator of OTDA in 1967 when Edmond C. Buckley retired.

In the post-Sputnik era, DOD was rapidly building up its own tracking facilities; i.e., SPASUR. The framers of the Space Act were concerned over duplication of facilities if NASA and DOD went their separate ways. Section 204 of the Space Act provided for a Civilian-Military Liaison Committee. In actual practice, this Committee was little used and eventually atrophied completely. Significant duplication was actually prevented by DOD's primary interest in detecting new, potentially threatening objects in space rather than acquiring scientific data from satellites or obtaining orbital elements with high precision. SPASUR and other DOD facilities must keep accurate traffic counts of what passes over. DOD's National Range Division and Satellite Control Facility possess some tracking and data-acquisition capabilities, which are employed with military and a few Air Force scientific satellites. There has been no attempt to duplicate STADAN. More effective coordinating groups, particularly the Space Flight Ground Environment Panel of the Aeronautics & Astronautics Coordinating Board (AACB) have functioned, often in the spotlight of Congressional attention, to assure an effective cross-exchange of information and to avoid unnecessary duplication of effort or facilities.[49] In fact, NASA and DOD have shared their facilities to a greater and greater extent. NASA provides NORAD with tracking data and tracks Air Force scientific satellites carrying Minitrack beacons. NASA also acquires telemetry data for many DOD scientific satellites.

The NASA-DOD interface is not as extensive on unmanned missions as it is on NASA's manned flights, where DOD is involved from launch through the recovery operation. Once an unmanned satellite leaves the vicinity of the launch range and is acquired by STADAN, DOD is essentially out of the picture. (See Chapters 3,4, and 5 for a discussion of the more intimate interfaces that prevailed during Mercury, Gemini, and Apollo.) Nevertheless, formal procedures have to be specified and agreed to, particularly at Cape Kennedy, where common schedule, safety, radio-frequency, and other interfaces exist in profusion. At the agency level, coordination procedures are specified in a broad fashion by Memoranda of Agreement between the NASA Administrator and the

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[48]NASA Memo 4132-8; JPC: mlk, Feb. 2, 1959. A request from NASA to the Chief, Army Communication Services Division, to turn over all station responsibilities. (In NASA Historical Office Vanguard files)

[49]The Space Flight Ground Environment Panel of the Aeronautics & Astronautics Coordinating Board (AACB), with separate sub-panels on Network Plans and Development effectively control this particular NASA-DOD interface today.

Secretary of Defense.[50] Within NASA, NASA Management Instructions provide more detailed interface control. One document of particular importance has been the November 21, 1966, memorandum from Deputy Administrator Robert C. Seamans, Jr., to the Associate Administrators, entitled: "Relationships within NASA and between NASA and DOD Elements in the Planning, Establishment, and Use of Launch, Launch Support, Tracking, Data Acquisition and Processing, and Communications Facilities." Of course, much less formal working relationships have evolved at the working levels.

Minitrack Operation - 1958-1962. This was a period of few major changes - one might call it a plateau - in Minitrack capabilities. More and more satellites were launched as NASA scientific programs began to materialize in hardware form. But the satellites were not large, there were not too many of them in orbit at one time, and their orbits usually were within the reach of the Minitrack net. It had to be this way, obviously, because the tracking and data-acquisition network was the horse that had to precede the cart. As NASA laid plans for the Observatory series of satellites, polar satellites, and satellites circling in highly eccentric orbits, NASA planners and engineers at Headquarters and Goddard had to keep one jump ahead with facilities that would do the required job.

When NASA took over the Nation's scientific space programs, the IGY had only three months to go; Vanguard had had one success and many disappointments; and there had been three successful Army Explorers and two failures - hardly a burden for Minitrack. During 1959, four more scientific satellites went into orbit. Some satellites, such as *Vanguard 1* kept on transmitting for lengths of time that began to worry those who looked ahead in a Malthusian way and feared that the sky would soon be so full of transmitting satellites that ground facilities would be saturated. Cutoff or "killer" timers began to be installed on satellites to counter this trend. But by 1960, most recognized that Minitrack would have to be enhanced in several ways within two or three years. This preparation and deployment of today's STADAN is the subject of the next section.

Network Modifications and Changes. Some Minitrack site

[50]For example: "NASA-DOD Agreement Regarding Management of AMR and MILA," January 1963; and "DOD-NASA Agreement Regarding Land-Based Tracking, Data Acquisition, and Communications Facilities," May 1965.

changes were made during the 1958-1962 period to improve geographical coverage and data acquisition. Stations were added at College, Alaska, East Grand Forks, Minn., St. John's, Newfoundland, and Winkfield,England. A few stations were closed down or shifted; for example, the move of the Havana equipment to Ft. Myers and the shutdown of Antigua. These changes did not add any radically new capabilities to Minitrack.

Some changes in telemetry and command antennas were made during this period, and supporting electronic equipment was improved. The "rockinghorse" antenna of Vanguard days was superceded by a manually pointed 9-Yagi array (Figure 2-10) and then by a few 16-Yagi arrays to improve telemetry reception and command transmission. The fundamental frequency of Minitrack was upped from 108 MHz to 136-to-137 MHz in 1960 to escape from local interference at the lower frequency and meet International Telecommunication Union (ITU) requirements. This change required relatively minor modification of the Minitrack interferometer. Unfortunately, complete frequency conversion was impossible between 1961 and 1965 because several active satellites were still telemetering useful data at 108 MHz.

Another rather interesting change to Minitrack involved the modification of the calibrating astrographic cameras for the purpose of optical satellite tracking in May 1960. The resulting cameras did not have the precision and acuity of the SAO Baker-Nunns, but the larger satellites could be tracked and, in addition, used for Minitrack calibration in the place of aircraft. Collectively, the new cameras formed the Minitrack Optical Tracking System (MOTS).[51]

Summarizing, in the first four years after NASA's creation in October 1958, Minitrack changed but little. There was no larger need - yet - satellites were few, far between, and relatively simple. Major changes were in the offing, however.

Metamorphosis of Minitrack into STADAN; 1963-1966

The preceding section hinted at major changes "brewing" beneath the calm surface of the 1959-1962 time period. To understand how and why Minitrack evolved into STADAN, let us first look at the pressures NASA's satellite plans exerted

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[51]David W. Harris, et al., "MOTS - The Minitrack Optical Tracking System," *Photo. Sci. Eng.*, Vol. VII, March 1963, p. 73.

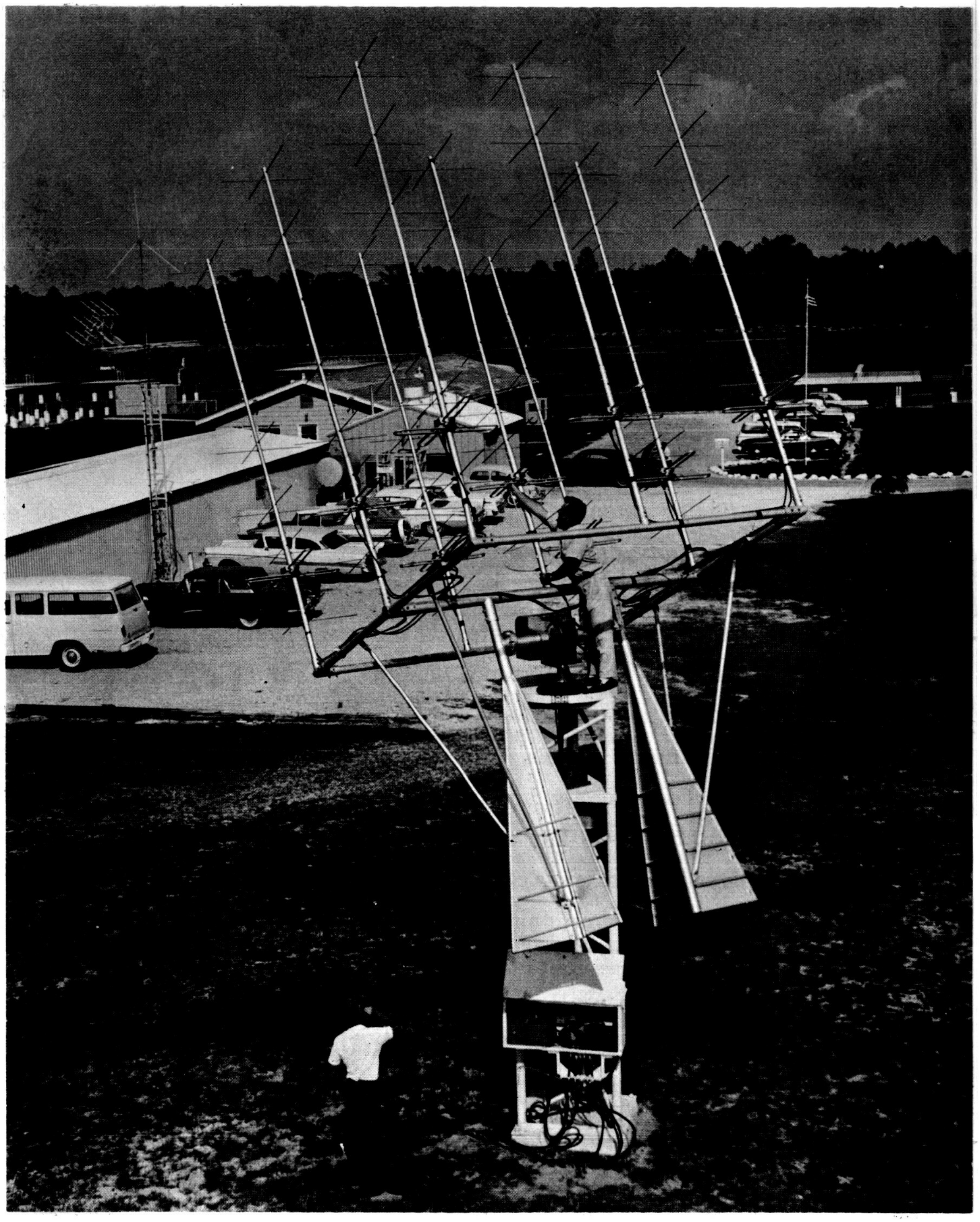

Fig. 2-10. A 9-Yagi, 136-MHz STADAN antenna.

on its tracking and data-acquisition facilities. The total picture can be best visualized with the help of a cause-and-effect table:

-Cause- Pressure Due to Planned Program	-Effect- Major Additions to Basic Minitrack
Tracking requirements of polar-orbit satellites and geodetic satellites.	Extension of geographical coverage to Alaska. See Appendix A for details.
Data-acquisition requirements of Observatory-class satellites and communications and meteorological satellite programs.	Installation of 26-m and 12-m paraboloidal antennas at Gilmore, Orroral Valley, and Rosman.[52] Addition of high capacity data links to Goddard.
Tracking requirements of synchronous satellites and those in highly eccentric orbits.	Goddard Range and Range Rate (GRARR) tracking systems installed at several STADAN sites and on mobile equipment.
Need for better command capability for complex Observatory-class satellites and large meteorological satellites.	SATAN command antennas with high-powered transmitters.[53]

[52]The STADAN 26-m and 12-m dishes are used for data acquisition not tracking. In the MSFN and DSN, however, the big dishes are essential to tracking.

[53]SATAN = Satellite Automatic Tracking Antenna.

With the advent of NASA, funding levels jumped from millions to billions, and the sheer magnitude of the Nation's space effort demanded a more rigorous approach. If tracking and data-acquisition equipment was to be developed and installed in time for a new satellite program, a forecast of satellite launchings had to be available. NASA's first formulation of a comprehensive plan was embodied in a secret document entitled "NASA Long Range Plan," prepared in December 1959 by the Office of Program Planning and Evaluation.[54] This plan was primarily a forecast of what NASA could do given certain budgetary constraints and reasonable extrapolations of the state of the art in launch vehicles - the pacing facet of space technology at that time. Plans such as this were continually modified, particularly under the pressure of the Soviet feats in space.[55] Despite their ephemeral character, these plans gave tracking engineers targets to shoot at, such as the planned Observatory-class satellites and synchronous communications satellites. To meet such requirements, Goddard engineers had to predict the state of the art two or three years in advance. Various technical solutions were studied and tried out in the laboratory. Finally specific approaches were selected and developed into operational hardware, such as the Goddard Range and Range Rate equipment.

In the paragraphs that follow, some of the key technical and historical features of these additions will be related. Separating out and listing the major additions to the basic Minitrack, we have:

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[54]Robert L. Rosholt, *An Administrative History of NASA, 1958-1963* (Washington, NASA SP-4101, 1966), p. 130.

[55]Perhaps the sharpest perturbation occurred on May 25, 1961, when President Kennedy announced that it was time for a "great new American enterprise" - landing a man on the Moon within the decade.

- Site additions and shifts
- The new 26-m and 12-m dishes
- The Goddard Range and Range Rate tracking equipment (GRARR)
- SATAN telemetry antennas and SATAN command antennas
- Enlargement and automation of the ground-based communication links between STADAN stations.

All these changes and additions have converted Minitrack into what is now called STADAN (Space Tracking and Data-Acquisition Network.)[56]

Station Site Changes. The early Minitrack sites were geographically constrained by the short range of the tiny Vanguard transmitter and the lack of precision tracking during the satellite injection phase downrange. No one was sure just where a satellite would pop over the horizon. Minitrack stations were thus deployed, rather close-spaced, along the now-familiar detection fence on the 75th meridian. Today, with downrange tracking ships and much better injection tracking, rough orbital elements are available even before the satellite leaves the launch range. Spacecraft, too, are more sophisticated and can carry beacons that send out strong signals. The Minitrack "detection-fence" approach has been abandoned in favor of fewer better-equipped stations located all over the world. First, though, there was the elimination of redundant Minitrack sites, such as Antofagasta. These changes were offset by the addition of new Minitrack sites well outside the 75th-meridian fence, e.g., Winkfield and College. The fact of today is that tracking is not the most important function of STADAN, as it was with Minitrack; data acquisition has assumed prime importance. STADAN is no longer characterized by an interferometer fence but instead by well-separated, high-data-rate paraboloidal antennas.

Every continent except mainland Eurasia possesses a site with a 12-m or 26-m dish.

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[56]Frequently, the word "Space" in STADAN's acronym has been interpreted as "Satellite," but this unnecessarily limits STADAN's utility with semantics. STADAN has been used for lunar purposes; viz., the Anchored IMPs, Explorers 33 and 35.

This distribution is necessary because today's satellites run the gamut in inclination from the equatorial Syncom to the Polar Orbiting Geophysical Observatories. Originally, as the station vignettes in Appendix A testify, there existed a more specific reason for locating stations away from the 75th meridian. The first Australian station at Woomera, for example, was placed there for geodetic purposes during the IGY. The Australian STADAN station in Orroral Valley, however, possesses a 26-m dish and conforms with STADAN consolidation philosophy stating that data acquisition is now STADAN's prime reason for being.

To summarize then, the geographic evolution of STADAN has consisted of three overlapping phases:

- The Minitrack 75th-meridian fence
- Geographically dispersed Minitrack stations
- Fewer, better-instrumented, well-dispersed STADAN stations.

The Big Dishes. The first 26-m antenna went into operation at the Alaska STADAN station in March 1962.[57] The main stimulus behind its design and construction was the Nimbus meteorological satellite program, which officially began at NASA in 1960. Minitrack data-acquisition capabilities were obviously inadequate for receiving the flood of cloud-cover pictures that Nimbus would generate. One or more wide-band, high-data-rate antennas were required.[58] A large, pointable antenna (Figure 2-11)was an expensive affair - roughly $910,000 for the design, engineering, fabrication and erection of the Alaska 26-m dish.[59] The 26-m dishes have obviously been well worth their price; NASA now owns over a dozen of them if all three tracking networks are included.

Since the equipment at the STADAN sites is described in great technical detail in readily available NASA documents, only events of historical interest are covered in

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[57]Sites with 26-m dishes were originally termed DAF (Data-Acquisition Facility) sites, but they are now classed as STADAN sites.

[58]The STADAN data acquisition rate has increased from 3 million data points per day in 1961 to 300 million in 1972.

[59]Interview with John T. Mengel, April 28, 1966.

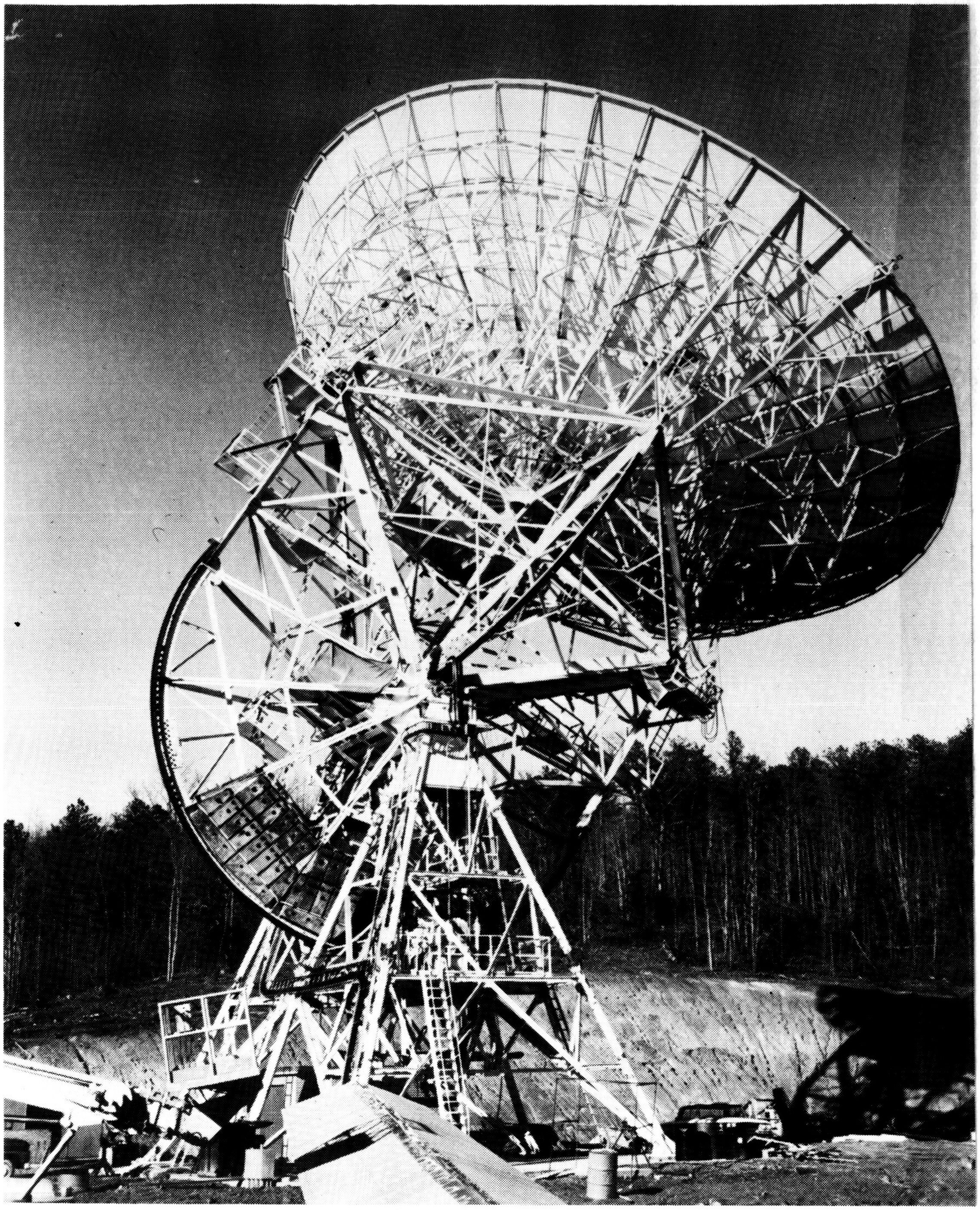

Figure 2-11. Photograph showing one of the two 26-m data acquisition antennas at Rosman.

this chapter.[60]

The price of the first Rosman 26-m antenna was brought down to $760,000, less for additional ones, but NASA decided to install cheaper 12-m paraboloids at sites where smaller antennas were adequate. (Figure 2-12) The first of these new antennas went into operation at Quito in December 1963.

STADAN seemed by 1966 to have reached an instrumentation plateau, just as Minitrack did at the end of the IGY. Data-acquisition facilities were then adequate for the satellite programs planned by NASA. Indeed, satellite science was being caught in a budget squeeze by the higher-priority Apollo program. Furthermore, there seemed to be a trend away from complex, high-data-rate Observatory-class satellites to larger numbers of smaller scientific satellites. The creation of the SAS (Small Astronomical Satellite) program illustrated this trend.

Goddard Range and Range Rate Equipment (GRARR). Although STADAN's primary mission has become data acquisition, the tracking function is no less vital than it was in the Vanguard days. Tracking, in fact, has become a great deal more difficult as NASA's programs have expanded to embrace Syncom, ATS, IMP, and the eccentric-orbit Observatories. The problems are two:

- In synchronous or stationary orbits the satellite bearing changes moves very slowly - perhaps not at all - with respect to the ground-based tracking station. Minitrack interferometry is powerless here because it cannot generate a precision orbit without many separate observations at well-separated spots. Minitrack yields only direction cosines and not the range and range rate directly, yet these are critical parameters in jockeying a synchronous satellite into orbit.
- Minitrack angle tracking is of little use when satellites are near apogee in an eccentric orbit. In this region, angles vary slowly but range and

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[60]The most descriptive reports are: *Satellite Instrumentation Network Facilities Report*, Goddard Rpt. X-530-62-3, April 1962 (note the early acronym - SIN); *Satellite Tracking and Data Acquisition Network Facilities Report (STADAN)*, Goddard X-539-64-159, June 1964; and *Space Tracking and Data Acquisition Network Facilities Report (STADAN)*, Goddard X-530-66-33, December 1965; *Space Tracking and Data Acquistion Manual*, Goddard X-530-69-109, 1969.

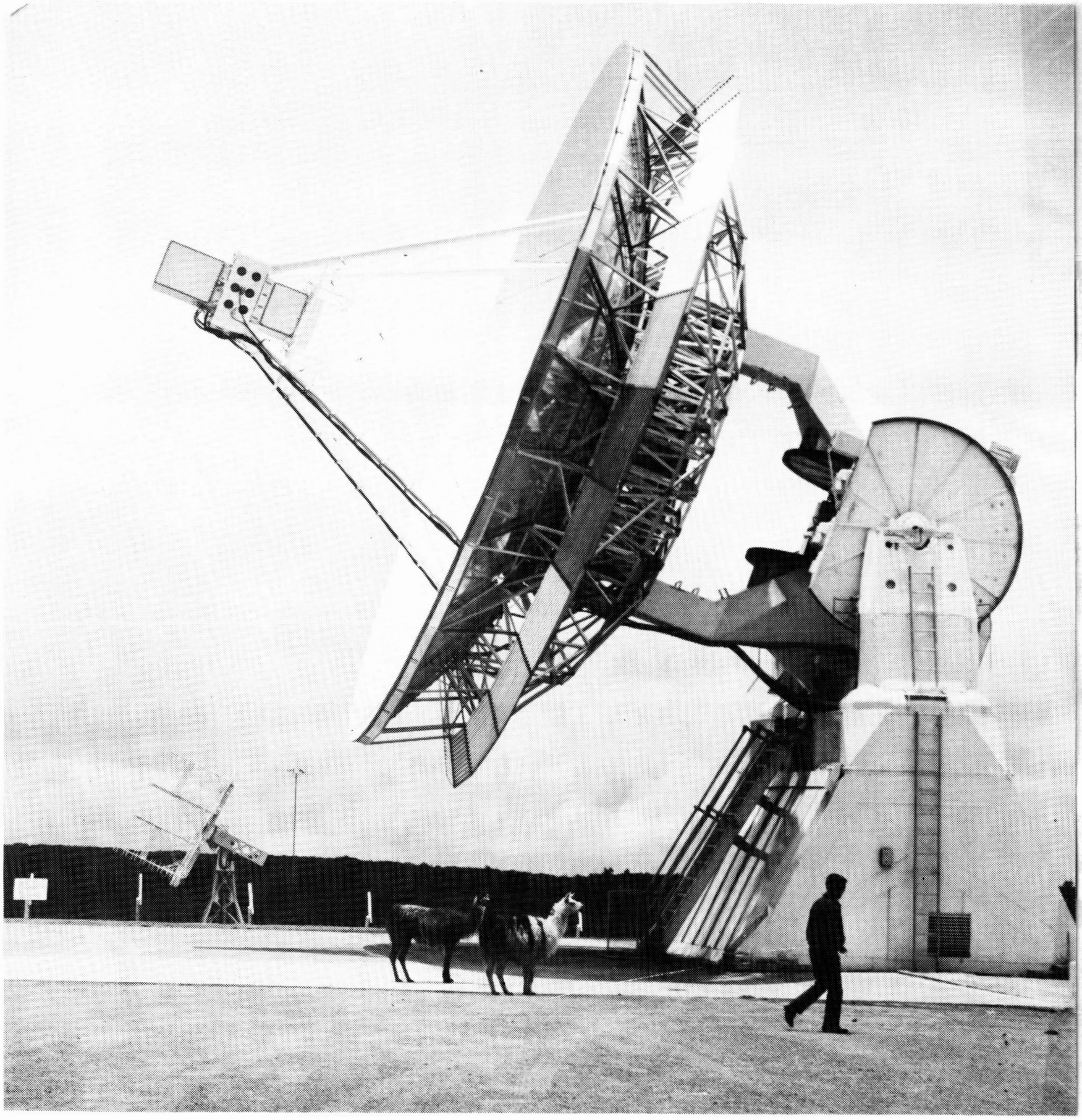

Figure 2-12. The 12-m data acquisition dish at Santiago.

range rate change quickly.

These tracking problems were recognized by NASA before 1960, when the essentials of GRARR were laid out by Edmund J. Habib, at Goddard, and Eli Baghdady, at Adcom, Inc.[61] In essence, GRARR sends a signal to the spacecraft, which replies through a transponder. In a concept called "sidetone ranging," time of signal transit to and from the satellite yields distance and Doppler measurements give range rate.

The major competitor of the GRARR concept in early 1960 was a refined version of Minitrack. Both John Mengel and his Deputy, Clarence A. Schroeder, both from NRL, initially favored a 2000-MHz radio interferometer.[62] The twenty-times-shorter wavelength would have conferred much higher accuracy and permitted NASA to capitalize on its extensive experience with Minitrack. However, Mengel and Schroeder were soon convinced that angle tracking alone -- even if made much more precise -- would not suffice for the nearly stationary synchronous satellites and high eccentricity orbits then in the planning stages.

Space Technology Laboratories built the first piece of GRARR equipment for the NASA Syncom program in 1961. Motorola, GE, and General Dynamics/Electronics have since constructed additional units.[63]

GRARR equipment was ultimately installed at five STADAN sites (Carnarvon, Santiago, Tananarive, Fairbanks, and Rosman) and used with great success with such satellites as the Syncoms, the IMPS, and the OGO series. (Figure 2-13) On *Explorer 35*, an *Anchored IMP* orbiting the Moon,

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[61]Edmund J. Habib, George C. Kronmiller, Peter D. Engels, and Henry J. Franks, "Development of a Range and Range Rate Spacecraft Tracking System," *NASA TN D-2093*, June 1964. (The three coauthors of Habib were part of the original Goddard GRARR design team.)

[62]Personal interview with Friedrich O. Vonbun, March 12, 1969.

[63]For an informal discussion of the Motorola GRARR program, see "Innovations in Satellite Tracking," *Engineering Bulletin*, Vol.XIV, no. 2, 1966, p. 14, (published by Motorola/Government Electronics Division).

Figure 2-13. The GRARR S-band antenna at the Carnarvon STADAN station.

range can be measured to within 1.6 km, even at lunar distances. Range rate can be measured to within 63 cm per second at the same distance. GRARR can be used reliably out to about 130,000 km. Tracking at greater distances is the function of the DSN, which employs a different ranging technique in place of the Goddard sidetone ranging. Otherwise the engineering principles are similar in the JPL and Goddard conceptions.[64]

SATAN Equipment. The early evolution of the "rocking-horse" and Yagi telemetry antennas was described earlier in this chapter. The installation of the big 26-m and 12-m wide-band, data-acquisition paraboloids did not diminish the need for better telemetry antennas to handle the smaller satellites. The big dishes can be used for the smaller Explorer-class satellites, but it is a poor use of their capability if an Observatory, a Nimbus, or some other large satellite is also within station range. The purpose of the SATAN antennas is to complement the data-acquisition and command functions of the big dishes, replacing the small, often hand-pointed, 9- and 16-element Yagis of Minitrack vintage. The SATAN antennas also perform as acquisition aids for the narrow-beam-width paraboloids. At sites with no big dishes, the SATAN antennas are of course the prime data-acquisition and command antennas.

There are two types of SATAN antennas: one for telemetry reception and another for command - the *down-link* and *up-link*, according to current terminology. (Figures 2-14 and 2-15)[65] Although the early Yagi antennas did not have automatic tracking capability, all recent versions do. Automatic tracking is, of course, inherent in the name of the antenna. SATAN telemetry-reception antennas operate in the 136-to-138 MHz range, and the command antennas transmit in the 123-MHz and 147-to-150 MHz bands.

Inhouse development of the SATAN antennas began at Goddard soon after the Center was created. By 1960, a developmental model tower and pedestal, servodrive system, and 108-MHz receiving-antenna array were installed at Blossom Point. Based on this development work, NASA held a competi-

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[64]See Chapter 5 for a discussion of the choice between the JPL and Goddard range and range rate systems for use in the Apollo USB system in the MSFN.

[65]Goddard Space Flight Center: *Data Systems Development Plan, Satellite Automatic-Tracking Antenna Network (SATAN)*, Revision 2, Sept. 23, 1965.

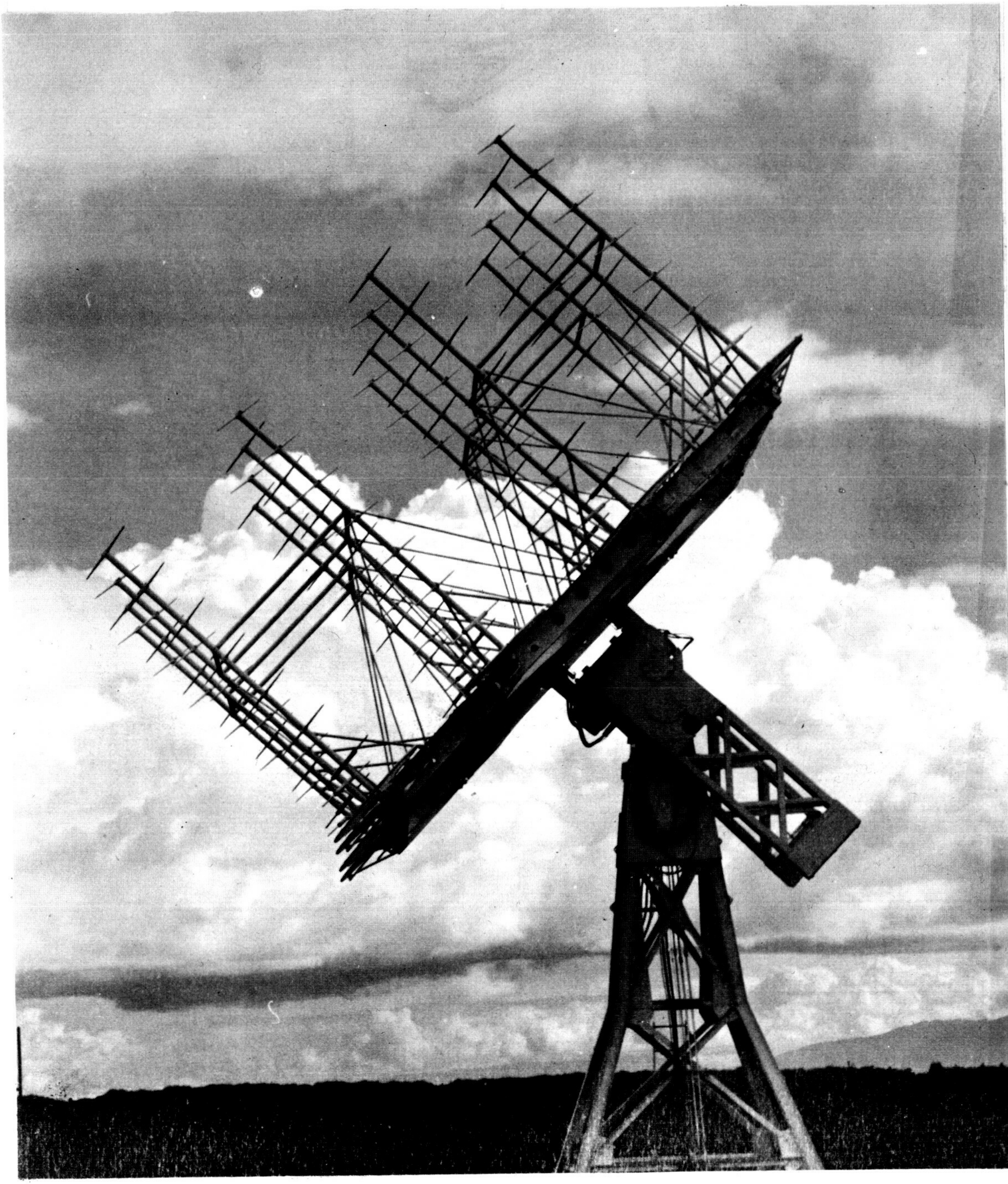

Figure 2-14. Photograph of a SATAN Telemetry Reception Antenna

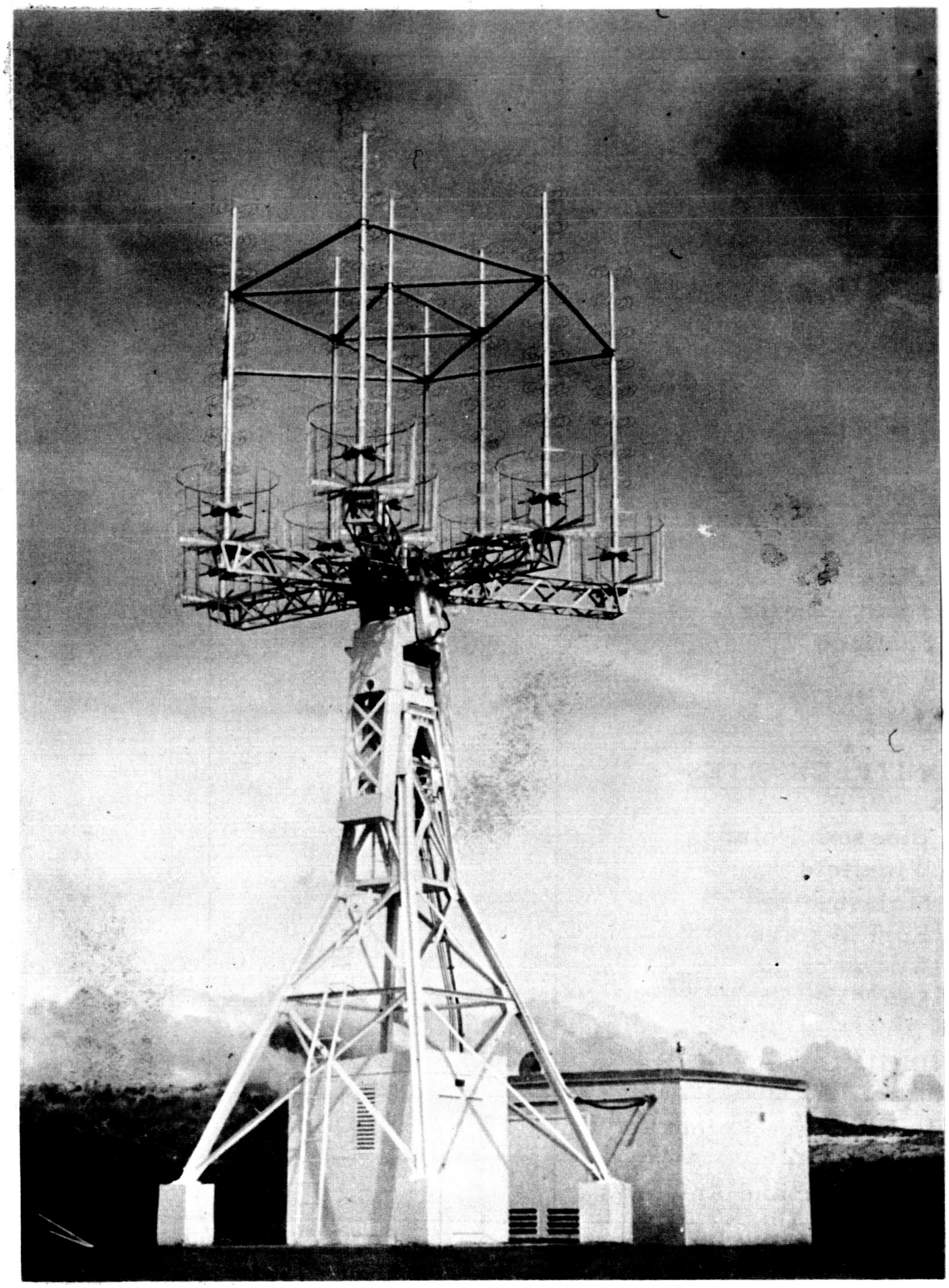

Figure 2-15. Photograph of a SATAN Command Antenna

tion for SATAN production. On August 17, 1962, NASA selected Dalmo-Victor Company and Amelco, Inc., to negotiate for R&D and production services for the SATAN program. By the end of 1968, 14 SATAN telemetry-receiving and 16 SATAN command antennas were installed at STADAN sites.

STADAN Consolidation and Computerization; 1966-1971

With its creation in 1958, NASA inherited the dozen Minitrack stations that NRL had established along the 75th meridian and the outliers at San Diego, Woomera, and Johannesburg. By the end of 1961 five of these original stations -- Antigua, Ft. Stewart, Grand Turk, Havana, and San Diego -- had been moved for one reason or another. Closures, however, were more than compensated by the opening of the new stations listed in Table 2-1. By 1965, 22 STADAN stations were sprinkled around the world.They varied from small command antenna sites (Kauai) to the 26-m antenna DAF facilities (Alaska). The maintenance of so many stations with the necessary communication links back to Goddard was not only expensive but also inefficient in the use of equipment. In 1965 satellites carried radio beacons and transmitters with ample power; further, tracking was now secondary in importance to telemetry. In other words, technology had advanced and missions had altered to the point where fewer, better-instrumented stations would serve NASA and the taxpayer better.

The year 1966 saw the phase-out of six STADAN stations. The Minitrack arrays at Blossom Point, College, East Grand Forks, and Woomera were all moved to other network locations. The operation of one of the 26-m dishes at the Alaska site was transferred to ESSA, so that it could work its own weather satellites. Finally, the STADAN site at Kano, Nigeria, was transferred to the jurisdiction of the MSFN. Excluding the Network Training and Test Facility (NTTF) at Goddard and the two collateral stations (Singapore and Solant), STADAN was streamlined to 17 stations with the equipment inventories specified in Table 2-2. (Figure 2-16)

During 1968 and 1969, STADAN was further streamlined when the Darwin, Lima, and Toowoomba stations were deactivated or placed in an inactive category.

STADAN Computerization. STADAN has been caught between the vise jaws of budgetary constraints on one side and the "space data explosion" on the other. Figure 2-17 shows the near-exponential rise in the rate of data acquisition. One would suspect at first that the same budgetary constraints would reduce satellite launchings and therefore dampen the driving

Table 2-1. ROSTER OF STADAN STATIONS: 1956-1971

Station	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ahmedabad							d									
Alaska							a	a	a	a	a	a	a	a	a	a
Antigua		a	a	a	a	b										
Antofagasta		a	a	a	a	a	a	b								
Blossom Point	a	a	a	a	a	a	a	a	a	a	c					
Brazilia								b								
Carnarvon									a	a	a	a	a	a	a	a
College Park							a	a	b							
College					a	a	a	a	a	a	c					
Darwin										a	a	a	a	c		
E. Grand Forks					a	a	a	a	a	a	b					
Ft. Myers				a	a	a	a	a	a	a	a	a	a	a	a	a
Ft. Stewart		a	a	c												
Gilmore								a	a	a	e					
Goddard (NTTF)											a	a	a	a	a	a
Grand Turk		a	a	a	b											
Havana		a	a	c												
Johannesburg			a	a	a	a	a	a	a	a	a	a	a	a	a	a
Kano										a	c					
Kashima Machi												d	d	d	d	
Kauai										a	a	a	a	a	a	a

Table 2-1. ROSTER OF STADAN STATIONS: 1956-1971 (continued)

Station	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Lima		a	a	a	a	a	a	a	a	a	a	a	a	c		
Majunga								a	b							
Mojave					a	a	a	a	a	a	a	a	a	a	a	f
Orroral Valley (Canberra)										a	a	a	a	a	a	g
Quito		a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Rosman							a	a	a	a	a	a	a	a	a	a
San Diego		a	a	a	c											
Santiago		a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Singapore								d	d	d	d	d	d	d	d	
Solant								d	d	d	d	d	d	d	d	d
South Point, Hawaii						d	d	d	d	d	d					
St. Johns					a	a	a	a	a	a	a	a	a	a	b	
Tananarive										a	a	a	a	a	a	a
Toowoomba										a	a	a	a	c		
Winkfield						a	a	a	a	a	a	a	a	a	a	a
Woomera		a	a	a	a	a	a	a	a	a	c					

a = active (See Figure 2-16)

b = phased out

c = equipment transferred elsewhere (See Appendix A for details.)

d = collateral station

e = transferred to NOAA (one 26-m dish)

f = ATS site only

g = GRARR equipment only

Table 2-2. DISPOSITION OF MAJOR STADAN EQUIPMENT IN 1966

Station	Code Name[c]	Approx. Latitude	Approx. Longitude	Telemetry[a] 26-m Dish	Telemetry[a] 14-m Dish	Telemetry[a] SATAN Rec.	Command[a] SATAN Comm.	Command[a] Yagi Comm.	Tracking Mini-track	Tracking GRARR	Tracking MOTS
Alaska (NASA)	ALASKA	64°59'N	147°31'W	1	1	2	2		1	1	1
Carnarvon	CARVON	24°54'S	113°43'E					1[i]		1	
Darwin[e]	DARWIN	12°17'S	130°49'E	14-ft dish[h]				1			
Ft. Myers	FTMYRS	26°33'N	81°52'S			1	1	3	1		1
Gilmore (ESSA)	ALASKA	64°59'N	147°30'W	1							
Johannesburg	JOBURG	25°53'S	27°42'E		1	1	1	1	1		1
Kauai	KAUAIH	22°07'N	157°40'W					2			
Lima[f]	LIMAPU	11°47'S	77°09'W			1	1	1	1		1
Mojave[d]	MOJAVE	35°20'N	116°54'W		1	1[b1]	1[b]	1	1[b]		1[b]
Orroral Valley	ORORAL	35°38'S	148°57'E	1		2	2	1[b]	1		1
Quito	QUITOE	00°37'S	78°35'W		1	1	1	3[j]	1		1
Rosman[d]	ROSMAN	35°12'N	82°52'W	2		3[j]	3[j]			1	1
Santiago	SNTAGO	33°09'S	70°40'W		1	2	1	1	1	1	1
St. Johns	NEWFLD	47°44'N	52°43'W					3[l]	1		1
Tananarive	MADGAR	19°00'S	47°18'E		1	2	2		1	1	1
Toowoomba[dg]	TOOMBA	27°24'S	151°56'E		g	1[k]		1[k]			
Winkfield	WNKFLD	51°27'N	00°42'W	4.3-m dish		1	1	1	1		1

[a]Many stations also have Yagi receiving antennas.
[b]No longer operational
[c]Six-letter communication format.
[d]Equipped with special ATS telemetry-and-command antenna.
[e]Deactivated in 1968
[f]Inactive as of October 1, 1969.
[g]Deactivated October 1, 1969. A 14-m dish was installed here for the ATS program after 1966.
[h]Moved to Kauai in June 1969.
[i]For Bios program. No longer used.
[j]Only 2 in 1969
[k]Removed before 1970.
[l]Only 1 in 1969.

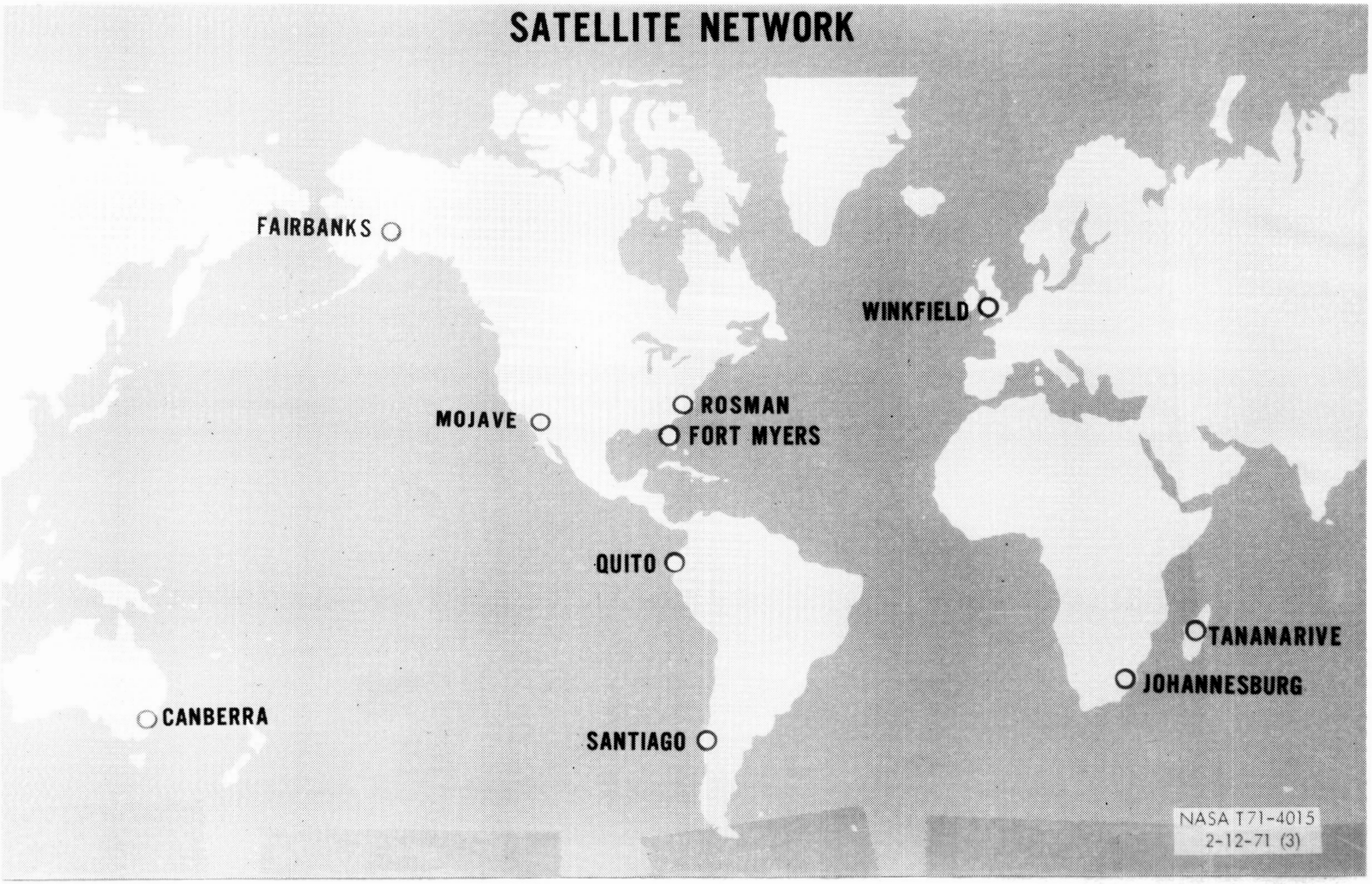

Figure 2-16. Geographical distribution of STADAN stations as of 1972.

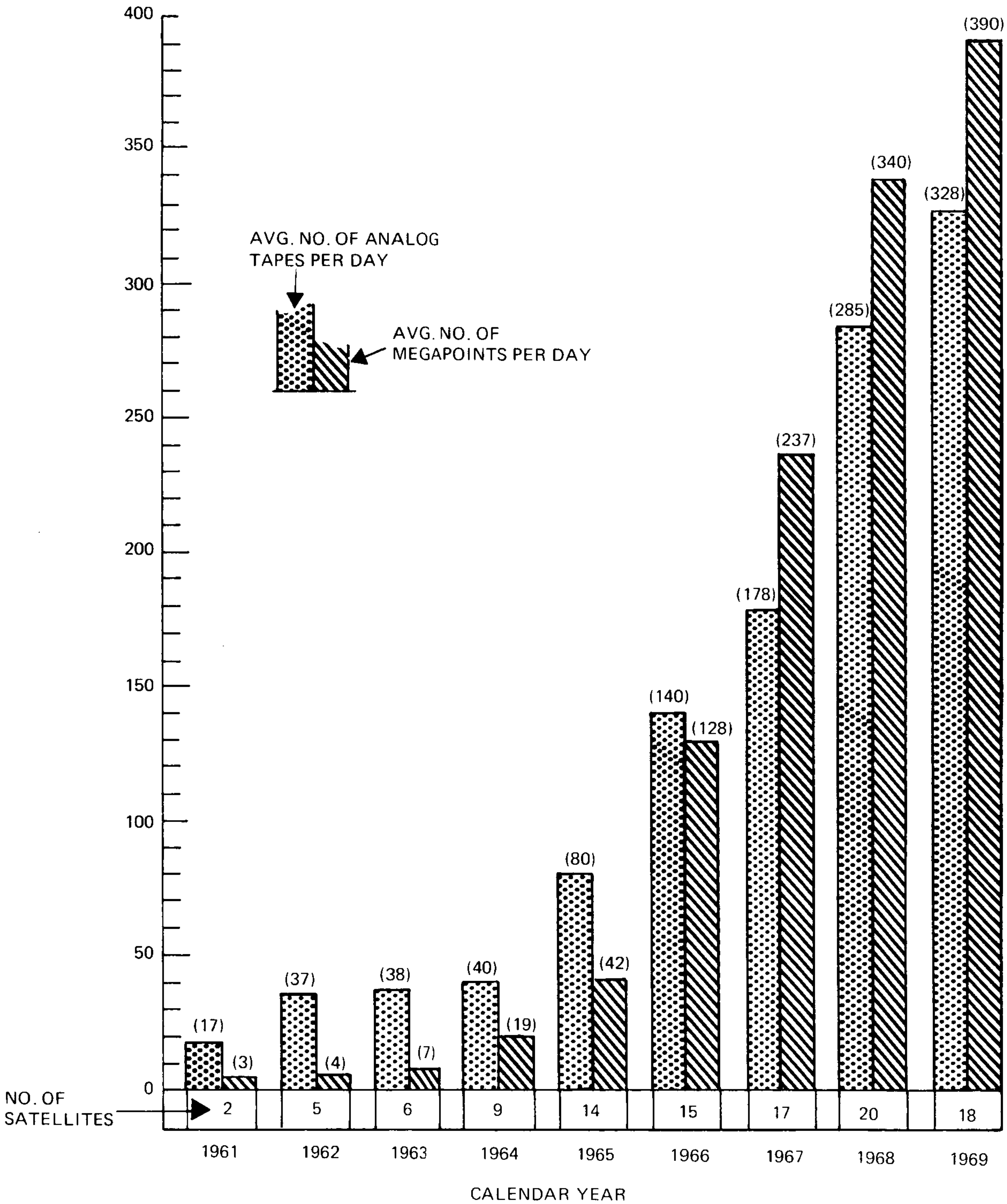

Figure 2-17. Data volume acquired from scientific satellites. The bars represent average quantities. (Courtesy of George H. Ludwig)

force behind the data explosion. NASA's satellite launch rate did stabilize at about 20 per year during the late 1960s, but each satellite can dump more data per station pass, and, on top of that, lasts longer. As a result, in 1969, STADAN collectively was recording some 300 hours of telemetry per day, representing about 390 megapoints per day.[66]

How could this increased flow of data be conveyed to the satellite users more effectively? Some possibilities were:

1. More ground-spacecraft communication links could be added. However, STADAN in 1969 could operate only 25 of the 31 links available to it because of the budget problem.
2. The "quality" of the data transmitted from the spacecraft could be improved by a process called "data compression." In essence, this means that redundant data would be partially eliminated and each bit transmitted would be more significant. Data compression has not yet been introduced to any important degree into NASA satellites. Data compression can also be carried out at the ground site to reduce the quantity of data that must be transmitted by mail or over NASCOM to the user. This approach has already been introduced into the MSFN. (Chapter 5) STADAN uses it for the OAO data stream.
3. STADAN stations could be computerized so that the same equipment could handle a greater flow of satellite-generated information. The augmentation of the stations with computers was the major new element of technology for STADAN during the 1966-1972 period.

The possibilities of computerizing STADAN stations came under study at Goddard around 1965. The advantages were obvious:[67]

- Ability to handle higher data flow rates
- Multimission capability (called flexibility)
- Possible higher station reliability
- Lower operating cost per satellite pass

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[66] In 1963, 38 STADAN ground-spacecraft links were operating, yet better equipment and station consolidation enabled the 25 links used in 1969 to record 2-1/2 times the quantity of data acquired in 1963.

[67] M.E. Shawe, "Station Automation," Goddard Rpt. X-521-66-168, 1966.

But there were also disadvantages:

- Greater station complexity
- The possibility that network reliability might be degraded rather than increased
- High design, procurement, and installation costs.

All in all, the advantages outweighed the disadvantages, and computers began to be installed at STADAN stations.

Some of the station operations which benefit from computer assistance are: station switchover from one satellite to another (an operation taking 15 minutes or so manually); prepass checkout; station operations during the actual pass (recording, analysis of spacecraft status, sending of commands, etc.); and postpass checkout. The mechanization of such station functions is in the direction of station "automation," although STADAN is far from the classical concept of automation in which human operators can be removed from the control loop. Of course, automation has always been present in STADAN to some degree. For example, in 1964, the more time-consuming manual functions were automated. Station switchover from one spacecraft to another or "prepass configuring" used to involve the manual throwing of many switches. These operations are now accomplished with preprogrammed automatic switches activated by circuit boards specific to each of the satellites being handled by the station.

During the late 1960s, the formal NASA program for implementing the first level of station computerization was called STOC (Station Technical Operations Control). Gerald M. Truszynski, in his February 1967 statement before the House Subcommittee on Advanced Research and Technology, described STOC in these terms:

> The STOC consoles consist of electronic equipment which accepts messages from the control center, displays operational requirements, permits rapid selection of needed support equipment, simulates characteristics of different spacecraft to permit checkout of the selected equipment, and reports station status back to the control center. These consoles will centralize many routine station functions, thereby permitting shorter station turnaround time between satellite passes. Because of the time saved, more satellites can be supported without the addition of new telemetry links.

In 1971, the STOC concept was enlarged to include the data acquisition function. This broader approach is termed STADAC, for Station Data Acquisition and Control. The addition of data handling to the STOC functions recognizes the increasing importance of real-time data acquisition in space science. When satellites were discovering new phenomena in outer space and making the first measurements on them, scientists were satisfied with magnetic tapes airmailed back from STADAN stations around the world. Now, however, space science has progressed to the stage where cause-and-effect experiments are being flown on Earth satellites. The requirement today is for real-time involvement of scientists with their experiments. In addition, some satellites require real-time control if their missions are to be successful. For example, the Atmosphere Explorers must be controlled carefully in real time as they penetrate into the fringes of the atmosphere. Considerations such as these have brought about the development of the STADAC concept.[68]

The heart of STADAC is a computer system containing control processors, telemetry processors, message handling processors, a main memory, a rapid-access memory, and a bulk memory. With appropriate software, the computer system performs the following seven functions:

- Data formatting
- Message handling
- Station scheduling
- Station equipment control
- Verification of communication link readiness
- Link control and monitoring
- Reporting on station equipment status.

Centralization of Mission Control. Another significant trend in STADAN evolution has been the closer, real-time relationship between satellites and the mission controllers back at Goddard. Very few, if any, controllable features were built into the early satellites. Tape recorders could be commanded to read out the data they had accumulated, but little else could be directed from the ground. With the introduction of more complex satellites, particularly the OGOs and OAOs, mission controllers possessed the command capability for controlling many more satellite functions as well as the scientific experiments onboard. With real-time NASCOM lines linking the Goddard mission controller directly to the STADAN stations afield, a "dialog" of command and response could be set up. In effect, the mission controller could "manipulate" or "drive" the satellite.

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[68]Interview with Robert Stephens, October 26, 1971.

These technical advances were reflected in the centralization of satellite mission control. Formerly, the technicians in the distant STADAN stations were the effective satellite controllers, just as they were in the early days of the MSFN, when the reliability of NASCOM was not fully proven. (See Chapter 3.) Today, satellite control has been transferred from the stations back to mission control centers in both STADAN and the MSFN.

The physical manifestation of this evolution was the installation of the so-called "project-unique" control centers at Goddard. Nine such control centers had been established by 1967:[69]

OSO	AE-B
OGO	ATS
OAO	Tiros
Space Physics	Geodetic Satellites
Multisatellite Operations	

As budget constraints began to affect space science programs in the late 1960s, it became obvious that each satellite could not afford the luxury of its own control center. Consequently, the project-unique centers were consolidated into MSOCC #1, the first Multisatellite Operations Center. The exceptions were the meteorological satellites, Nimbus and Tiros, which were controlled from a special control center. MSOCC #2 was built later in response to the more demanding requirements of the new OSOs, which were considerably more sophisticated than the early OSO, and the Atmosphere Explorers (AEs), which demanded real-time control.

STADAN Historical Summary; 1955-1971

The history of U.S. satellite tracking, stretching from the concept of Minitrack to the STADAN of today, can be summarized by six points:

1. The insight of the NRL group into the importance of satellite electronic tracking helped them win the official U.S. program in 1955.
2. Two buildups and two plateaus characterize Minitrack/STADAN history. (Figure 2-18).
3. The requirements of synchronous and high-eccentricity satellites made it necessary to supplement interferometer tracking with GRARR tracking during the early 1960s.
4. The emphasis in STADAN's mission changed from tracking to data acquisition in the mid-1960s.

[69] "Space Tracking and Data Acquisition Manual," Goddard Rept. X-530-67-304, 1967.

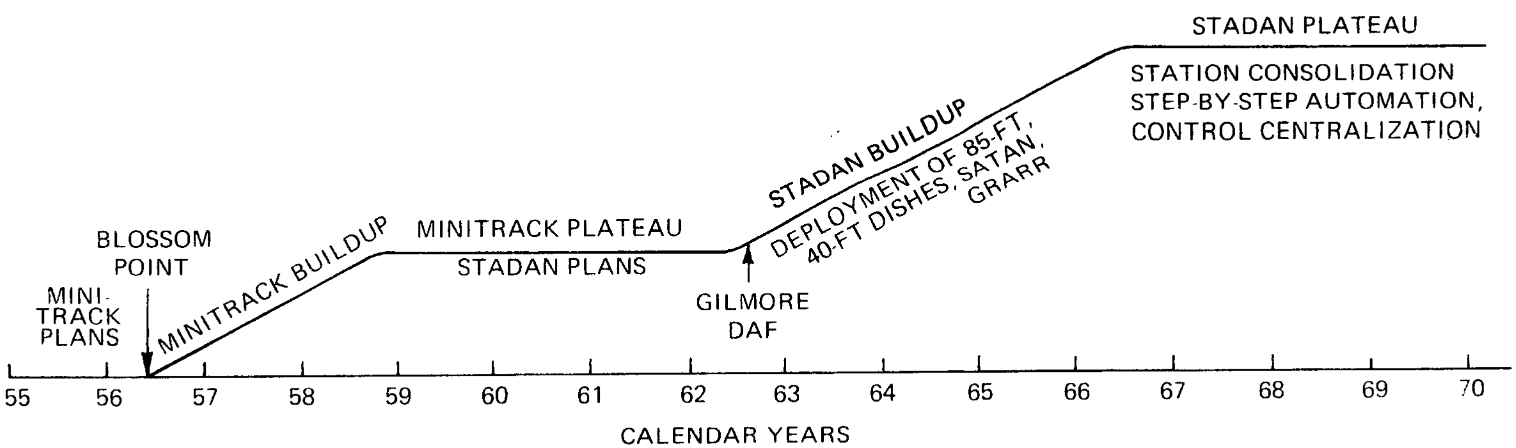

Figure 2-18. Sketch Showing "Idealistic" View of Minitrack and STADAN Evolution

The 26-m and 12-m dishes and SATAN antennas were added to cope with this increased requirement.

5. Since 1963, there has been a consolidation to fewer but better-instrumented stations. (Table 2-2)
6. During the late 1960s and early 1970s, STADAN evolution was characterized by the increasing computerization of station operations, including data handling, as part of the STOC and STADAC concepts.

Chapter 3. ORIGIN AND GROWTH OF THE MSFN

Role of the MSFN

Between 1958 and 1971, NASA invested nearly one-half billion dollars in the global complex of tracking and data acquisition stations called the Manned Space Flight Network (MSFN). The real value of this network is, of course, reflected in the repeated successes of the Mercury, Gemini, and Apollo flights. In addition, as in the case of STADAN, the MSFN is a welcome emmisary of the United States in many foreign countries. It is also a technological spearhead in the fields of communication, control, data processing, and large-scale system development.

The technical functions of the MSFN include spacecraft tracking, data telemetry, spacecraft command, and, in addition, two functions not normally required of STADAN: voice communication and television (video) transmission between the spacecraft and the ground.

Tracking and communicating with an orbiting spacecraft are difficult enough, but when the spacecraft heads toward the Moon, a quarter million miles away, new problems arise. The technical solutions and their political environments make fascinating history.

The MSFN prime functions require that the network radars and radios, those workhorses of tracking and wireless communication, must be spaced around the world beneath the spacecraft's projected orbit. But the evolution of radar, radio, and associated electronic paraphernalia tells only part of the technical history. The network stations also have to be tied together into a viable whole by ground communication links (submarine cables, microwave towers, etc.), by a common and very precise timing system, and by the authority of a centralized control center that can "call the shots." Backing up the network are banks of computers that process data, drive displays that aid the mission controller in making decisions, and "exercise" the network by simulating everything from an astronaut's blood pressure to spacecraft reentry. Radar and radio antennas, like the tops of icebergs, are only the obvious manifestations of a larger entity.

Pre-NASA Developments in Tracking, Data Acquisition, and Command

Origins of MSFN Technology. Radios, radars, and digital computers are primarily creations of the 20th Century. The histories of the various technologies that contributed heavily to the success of the MSFN are not long in time but they do present a bewildering confusion of project names, pieces of hardware, and organizations. The technical developments can be broken down into five categories:

1. Technique research and development (radar, telemetry, network concept, etc.)
2. Tracking of missiles and data acquisition
3. Tracking of research aircraft and data acquisition
4. Tracking unmanned satellites and data acquisition
5. Tracking manned satellites and data acquisition

Except for the first category, the physical manifestations of these developments were specific ranges and networks; that is, well-organized groups of ground stations designed to track and acquire data from specific classes of aircraft and spacecraft. (Figure 3-1)

Technique Research and Development. The concept of a manned Earth satellite preceded the 1958 Mercury program by at least a century. Edward Everett Hale wrote of a manned, navigation satellite in his story "The Brick Moon," which appeared in the Atlantic Monthly in 1869. Hermann Oberth, the great German astronautical pioneer, suggested a large, multimanned "space station" in his 1923 classic *Die Rakete zu den Planetenraumen*. Hermann Noordung and Guido Von Pirquet developed the space-station concept further in the following decade.[1] Although these early thinkers devoted much attention to the rocket launch vehicle, artificial gravity, and power production; the problems of tracking and communicating with the space stations were scarcely mentioned. After all, space travel was likened to seafaring in those days. On the deep ocean, on-board navigation with compass and sextant was the only way the captain could find his position. Certainly his ship could not be tracked from shore. The ocean analogy prevailed. Except for Oberth's almost off-hand thought about communicating with the Earth below by heliograph, the first astronauts were to be shot off into space without network support from below. Like Columbus, they would tell of their travels when they returned to port.

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[1]Willy Ley, *Rockets, Missiles, and Space Travel*, (New York; 1958), p. 368

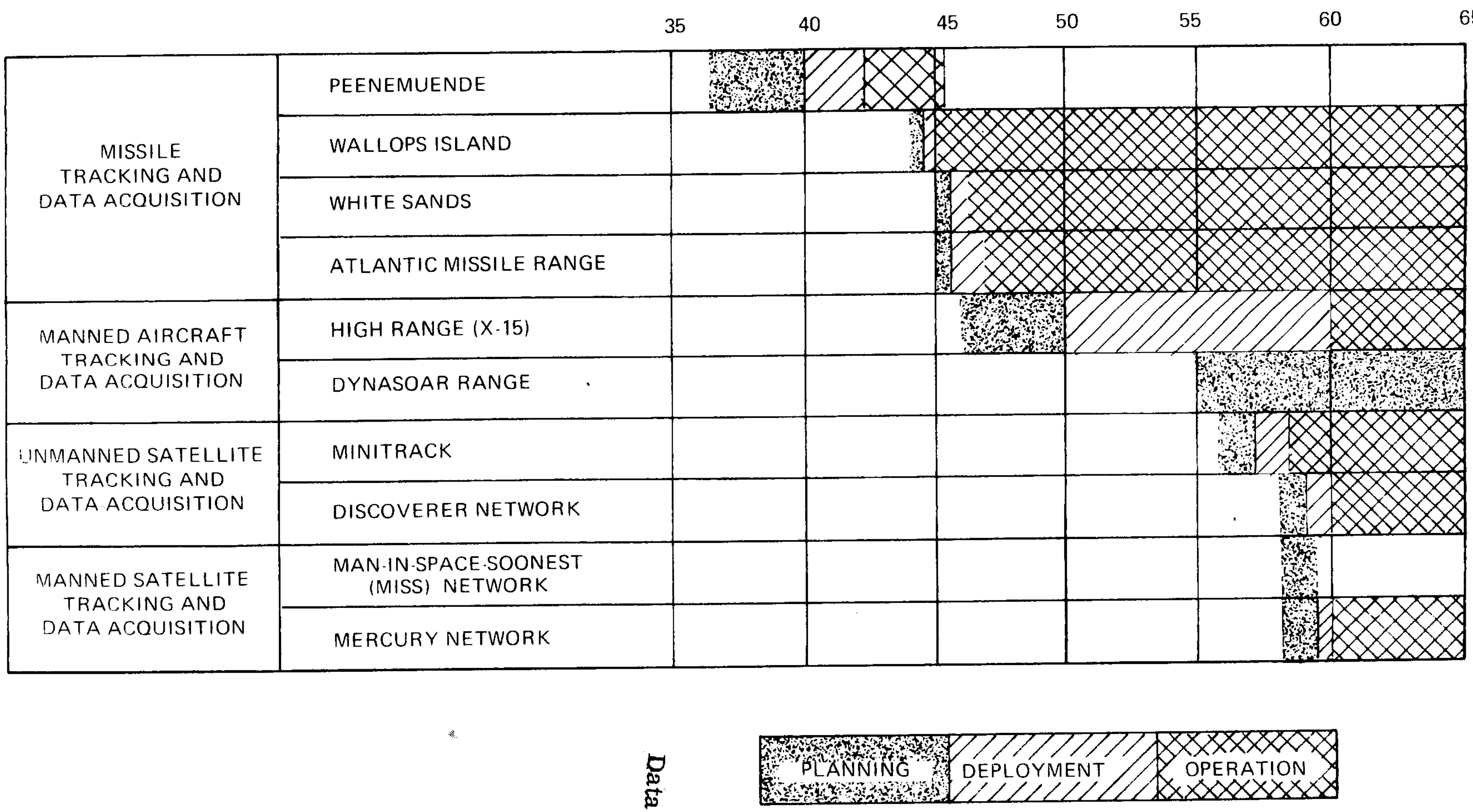

Figure 3-1. Evolution of ranges and networks that have contributed to the Manned Space Flight Network, 1935-1965.

For manned space flight to succeed, though, the concept of ground instrumentation had to replace that of on-board navigation. The first manned capsule could not be the self-sufficient Space Age *Santa Maria* or *Golden Hind* envisaged by the astronautical pioneers. Engineers, scientists, and doctors wanted to know where the capsule was and how the astronaut was bearing up under the rigors of space flight *at every moment;* that is, in "real time."[2] Considerations like these led the United States space program in the direction of strong ground support.

The greatest stimulus for the application of the tracking and radio communication techniques that had been accumulating for several decades was the ballistic missile.

Peenemuende. To test their V-2, the Germans had constructed a firing range extending from the launch pads at Peenemuende northwestward along the Baltic coast. Several optical and radio Doppler tracking stations followed the often erratic missiles flying along this first missile range.

The import of Peenemuende lies not so much in missile tracking as in the deployment of a chain of interconnected tracking stations - that is, the creation of a range extending beyond the line of sight. Short firing ranges were not new. Congreve had tested his war rockets at the Royal Laboratory's artillery range at Woolwich as early as 1802. But the Peenemuende range was over 100 miles long and its tracking stations were tied together by geodetic survey, a common time base, and rapid communication.

Langley and Wallops Island. During World War II, radar proved itself a superb tool for finding and tracking the rather slow-moving aircraft of the day. Less well known is the fact that radars were also used to track bombs and large naval shells in various test programs. This fact is doubly pertinent because: (1) Bombs and shells are high speed test vehicles and (2) NACA personnel at the Langley Aeronautical Laboratory in Virginia, participated in this work, giving NACA some highly important experience in radar tracking. Both the target acquisition and target lock-on problems were similar to those that would be encountered in the Mercury program some fifteen years later.

NACA established the Pilotless Aircraft Research Sta-

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[2] "Real time" is engineering jargon for near-instantaneous transmission and receipt of information. The finite speed of light and circuit delays make true instantaneous communication impossible.

tion at Wallops Island, Virginia, in the spring of 1945. A group of engineers at nearby Langley Aeronautical Laboratory comprised PARD, the Pilotless Aircraft Research Division. [It is interesting to note that PARD was headed by Robert R. Gilruth until the middle 1950s. Gilruth later led the Project Mercury Space Task Group (STG) and eventually became Director of the Manned Spacecraft Center at Houston.] PARD's mission was to test model aircraft and aerodynamic shapes by propelling them by rocket or "gun" out over the Atlantic, tracking them with radar, and analyzing their telemetry signals. On July 4, 1945, PARD launched its first rocket. A great variety of aerodynamic shapes and models of U.S. civilian and military aircraft followed over the years.

The real significance of Wallops and PARD is that through them NACA built up over the years a substantial reservoir of tracking and telemetry experience. Wallops Island and Edwards High Range (discussed later) turned out to be excellent training grounds for the personnel ultimately assigned to the construction on the Mercury Network.

White Sands. The V-2 and World War II radar met again in 1945 at White Sands Proving Ground, in New Mexico. This inland range, which occupies much of the rugged territory between El Paso and Albuquerque, was officially established on July 9, 1945, by the U.S. Army Ordnance Corps. The first V-2 was fired at White Sands on April 16, 1946. Significantly, some sixteen years later, a White Sands radar tracked John Glenn's Mercury capsule as it descended toward reentry and splashdown in the Atlantic.

In May 1946, the Army Signal Corps sent a group of 13 people to White Sands in response to a request from the Ordnance Corps to help instrument the embryonic range. Heading this group was Ozro M. Covington, who - 14 years later - would join NASA and become instrumental in deploying the MSFN for the Gemini and Apollo flights. Thus, White Sands began its role as a wellspring of technology and personnel so vital in later years to the MSFN.

Two important technological developments to come out of White Sands, insofar as the MSFN was concerned, were:

1. The FPS-16 instrumentation radar
2. The Minstrel real-time, digital data system concept.

The FPS-16 radar was developed to replace the venerable SCR-584 radars of World War II vintage. The accuracy of the SCR-584 was an order of magnitude too small; and the analog data pickoff capabilities were completely inadequate for missile tracking. The answer to these problems was the so-called "instrumentation" or "precision" radar. The weakness of optical tracking supplemented by antique radars became obvious in 1947 when an errant V-2 landed in a cemetery near Juarez, Mexico. The significance of real-time tracking data was now obvious to everyone.

Even though the instrumentation and communication support at White Sands were at the forefront of technology, new missile systems forced the Signal Corps to a still higher level of sophistication. In 1956, the problem of tracking several missiles fired at supersonic drones began to loom on the horizon.

> We knew that the present method of system coordination and control involving, as it does, human operators in many critical spots and a multitude of "black boxes" designed to solve specific problems, could not handle these missions. Having started programs to assure a suitable basic radar and a communications system capable of providing the necessary data and control circuits, our next question was: what is necessary to tie these into an operating system capable of meeting the demand?[3]

The answer to this question - at least in the eyes of the Signal Corps contingent at White Sands - was a *centralized real-time* control center into which funnelled all tracking and telemetry data in *digital* form. The concept was called MINSTREL (Missile Instrumentation by Electronic Means).

In sum, White Sands was a focal point for transferring V-2 and Peenemuende technology, for pioneering new range concepts, and for developing a group of key NASA personnel.

The Atlantic Missile Range. As missiles proliferated, so did instrumented test ranges. A dozen or more moved from concept to reality as each military service got into the missile business. When one says "missile range" without qualification, thoughts immediately focus on that multibillion dollar complex we now call the Eastern Test Range (ETR).[4]

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[3]White Sands Proving Ground, "Introductory Statement, MINSTREL presentation," March 1958, by Ozro M. Covington.

[4]Née Long Range Proving Ground (LRPG) and Atlantic Missile Range (AMR).

The technical history of the ETR consists primarily of range expansion and refinement of the lessons learned at White Sands and older ranges. An administrative history of the ETR has already been written, and the reader is referred to it for details.[5]

Tracking Research Aircraft and Balloons. The tracking of research aircraft, like the Wallops Island work, contributed heavily to NACA knowhow. NACA work with the X-15, for example, proved important during the design and evolution of the Mercury Network. Research aircraft fly high and fast and appear much like satellites to tracking equipment in the fact they cross the sky at similar angular velocities. In many cases they are manned, requiring the development of the MSFN functions of data acquisition, voice communication, and radio command. Because research aircraft fly great distances, single radar stations do not suffice; ranges consisting of several stations have to be built and connected together with common communications and timing systems.

NACA became involved with the testing of high speed research aircraft in 1946, when, on September 30, a group of 13 engineers and technicians were transferred from Langley Aeronautical Laboratory to the Air Force test facility at Muroc, California.[6] This group, under Walter Williams, became the nucleus of NACA's High Speed Flight Station[7] at Edwards Air Force Base, which includes the old Muroc facility.

The stimulus for the transfer of Langley engineers across the continent was the flight testing of the X-1 rocket plane. The first powered test flight of the X-1 was made at Muroc in December 1946.[8] It was tracked by radar, but no range of interconnected stations existed at this point in time.

It was the X-15 program that brought the NACA High Range into being. According to Gerald M. Truszynski:

> High Range was the first extended, but cohesive range designed, built, and operated by NACA. It was NACA's first direct experience with a range with a control center and data

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[5] Mary S. Touchstone, *History of the AFMTC*, AFMTC Historical Publications Series 65-133-1, 1965. Note: AFMTC = Air Force Missile Test Center.

[6] Eugene M. Emme, *Aeronautics and Astronautics*. An American Chronology of Science and Technology in the Exploration of Space. (NASA, Washington, D. C., 1961), p. 55.

[7] Now called the NASA Flight Research Center.

[8] Frederick I. Ordway, III, and Ronald C. Wakeford, *International Missile and Spacecraft Guide*, New York, 1960, p. 155.

transmission in real time.[9]

At first High Range was administered by Langley's Instrument Research Division under Edmond C. Buckley. Many of the key engineers and managers of the Mercury Network were to come from this group in the future.

The joint USAF-NASA X-15 program led directly to the proposed USAF X-20 or Dynasoar aircraft, a boost-glide rocket plane with a round-the-world range. Dynasoar began officially for NACA on Feb. 14, 1956 when the joint Air Force-NACA "Round Three" Steering Committee was established to study the feasibility of Dynasoar.

NACA and the Air Force both realized that the High Range at Edwards was far too short to test an intercontinental vehicle like Dynasoar. The range would have to be global in extent, just as if Dynasoar were a true satellite. However, because only a single circuit of the globe was planned, the chain of stations that would follow Dynasoar during its flight would be more properly called a "range" rather than the two-dimensional "network" needed for satellites that make many orbits.[10] Nevertheless, the Dynasoar Range introduced both the Air Force and NACA to the problems of tracking test vehicles all the way around the world.

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[9]Interview with Gerald M. Truszynski, Nov. 21, 1967. Truszynski left Langley for Edwards in March 1947 and directed the construction and operation of High Range. In June 1960, he transferred to Washington to work under Edmond C. Buckley. Truszynski is now Associate Administrator, Office of Tracking and Data Acquisition (OTDA), revealing the significance of High Range in adding to NASA's tracking knowhow and in shaping the NASA tracking organization.

[10]The Earth rotates approximately 15° per hour under the satellite, causing it to cross the equator at a different point each orbit.

Figure 3-2. (a) Map of High Range. (b) High Range ground communication.

Tracking Unmanned Satellites, the Pre-Mercury Networks. What are the differences between ranges, such as High Range and the ETR, and "networks?" Ranges are narrow, with finite length; networks cover wide geographic areas and often completely circle the globe.

The essence of the network invention is "commonality;" commonality in time, geodetic reference datum, language (word format), and communication channels. One of the greatest management challenges that faced the MSFN during its evolution was getting every one to use a common language and common procedures.

Two tracking networks preceded the Mercury Network; the Minitrack Network, which was used for tracking the tiny Vanguard satellites, and the Discoverer Network used for tracking military satellites.

The Discoverer Program was established in 1958 by the Advanced Research Projects Agency (ARPA) of the Department of Defense to investigate the various technological aspects of putting man into space; viz., communication, attitude control, recovery, and space medicine. Plans actually called for orbiting progressively larger vehicles until man himself was a passenger. The Discoverer program never got that far, but it did explore many technical problems of value to the Mercury program. Here, the Discoverer radar network is of significance because it was the first integrated, world-wide radar network.

The evolution of the Minitrack Network has already been described in Chapter 2. Although Minitrack was operational in late 1957, its stations were not well-placed for a manned satellite program and, more fundamental, its radio interferometers could not provide orbital data quickly enough to enable go-no-go decisions to be made in time. (See later discussion.) What Minitrack did do for Mercury was to give engineers a taste of the problems of real-time, world-wide communication, the process of getting permission to build tracking stations on foreign soil, getting the equipment there, and bringing it to operational status.

Tracking Manned Satellites. To those few who thought about manned space flight in the 1946-1957 time period, it was manifest that: (1) Any manned rocket was almost certain to be launched along the Atlantic Missile Range where it could be tracked prior to and after orbital insertion by the existing chain of radars, and (2) The Department of Defense had amassed much rocket experience. Almost all rockets were military rockets; and civilian NACA had little inclination to launch big rockets.

It is not surprising, then, to find the first manned space flight studies emanating from the Department of Defense. The first formal man-in-space effort began in March 1956, when the Air Force began work on Project 7969, Task 27544. Amplifying the numerical code was the title: "A Manned Ballistic Rocket Research System."[11] This study proposed a series of recoverable satellites, beginning with small, unmanned craft and ending with larger, manned space capsules. Project 7969 lasted about nine months before it was discontinued for lack of funds.

In 1956, however, the most important effect of Project 7969 was its pressure on NACA to push forward with studies of manned space flight. At this point, NACA was not in competition with DOD for leadership of the nation's space program. The two organizations were working hand-in-hand on the X-15 rocket plane and the X-20 Dynasoar. Indeed, through most of 1957, events seemed to be moving most satisfactorily and reasonably toward eventual manned orbital flight.[12] Unfortunately for the Air Force-NACA plans, the Soviet Union launched *Sputnik 1* on October 4, 1957. Reasonably paced space programs instantly became unreasonably slow.

It is important to point out that the various government organizations were talking together in a productive fashion about ranges and networks. Interagency committees were prime vehicles of communication and sounding boards for proposals on how the United States should organize its capabilities to overtake the Russians. In the field of tracking, for example, on March 20, 1958, Hugh Dryden, Director of NACA, requested by letter the participation of a wide spectrum of government and industry experts on a Working Group on Ranges, Launch, and Tracking Facilities. Dryden's letter pulled together these people:

J.R. Dempsey (Chairman)	Convair/Astronautics
Robert R. Gilruth, (Vice Chairman)	NACA-Langley (later to head Mercury)
Col. Paul T. Cooper	From the AF Missile Test Center at the Cape

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[11]Michael Chriss, "Establishment of NASA's Manned Tracking Network," NASA Historical Note HHN-54, 1965.

[12]For details on these programs, see Loyd S. Swenson, Jr., James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury* (Washington: NASA SP-4201, 1966).

Lee Gerard deBey	A leader in tracking R&D from the Army Ballistics Research Laboratory (BRL) at Aberdeen, Maryland
Carl E. Duckett	From the Army Ballistic Missile Agency, where von Braun worked, but formerly with the White Sands Signal Corps group
Cmdr. Robert F. Freitag	From Point Mugu, California, where the Navy was building the Pacific Missile Range (PMR)
J. Allen Hynek	Who was setting up the Baker-Nunn tracking network for the Smithsonian Astrophysical Observatory
John T. Mengel	In charge of the Minitrack group at the Naval Research Laboratory (NRL)
Grayson Merrill	Fairchild

As this committee met through the spring of 1958, it became obvious that some sort of civilian space agency would be established, probably with NACA as the foundation. With this in mind, the committee began to assess the assets and liabilities of the U.S. position in tracking and data acquisition. One recommendation stated that the new space agency should build its own real-time world-wide communications system. One U.S. liability was stressed very strongly:[13]

> Although relatively large sums have been allocated to the procurement of "crash program" hardware for tracking, little support has been given to advancing the state of the art in the several critical areas. It is strongly recommended that the NASA coordinate, initiate, and adequately support a sound research and development program leading toward improved tracking, communications, and computational techniques and facilities for the United States satellite and space research programs.

These recommendations were heeded after NASA was organized.

Still another committee helped pull together the many strings in the area of tracking and data acquisition.[14] This was an ad hoc ARPA committee including:

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[13] Working Group on Range, Launch, and Tracking Facilities, "Ground Environment for a National Civil Space Research Program," July 16, 1958.

[14] Memorandum for the Director, ARPA, Subject: Ground Based Information System for Support of Manned Space Flight. (The committee was commonly called the GBIS Committee.)

Lt. Col. Herman Dorfman (Chairman)	Headquarters, Air Research and Development Command (ARDC)
Edmond C. Buckley	NACA-Langley (later to head all NASA tracking and data acquisition work)
John T. Mengel	Heading the NRL Minitrack group (later to head Goddard's Tracking and data acquisition group)
Lee Gerard deBey	BRL
Capt. V.W. Hammond (Advisor)	ARDC (later assigned to NASA)
Capt. C.J. McCarthy (Advisor)	ARDC

The newspapers were still full of Sputnik and introspective hand-wringing when the long-planned "Round 3" conference to discuss Dynasoar studies convened at NACA's Ames Aeronautical Laboratory during the week of October 15, 1957. Alfred J. Eggers, Jr., of Ames, suggested several possible manned satellite vehicles incorporating some aerodynamic lift to the assembled NACA and DOD representatives. According to Hartley A. Soulé, it was this meeting at Ames that really started people at Langley thinking about manned space flight.[15] Just two months later, Maxime Faget, of Langley, proposed the ballistic (i.e., almost no lift) capsule that eventually became the Mercury spacecraft. In this way, the Dynasoar studies served as proving grounds where NACA and DOD spacecraft ideas were evaluated.[16]

As discussed earlier, Dynasoar also introduced NACA-Langley engineers to the problems of large tracking ranges, for Dynasoar was conceived as an intercontinental bomber operating at the outer fringes of the atmosphere. Originally, two Dynasoar ranges were under consideration: (1) East along the AMR, beyond Ascension, and out over an extension of the AMR toward Africa; and (2) West from the AMR, over White Sands, and towards the radars at Edward Air Force Base in California. When Langley pieced together the Mercury Network, both the east and west Dynasoar ranges were, in effect, hooked together - and with good reason because many facilities were already in place.

By March 1958, Langley studies had concluded that existing ICBMs must be used as launch vehicles for manned satellites. Events moved quickly. Capsule details were drafted. In June 1958, a working group was formed from Langley and Lewis personnel to draft a program for manned space flight.[17] Most of the push toward strong NACA involvement in

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[15] Interview with Hartley A. Soulé, January 26, 1967.

[16] For details of these capsule studies, see *This New Ocean*, *ibid*.

[17] Full names: Langley = Langley Memorial Aeronautical Laboratory, Hampton, Va.; Lewis = Lewis Flight Propulsion Laboratory, near the Cleveland airport.

space came from Lewis and Langley men, who felt that NACA should take on systems responsibility in addition to NACA's historical research role.

During the spring, both laboratories wondered how they might contribute to the space program - particularly if NACA were given a major part to play. This pressure to enlarge NACA's purview came largely from deep within NACA where many young engineers were pushing against NACA's conservative boundaries. In this search for a role in space, an important decision was made at Langley. Edmond C. Buckley, who headed the Instrumentation Research Division (IRD), set aside a dozen or so engineers to examine space instrumentation problems. Among the questions asked was: What can NACA contribute to ground instrumentation and ranges? The deliberations of this group will be detailed in the next section. The important point here is that someone in NACA sat down and began to tangle with the unexpectedly difficult problems of designing and deploying a global tracking and data acquisition network.

The DOD contenders for the leadership of the space program also had their spacecraft designs. The Air Force had its MISS (Man in Space Soonest) Program, which officially dates from a letter ARPA sent to the Air Force on February 28, 1958, telling it to get a man in space as soon as technology permitted. Of course, the Air Force had been studying man-in-space questions under programs such as Project 7969 for several years. MISS, though, was the major Air Force effort. MISS contemplated beginning with orbital flight within a year or two, and concluding in 1965 with a manned landing on the Moon. The total cost of MISS was estimated at about $1.5 billion.[18] In early 1958, MISS seemed very likely to be the official U.S. man-in-space program.

During the MISS studies, NACA continued its technical support of the Air Force. Of interest here is the fact that the Air Force had engineers in its Ballistic Missile Division and Space Technology Laboratories look at the tracking requirements for MISS. Two MISS consultants were Edmond C. Buckley, from Langley, and John T. Mengel, from the Navy's Project Vanguard; both of them would become key figures in the development of NASA's MSFN. So it was that NACA and the Air Force undertook tracking studies that were more in parallel than in competition with one another.

Some results of the Air Force MISS study were published in a report entitled "Ground Based Information Systems

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[18]See *This New Ocean, ibid.*

for the Support of Manned Space Flight," dated June 20, 1958, also called the GBIS report, which was submitted to ARPA. In essence, GBIS was proposed as a national resource which would be pieced together from existing stations and equipment plus one or two new sites. Since MISS would be launched from the Cape, GBIS proposed to use General Electric guidance and tracking equipment already developed and installed for the Atlas program. A phase-comparison tracking system, after the fashion of Minitrack or Microlock would also be added at the Cape. Downrange, GBIS proposed employing the C-band radars (FPS-16s) and S-band and X-band radio guidance equipment already in place. The MISS spacecraft, of course, would have to carry both X-band and S-band beacons. New stations would be constructed at Woomera, Australia, and Cooke Air Force Base, Calif. The MISS Network would be controlled from an Air Force Satellite Central Control Station (SCCS) to be set up at Holloman Air Force Base in New Mexico. Backing up the primary tracking and data acquisition stations would be the Navy Minitrack interferometer network, COTAR tracking equipment at Eleuthra Island and Ascension Island, and, perhaps, some BRL DOPLOC equipment at strategic spots.

The GBIS plan indicated that tracking, telemetry, voice communication, and television coverage would not be less than 10 minutes for any given orbit. During these ten-minute periods, there was to be real-time readout of on-board tape recorders which stored data through the 90-minute dead times.[19] Recovery of the MISS spacecraft was to be in the central United States on the fourteenth orbit.

The importance of immediate orbital information and its influence on the go-no-go decision was recognized; long-range guidance equipment installed at Cape Canaveral was to monitor the critical orbital insertion phase. The Naval Research Laboratory would help with orbital computations. The GBIS report summarized related construction costs and operational costs at $52,648,570.[20]

In retrospect, one wonders whether the network studies of NACA and the Air Force had any effect on the ultimate decision that gave NACA the man-in-space program. It turned out that the technical results had little effect, although there was one serious technical problem connected with the MISS firing azimuth. To make full use of the AMR radars, the MISS space capsule would have been fired directly down the AMR, an approach that would have spread the possible capsule recovery zones over a wide area. (NACA wanted to fire in a more northerly direction so the orbital traces would come together in a single recovery zone within easy reach of U.S. facilities.) The really important problem,

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[19]Mercury criteria and planning were quite different: no TV, a 10-minute deadtime, and water recovery. Mercury thus required more stations (for shorter dead time) but no video link (for TV).

[20]George B. Graves, Jr., (Langley) recalls that others put the cost for the MISS network as high as $200 million.

however, was that no matter how the capsule was launched it would be necessary to construct some tracking stations in foreign countries for comprehensive coverage of the flight. And to some countries, U.S. military installations were out of the question at that time; for these countries suspected that the proposed tracking radars might also watch missiles and spy satellites. On the other hand, a purely civilian program with scientific goals that the whole world could embrace would be much more palatable, even desirable. The fact was that a purely military, worldwide network with frequent astronaut contacts (short deadtime) could not be built. This consideration was one of many that led Congress to draw up the Space Act specifying a civilian space agency. The culmination was President Eisenhower's Executive Order 10783 establishing NASA on October 1, 1958.

Of course, the considerations in and out of Congress were much more involved than the single factor described above. What is interesting is that the man-in-space network did have an important influence upon the organization of the national space program.

By October 1, 1958, the date of NASA's birth, all DOD man-in-space proposals had been set aside in favor of a civilian program. The NASA program, though, was not yet well-defined and even lacked a catchy code name. The Langley network studies of 1958 might best be called embryonic. Even worse, NASA owned few tracking facilities beyond a radar or two at places such as Wallops Island. NASA's employees could cite range experience at the Edward's High Range and at Wallops, but it was decidedly less than that of the military. It was the military that had the experience and facilities. And the DOD had just been denied leadership of the man-in-space program. As NASA was born, two questions were paramount.

1. Would NASA be able to pull together a strong man-in-space program?
2. Would NASA and DOD be able to work together smoothly and in the construction of an effective worldwide network?

Building the Mercury Network

The Objectives of the Man-in-Space Program. A quotation is in order:

> The objectives of the project are to achieve at the earliest practicable date orbital flight and successful recovery of a manned satellite, and to investigate the capabilities of man in this environment.[21]

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[21] Minutes, Panel for Manned Space Flight, Appendix A, 1, Warren J. North, secretary, Sept. 24 and 30, and Oct. 1, 1958.

These might be the objectives of any man-in-space program, unspecific as they are. In fact, they were written by the joint ARPA-NACA Manned Space Flight Panel during the last week in September 1958, just prior to NASA's investiture. At this moment in history, the nation's manned space flight program was as general and formless as the quoted objectives. The creation of NASA on October 1 acted as a lens to focus the many diverse American efforts, not only within the government but inside NASA itself.

To "get on with it," as T. Keith Glennan, the new NASA Administrator, put it, a second focusing lens had to be added to the organizational instrument. The second lens was the Space Task Group (STG). Created mainly from Langley engineers and management personnel, STG was housed at Langley but theoretically came under the jurisdiction of the new Space Projects Center that would soon become the Beltsville Space Center and, eventually, Goddard Space Flight Center. STG was to be moved physically to Beltsville, Maryland, as soon as the new Center was constructed. This early jurisdictional and organizational intent was to have a strong effect upon the evolution of the management responsibilities of the MSFN. In these formative months of late 1958 and early 1959, organizational lines of authority were almost irrelevant as everyone pitched in to get the "official" man-in-space program rolling.

What had happened to the small "range" study group that Edmond C. Buckley had started thinking about network problems in the spring of 1958? Known informally as the Tracking System Study Group, it was still looking at network problems in the fall of 1958. STG had not yet asked this group for network support.

From a network standpoint, STG and Buckley's group had nothing more specific to work toward than the general objectives prefacing this section. Someone had to turn these generalities into specific, detailed requirements and thence into hardware.

Early Langley Network Studies. The Tracking System Study Group had been looking at "range problems in space flight" for almost six months wher STG was created. Officially, the engineers in the former group remained attached to Buckley's Instrumentation Research Division.

Names and assignments of the key engineers:

George B. (Barry) Graves, Jr.	Network configuration
Robert L. Kenimer	Tracking
William J. Boyer	Ground communication and data transmission
James H. Schrader	Telemetry and vehicle communication
Eugene L. Davis, Jr.	Computing
Howard C. Kyle	Control Center

The network job turned out to be bigger than anyone had anticipated. Fortunately, Langley had excellent channels to the electronics industry by virtue of its radar work (at Wallops Island) and to DOD experience through its several memberships in the DOD-sponsored Inter-Range Instrumentation Group (IRIG). These connections were to pay off handsomely because, before 1958 passed, Langley engineers had identified three major problem areas connected with network support of manned satellites that were underestimated in all of the previous network studies.[22]

First, somewhat to their surprise, the Langley study group found that there was no such thing as a commercial or military real-time, worldwide communication system. Here was a vital ingredient of mission control that was completely missing. Neither were there reliable, high-capacity data links that could carry the torrents of data between the mission computer center and the mission control center. Third, good radars were available, but their beams were too narrow to expeditiously locate and lock onto high, fast-moving satellites.[23] Save for the radar acquisition problem, the toughest jobs were connected with reliable, real-time communication right here on Earth.

STG soon discovered that the weight of the network job was diverting its attention from the critical spacecraft and booster problems. In January, 1959, Charles W. Mathews of STG recommended to Abe Silverstein, Director of Space Flight Development at Headquarters, that STG be relieved of the responsibility for building the network. The Langley group that had been studying range problems since the spring of 1958 was the logical nucleus of an official Mercury Network organization. Silverstein formally directed this change in a memorandum to J. W. Crowley, Headquarters Director of Aeronautical and Space Research, on February 16, 1959.[24] Silverstein's memo asked Langley to "complete and

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[22]It is tempting to use the word "Mercury" here, but the name was not officially adopted until Dec. 17, 1958.

[23]The Langley group also considered a "cheapie" Doppler network, but the necessary equipment was not considered stable enough from an electronics standpoint.

[24]Memorandum from Abe Silverstein to the Director of Aeronautical and Space Research, February 16, 1959. Subject: Planning and Contracting of Tracking, Instrumentation and Control Center Facilities for the NASA Manned Satellite. Crowley's subsequent directive to Floyd Thompson at Langley is dated Feb. 20, 1959, but this was preceded by a telephone call to Thompson from Silverstein on Jan. 16, 1959.

refine" network plans to satisfy requirements generated by STG and to "place and supervise" contracts for generating procurement specifications and final network deployment. The memo also suggested that Langley make use, wherever practical, of the personnel and facilities of the Pacific Missile Range, the Atlantic Missile Range, the White Sands Missile Range, and the Eglin Gulf Test Range.

The result of Silverstein's telephone call and subsequent memo to Floyd Thompson at Langley was the official formation of the Tracking and Ground Instrumentation Unit (TAGIU). Actually, Thompson did not wait for Silverstein's memo. He immediately asked Harley A. Soulé, Assistant Director of Research, to get things moving. Soulé enlarged the network organization in Buckley's Instrumentation Research Division (IRD), and, on January 26, 1959, TAGIU became a separate and official group that reported directly to Soulé.

What happened to Edmond C. Buckley, head of IRD, during these organizational changes? Although the official transfer had not yet taken place, Buckley and two other top IRD men, Francis Smith and Morton Stoller, were moving to Washington to take jobs at NASA Headquarters. Leadership of TAGIU was assigned to Barry Graves, who had been part of IRD's Tracking System Study Group since its beginning. Leading the TAGIU cast in January 1959:

George B. Graves, Jr.	Electronics, Head of TAGIU
James J. Donegan	Computers
H. William Wood	Logistics
Paul Vavra	Assistant to Graves
Ray W. Hooker	Site selection and A&E (Architect and Engineering) services

Aiding Soulé and TAGIU was Sherwood L. Butler, Langley's Procurement Officer, who handled the immense task of contracting for services, equipment, and supplies.

TAGIU quickly grew to 35 people. It was heir to Langley's radar and high-speed flight experience, plus a half-year of network studies. This was a good foundation, but everyone in TAGIU knew that they still needed help. Though TAGIU engineers knew roughly what the Mercury Network should look like, they did not have the detailed specifications needed to procure hardware and begin setting up stations. Among the first items of business, then, were getting some industrial help under contract and enlisting the Air Force's aid.

Furthermore, TAGIU had to work out its management interface with STG. TAGIU had to be responsive to STG requirements, yet STG and TAGIU lines of authority met only at the Administrator's office at Headquarters. (See Figures 3-3 through 3-5)

In management language, TAGIU provided functional support to STG, but could, if it wished, carry disagreements all the way to Headquarters. Happily, the man-in-space job was so challenging that few worried about anything except getting the job done.[25] It was just as well because years of hard, pioneering work lay ahead.

<u>Evolution of Network Philosophy and General Requirements.</u> Now that TAGIU had been officially charged with getting a Mercury Network built and checked out, effort shifted from studies to hardware procurement and deployment. Studies had to be turned into hard specifications.

The major functions of the Mercury Network had already been determined: tracking, telemetry reception, voice communication, and capsule command. But these functions could be performed in almost an infinite number of ways. STG and TAGIU therefore generated some general ground rules that narrowed the horizons somewhat:[26]

1. The orbital inclination of about 32-1/2° was fixed early. It permitted maximum use of DOD facilities; it kept the capsule over the U.S. much of the time; it did not overfly countries which might object; it resulted in acceptable recovery areas close to U.S. naval facilities.

2. The AMR would be employed for launch and recovery; this was almost unavoidable because of AMR's superb facilities and experience.

3. The network would be worldwide, using stations in foreign countries where necessary, and would operate on a real-time basis to keep close tabs on the space capsule and its occupant.

4. The space medicine people strongly requested continuous voice contact with the astronaut, but this requirement proved impractical to meet. STG and TAGIU moved ahead using the goal of a maximum of 10 minutes dead time between

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[25]STG and TAGIU occasionally disagreed, but disputes were usually settled on the Soulé-Gilruth level.

[26]"Specifications for Tracking and Ground Instrumentation System for Project Mercury," S-45, issued by TAGIU on May 21, 1959.

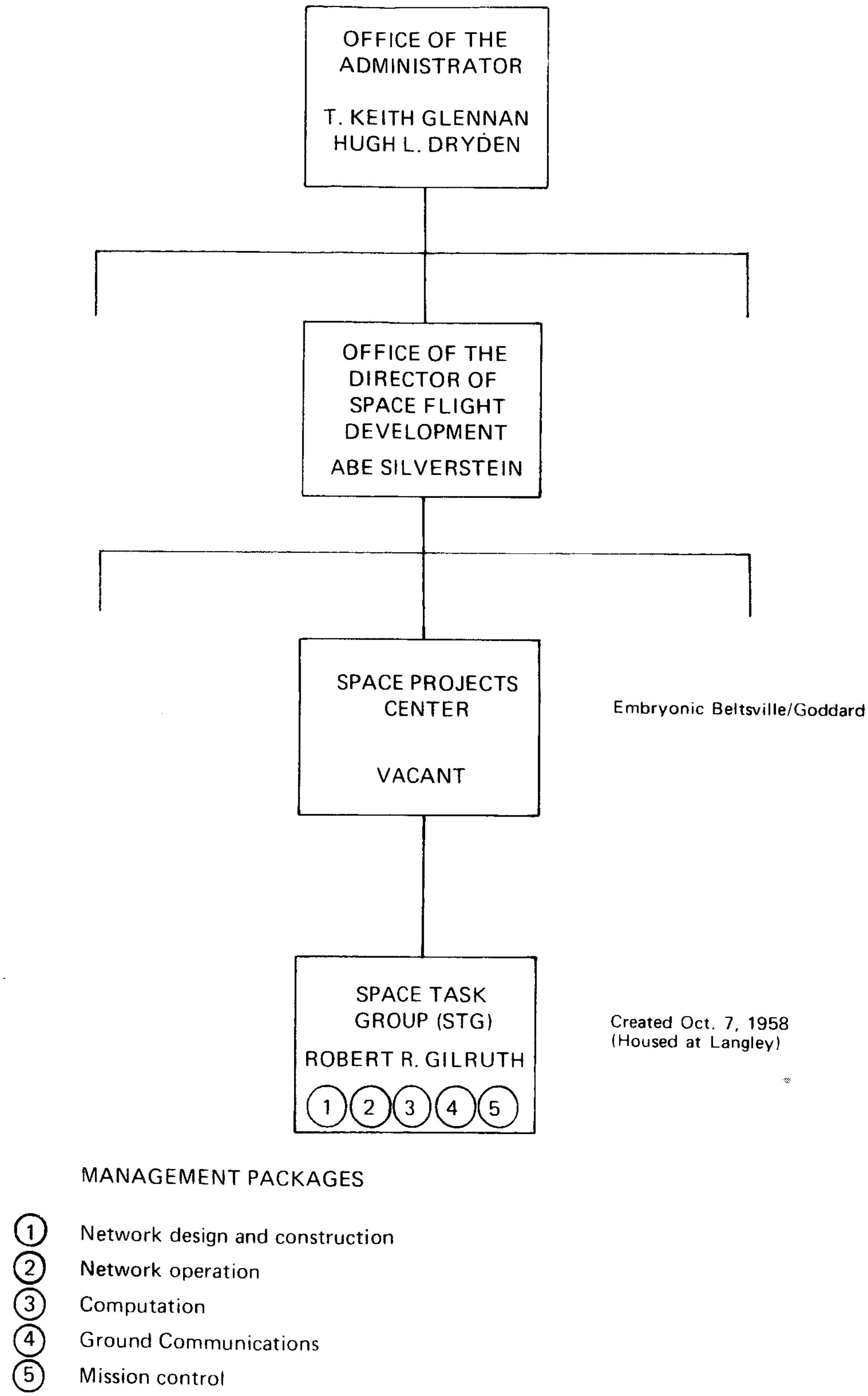

Figure 3-3. Organization of Mercury Network management, late 1958

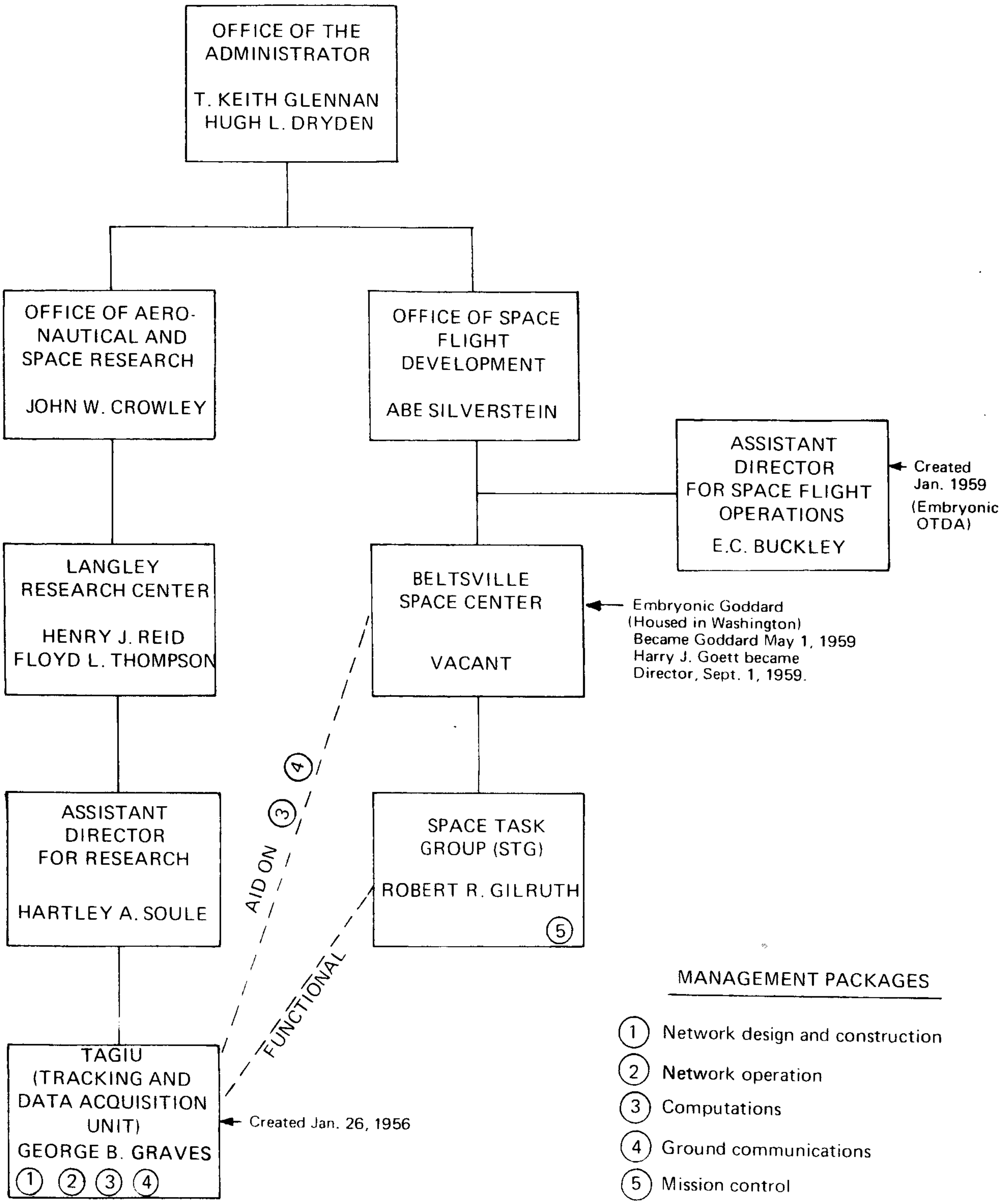

Figure 3-4. Organization of Mercury Network management, early 1959

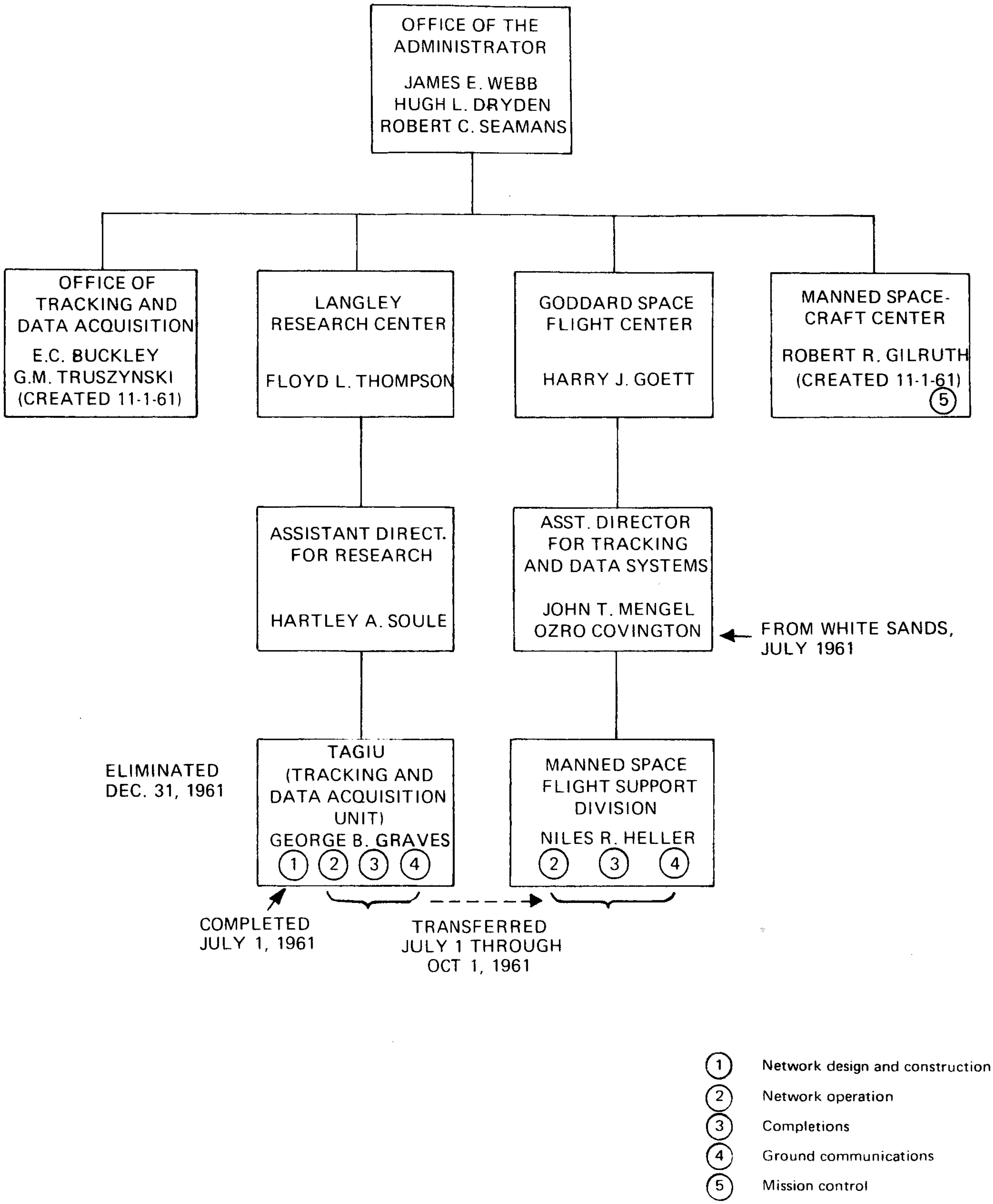

Figure 3-5. Organization of Mercury Network management, late 1961

voice contacts despite the controversy.[27]

5. A centralized control center would be built, but flight controllers would be located at each station in case of communication difficulties.

6. Proven equipment would be employed, with a minimum of research and development.

In addition to these generalized requirements, TAGIU had pinpointed some unique features of the proposed Mercury Network.

1. To enable a go-no-go decision to be made and to effect emergency reentry before the spacecraft approached the African land mass, the network radars would have to give the computers enough good, real-time data to calculate the orbit accurately *before* the spacecraft passed beyond Bermuda.

2. The existing radars would need acquisition aids because of their narrow beams.

3. Only computers could cope with the flood of tracking and telemetry data arriving from network stations. A centralized computer facility with a good data link to the mission control center would solve this problem.

4. Frequent network "simulations" or "exercises" would be needed to train operators, keep them on their toes, and locate weak or deficient ("red") spots in the network.

5. Only extensive redundancy and the use of "hot spares" could possibly provide the reliability that would make the network safe for manned flight. Alternate communication links would have to be provided in many places to keep the network "green" during long space missions.

Contrary to some descriptions of the Mercury Network claiming that no R&D was attempted and that most equipment was "off-the-shelf," the network concept slowly evolving from TAGIU and STG deliberations could never have been built under such conditions.

In technical situations as fluid as the Mercury project, strictly logical, cause-and-effect sequences are never the rule. Rather there is frequent cycling or iteration of mission requirement and engineering response. STG would want something; TAGIU would say that it could not be done that way, but by changing this or that factor an acceptable solution might be found. It is proper and accurate to say that STG and TAGIU jointly "negotiated" the major requirements and network features.

During the first quarter of 1959, the major network

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[27] Interview with George B. Graves, Jr., Jan. 26, 1967.

features became more distinct. Technical detail began to replace sketches and rough estimates. Procurement of network equipment, however, was a time-consuming task. As Hartley A. Soulé recalls the situation:[28]

> When the go-ahead was given to Langley there was a year or a year-and-one-half completion date attached. As procurement procedures take time, most effort in the spring of 1959 was aimed at compressing the time for these procedures. Every one at Langley was so busy briefing contractors, writing the specifications and evaluating proposals there was little time to do much else. Meetings were small and limited to obtaining the answers to specific questions raised by the attempt to put the requirements down on paper.

Before detailed network specifications could be drawn up, two important points had to be decided.

The more critical point revolved around the opinion of the space medicine people that continuous voice contact was essential. STG and TAGIU knew that this requirement could never be met within the time and budget limitations. Only when STG pointed out that nothing could be done for an astronaut until he approached the next recovery area, regardless of his condition or the amount of voice contact, did the doctors relent and agree to the ten minutes dead time stipulation. The doctors had honest fears about the effects of the space environment on the astronaut. Nausea, for example, might choke an astronaut in a spacesuit. Capsule designers took care to make reentry controllable by a capsule timer so that an unconscious astronaut could be brought back to Earth automatically.

The second point also involved safety. The go-no-go decision right after launch could be made only with tracking data from Bermuda. Yet, suppose during the critical period of orbital insertion, the radio link with Bermuda were lost --a not unlikely prospect considering Bermuda's downrange distance of over 600 miles. TAGIU was convinced that a centralized mainland computer center (probably at Greenbelt, Md.) would be more effective than many on-site computers.[29]

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[28] Letter from Hartley A. Soulé to Alfred Rosenthal, dated August 19, 1967, in response to a request for comments on the first draft of this essay.

[29] James C. Jackson, of Goddard, recalls that Bell Telephone Laboratories proposed to have the entire control center

But to guard against the possible loss of Bermuda during orbital insertion, TAGIU decided to install enough computing equipment at Bermuda so that the local flight controller could make the go-no-go decision in case of communication difficulties.

With these points resolved, TAGIU was ready to draw up detailed network specifications in the early spring of 1959. To help in this effort, TAGIU placed four contracts with industry:

Ford Aeronutronics	To study radar coverage and trajectory computation requirements.
RCA Service Corp.	To write the actual specifications.
Space Electronics	To design the mission control center.
MIT Lincoln Laboratories	For general consultation and proposal evaluation. (Lincoln Labs consulted with TAGIU throughout the Mercury Program.) Its experience with SAGE (Semiautomatic Ground Environment) was invaluable.

TAGIU was overloaded with work despite the help from the above four contractors. Hartley A. Soulé decided to ask John T. Mengel, then at Goddard Space Flight Center with most of his NRL staff,[30] for help in the computing area. Goddard was a logical source for such help because it was expanding its computing facilities rapidly and had taken over the Vanguard Computation Center set up by the Naval Research Laboratory. Before long, 60 Goddard and IBM personnel were assigned to Mercury under Niles R. Heller. Bringing Goddard on board helped set the management pattern for the MSFN, as events soon proved.

As TAGIU and its contractors were generating network specifications, the search was on for an industrial team that could meet the challenge of constructing a worldwide network around the core of extant DOD range sites. A preliminary bidder's conference was held at Langley on April 2, 1959, almost two months before TAGIU issued the first set of

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computerized to make all mission decisions. There would have been decision-making criteria for all foreseen situations based on preprogramming. Personal interview, January 6, 1967.

[30]The Beltsville Space Center became Goddard Space Flight Center in May 1959.

network specifications. Twenty industrial teams attended this meeting. But before any company could bid on the network job, they had to know what it was. TAGIU's most important job was now specifications writing.

S-45, A Milestone. The first relatively sharp picture of the Mercury Network came into focus on May 21, 1959, when TAGIU issued "Specifications for Tracking and Ground Instrumentation Systems for Project Mercury," known universally thereafter as "S-45." The primary purpose of S-45 was to initiate competition and give industry enough information to bid intelligently for the network job. Time was running short, and TAGIU had to get men out in the field setting up stations. In fact, S-45 stipulated an operational range before June[31] 1, 1960, STG's date for the first Mercury orbital mission.

S-45 turned out to be only the first frame in a series of network "pictures" -- a first iteration, if you will. S-45 still lacked depth and detail. Feedback from inside and outside government gave rise to a second iteration, S-45A, dated July 29, 1959. The third and final iteration, S-45B, did not appear until October 30, 1959. S-45B reflected an economy move within NASA (more on this later). S-45 and its progeny achieved their main purpose; a contractor was chosen to build the Mercury Network.

The tight Mercury schedule could not wait for all of the S-45 iterations. Langley sent out proposal requests based on S-45 on June 22, 1959, and a number of industrial teams set to work deciding how they might tackle one of the biggest jobs yet spawned by the space program. By mid-July TAGIU had received and evaluated all the proposals. On July 30, 1959 -- one day after the issuance of S-45A -- NASA awarded a letter contract to a Western Electric team that included the Bell Telephone Laboratories, Bendix, Burns and Roe, and IBM.

The S-45 series reveals the telescoping of cause and effect that occurred many times during the race toward an operational network. Western Electric (WECo, pronounced wee'co, in Mercury vernacular) based its technical proposal on S-45, its cost estimate on S-45A, and its final report on S-45B.

Just what did S-45 prescribe? First, TAGIU network philosophy came through clearly and (as government specifi-

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[31] Early Mercury ballistic shots, such as MR-1, did not require a complete, worldwide network.

cations go) succinctly:

> The design approach shall emphasize the use of proven, reliable systems which require a minimum of modification or further development. In the planning and design of the system, the safety of the astronaut shall be the major consideration. Conservative design principles, back-up systems and standby spares shall be used to effect a high degree of reliability.

Of course, S-45 had to go into considerably more detail to be of use to Western Electric. Here is how TAGIU visualized the Mercury Network in the spring of 1959:[32]

S-45 Tracking Specifications. Continuous tracking of the space capsule from liftoff through orbital injection was essential to a valid go-no-go decision. After orbital injection, intermittent tracking was sufficient.[33] Continuous tracking was again specified during reentry in order to fix the splashdown point accurately.

A network of proven C-band and S-band radars was specified; some stations would use both for purposes of redundancy. The RCA C-band FPS-16 (Figure 3-6) and the S-band Verlort (Very Long Range Tracking) radar (Figure 3-7) built by Reeves Instrument Corporation were stipulated. Both radars had been developed for DOD.

The only major, really new piece of tracking hardware specified was an Active Acquisition Aid (AAA) that would help the narrow-band radars find their tiny target. The AAA was to have a beamwidth of about 30° with a range of 1470 km when manually controlled, and 1100 km under automatic control.

Radar "skin-tracking," which uses direct reflections of radio waves from the target, was not considered reliable enough at satellite ranges to be employed in the Mercury

[32]The final, operational Mercury Network did not differ greatly. It could not, because there was no time left for major changes.

[33]Orbital perturbations caused by atmospheric drag were difficult to predict in advance for Mercury. Unmanned scientific satellites had already demonstrated that air densities at Mercury's altitude were higher than originally expected and also variable with time.

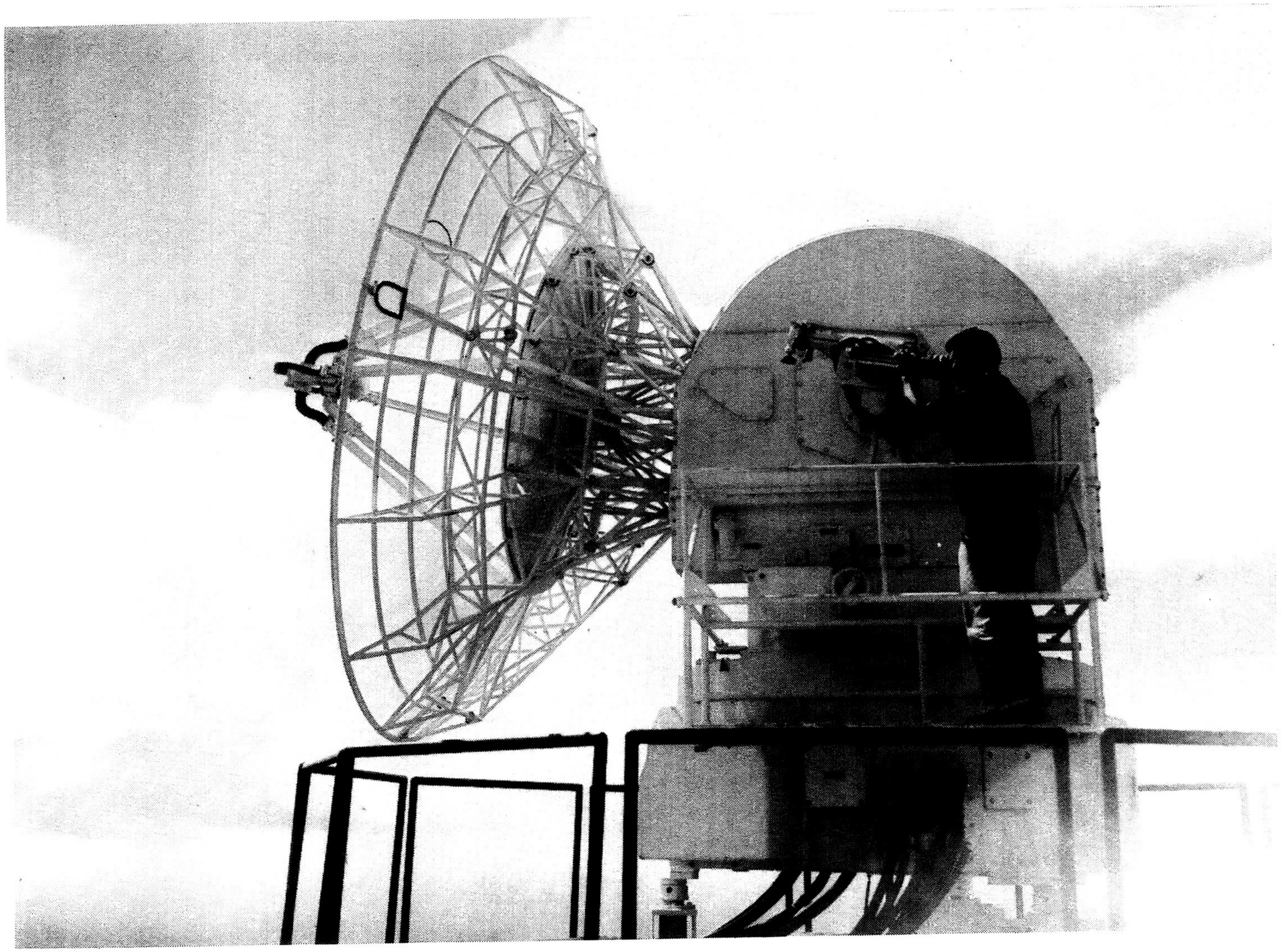

Figure 3-6. The Hawaii FPS-16 radar. (NASA photo)

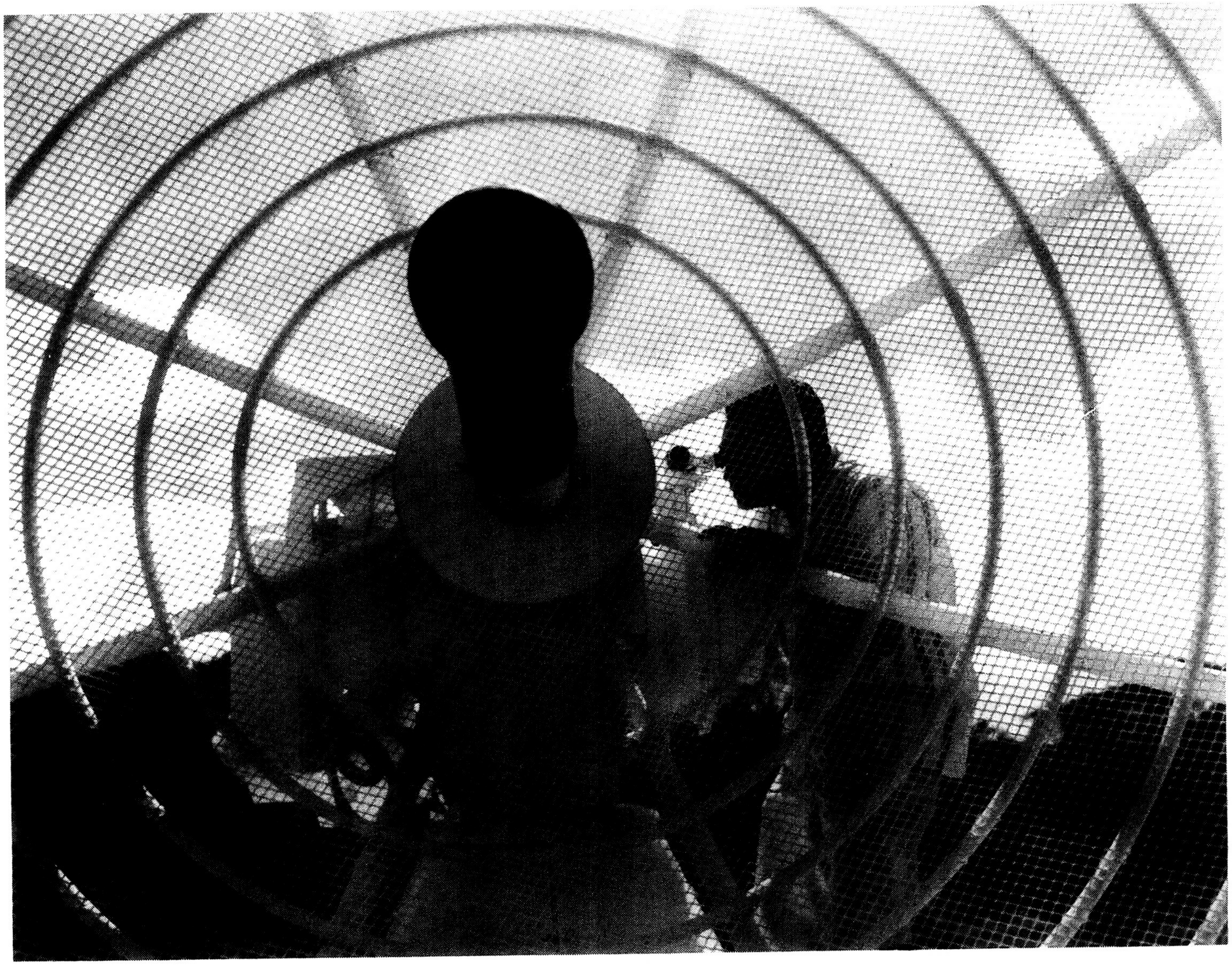

Figure 3-7. The Verlort radar dish.

Program. Two radar-triggered beacons (or "transponders") were specified for each capsule to provide the radars with healthy return signals to analyze.

S-45 Telemetry Specifications. Obviously, the telemetry receiving equipment at the network sites had to be compatible with the capsule transmitters being built under the direction of STG. The well-proven PAM/FM/FM system of telemetry was selected.[34] S-45 specified IRIG channels 5, 6, and 7 for the receivers, recorders, and display equipment at each site. In 1959 and 1960, the needed telemetry hardware was either off-the-shelf or could be built with negligible technical risk. A significant requirement was that two independent links be established between capsule and ground to satisfy the general redundancy criterion.

S-45 Voice Communication Specifications. The network contractor had to supply equipment for voice transmission and reception at each site. UHF (ultrahigh frequency) radio was specified for the primary link, with a complete set of backup HF equipment. In addition, a second set of UHF equipment had to be on standby at all sites. S-45 reiterated the ten-minute deadtime maximum that STG and TAGIU thought adequate and practical for Mercury. S-45 also delineated the various operating modes and equipment details that are of little interest to this historical development.

S-45. Command Specifications. Each network site had to have two FRW-2, 500-watt command transmitters, each with a nominal range of 1300 km. Like much Mercury equipment, the FRW-2 transmitters were off-the-shelf military hardware, needing little modification. The function of the command transmitter was to provide a separate and independent way to control the spacecraft in case the astronaut became incapacitated.

S-45 Ground Communication Specifications. Strangely, the real technical frontiers were discovered in ordinary terrestrial communication. Real-time, worldwide ground communication was specified. In Mercury practice, delays of two or three minutes were common and acceptable.[35] The speed of

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[34]IRIG nomenclature. PAM = Pulse Amplitude Modulation, FM = Frequency Modulation. IRIG = Inter-Range Instrumentation Group.

[35]Real time in today's MSFN means delays of only one or two seconds -- often less.

the duplex (two-way) teletype circuits was set at a minimum 60 words per minute; and the duplex voice circuits had to have a bandpass of 280-2800 Hz. The types of traffic anticipated were telemetry, commands, radar acquisition data, tracking data, voice messages, and routine teletype messages between sites. These kinds of traffic had been handled before in commercial and military communication networks. What was different about Mercury? First, there was the physical size of the network. When completed, the Mercury ground communication network consisted of 163,000 km of teletype lines, 97,000 km of telephone lines, and 24,000 km of high-speed data lines. Single sideband (SSB) radio communications equipment was installed at some stations late in the Mercury program. Second (and toughest) was the high degree of reliability required -- 99.99% between Hawaii and the continental U.S. Requirements like this forced network designers to lease or install many alternate, redundant communication links.

S-45 Computer Specifications. By the time S-45 appeared, NASA had definitely decided to install a Mercury computer center at Goddard, with a secondary computer center at Bermuda to help make the go-no go decision should communications to and from Bermuda falter. The mission of the Goddard Computing Center was to make those computations necessary for real-time monitoring and control of the spacecraft. The Goddard computers had to drive displays at the control center -- that is, provide signals to visual devices, such as plot boards and digital displays, that would present helpful flight data to the decision makers. Other tasks assigned to the Goddard computers were: compute acquisition data for all sites; compute retrofire times; compute anticipated splashdown points; compute orbital parameters; and so on. To meet the redundancy criterion, two separate IBM 7090 computers were to run in parallel at Goddard.

A further and quite different sort of requirement was placed on the computer center. It was to aid in network simulations, the make-believe missions in which events are duplicated electronically. When S-45 was issued, no one anticipated how important and how large this task would be.

Computer programming was well-developed for business and mathematical problems but in a rudimentary state for network problems. The computers had to be told, step by step, how to take each piece of data from each site and turn it into meaningful displays for the mission controllers. In current terminology, there was a severe "software" problem.

S-45 Control Center Specifications. STG had decided to install the Mercury Control Center (MCC) at Cape Canaveral.

(Figure 3-8) Again, Bermuda would have to be built to back up mainland facilities should communications break down. Like the Computer Center, the MCC broke new technological ground.[36] Because of this, the specific functions of the MCC are listed:

1. Coordination with AFBMD-AFMTC (Air Force Missile Test Center; i.e., the Air Force part of AMR), including monitoring vehicle propulsion and guidance, and assistance in range safety.
2. Control of all stations outside AFMTC.
3. Continuous monitoring of pilot and capsule.
4. Dispatch of instructions to the astronaut.
5. In-flight trajectory monitoring.
6. Dispatch of commands to the capsule (as opposed to astronaut instructions).
7. Initiate normal reentry and recovery.
8. Initiate emergency landing at completion of passes 1 or 2.
9. Initiate emergency aborts.
10. Supply splashdown information to the search and recovery teams.

S-45 did not go into detail about how these functions were to be implemented. In the main, S-45 contained broad specifications that left WECo both latitude and responsibility.

<u>S-45 Timing System Specifications</u>. For tracking data to make any sense to the computers, time and place had to be known accurately for each observation. S-45 specified a timing system that could be synchronized to WWV signals with an accuracy of 0.001 sec, with less than 0.001-sec drift in 48 hours.

<u>S-45 Site Specifications</u>. A total of 17 network stations were planned when S-45 was issued. Some of these sites were already part of DOD ranges. The new sites specified by TAGIU essentially connected the AMR to the PMR across Africa, the Indian Ocean, Australia, and the Pacific. And, of course, Bermuda had to be added to follow the Mercury capsule as it flew north from the Cape and away from AMR sites. As the following list will show, S-45 did not pinpoint the new sites with precision, for site survey teams had not yet been dispatched.

To avoid redundancy in this history, the final Mercury

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[36] The Air Force also pioneered this area during the building of NORAD support facilities, such as SAGE and the DEW line.

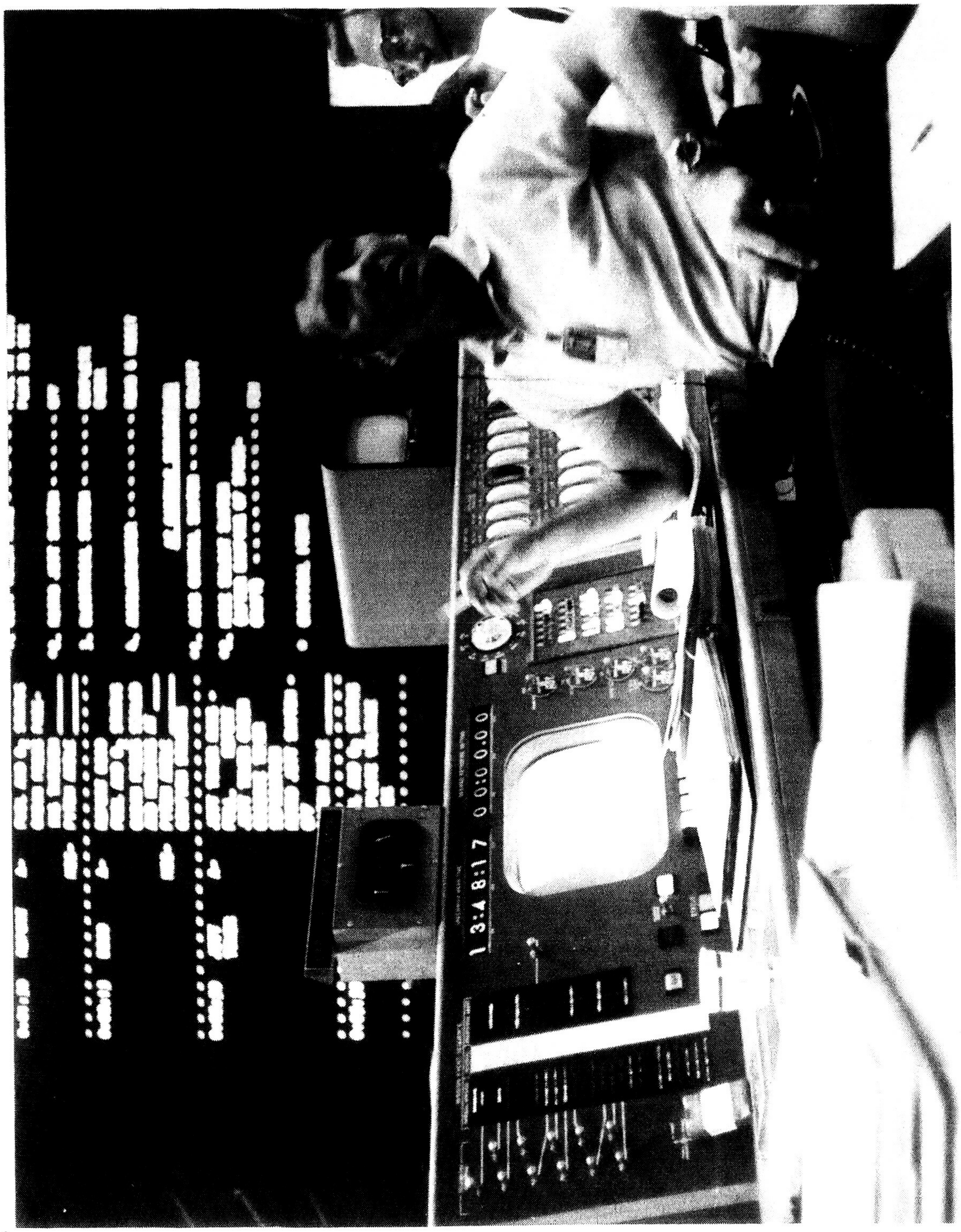

Figure 3-8. The Mercury Control Center (MCC) at Cape Canaveral.

Network is illustrated in Figure 3-9, while the stations and their equipment are detailed in Table 6. At this point, only those site specifications listed in S-45 that were different from the final network are mentioned. (Table 3-1) Further details about each site can be found in Appendix A.

S-45 was the first definitive blueprint for the construction of the Mercury Network. It gave NASA and its contractors the necessary details to begin site surveys and hardware construction.

Network Management During Mercury. During late 1958 and early 1959, as the Mercury Program began to gather momentum, getting the job done always took first priority. TAGIU and STG were both of Langley parentage, and confrontations were few. Embryonic Goddard, heavily staffed by former Naval Research Laboratory personnel, had not really fixed its own destiny within NASA, and, in addition, had no permanent Director. Events during those fast-moving days affect the management of the MSFN even today.

First, what were the well-defined "pieces" or "management packages" of the Mercury Network? There were five:

1. Design and deployment of the network.
2. Operation, maintenance, and enhancement of the finished network.
3. Computation[37]
4. Communication between stations.[37]
5. Mission control.[37]

Within NASA, the players in this drama were Langley's TAGIU, STG, Goddard, and NASA headquarters. Outside NASA, the Air Force was anxious to acquire some of these "packages," particularly that of network operation.

STG was officially created on October 7, 1958, primarily from Langley personnel. At first, STG was attached to Goddard rather than Langley, because, as mentioned earlier, NASA Headquarters had every intention of moving STG bodily to the new Beltsville Space Center, abuilding near Greenbelt, Maryland, a few miles north of Washington. As the manned space flight program expanded beyond all expectations, it became apparent that Goddard could no longer absorb STG and still carry out all its unmanned satellite programs. In addition, it seemed certain that the manned space flight activity would continue well beyond the Mercury program, and that it needed a NASA center of its own. Besides, Goddard

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[37]Assigned to Goddard in Mercury specifications.

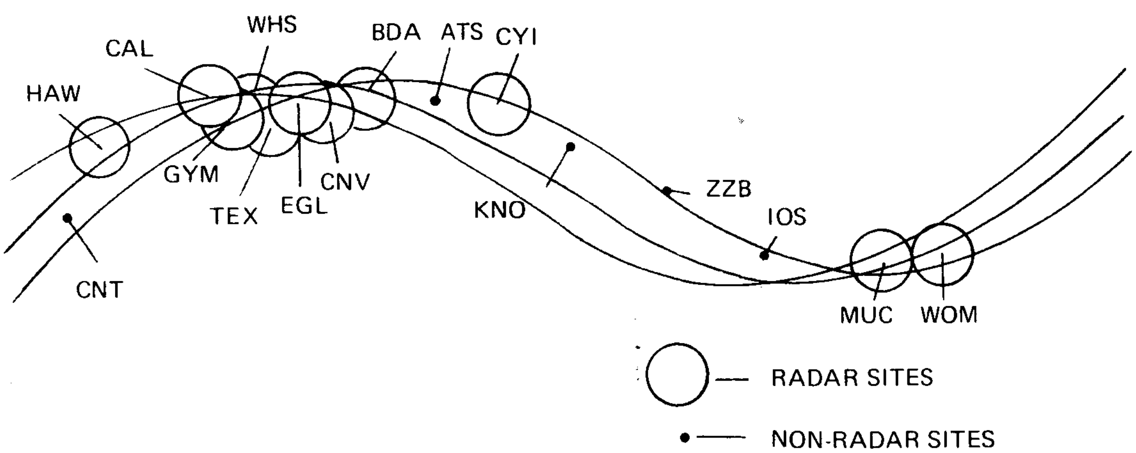

Figure 3-9. The Mercury Network stations, with a three-orbit satellite trace superimposed. See Table 3-4 for key to station code letters and equipment disposition.

Table 3-1. S-45 SITE SPECIFICATIONS

S-45 Designation	Final Location	Difference between S-45 and Final Network[a]	Remarks
1. Cape Canaveral	Cape Canaveral	S-45 did not specify command capability and FPS-16 radar.	For launch tracking and monitoring
1a. Grand Bahama I.	Grand Bahama I.		
1b. San Salvador	Grand Turk I.	Site changed. See Appendix A.	
2. Bermuda	Bermuda		See text for special position of Bermuda in network.
3. Mid-Atlantic Ship	Atlantic Ship	S-45 did not specify AAA.	
4. Northwest Africa (originally Annoban I.)	Grand Canary I.	S-45 did specify command capability.	Needed for tracking after abort near insertion point.
5. Southwest Africa	Kano, Nigeria	S-45 did specify command capability, did not specify AAA.	
6. Southeast Africa	Zanzibar	S-45 did specify command capability, did not specify AAA.	
7. Indian Ocean Ship	Indian Ocean Ship	S-45 did not specify AAA.	
8. West Australia	Muchea, Australia		For "antipodal" tracking and to reset timer for Pacific abort.
9. Woomera	Woomera	S-45 did specify command capability.	
10. Solomon Islands (originally Guadalcanal)	None	Station dropped on Sept. 25, 1959 for cost and technical reasons.	For coverage during passes 2 and 3.
11. Canton I. (originally Christmas I.)	Canton I.	S-45 did specify command capability, did not specify AAA.	

12. Hawaii (originally Oahu I.)	Kauai I.		Resets timer for normal reentry. Some data to be sent real time.
13. Southern California	Pt. Arguello		Real-time data link.
14. West Mexico	Guaymas, Mexico		For tracking after retrofire. Real-time data link.
15. White Sands	White Sands	S-45 did specify command capability.	
16. South Texas	Corpus Christi		Real-time data link.
17. Eglin, Florida	Eglin, Florida	S-45 did specify command capability and C-band radar	High-speed data link. MPQ-16 radar was used.

[a] See Table 3-3.

had already been identified as NASA's center for unmanned satellite science and technology. Thus STG became identified as the nucleus of the proposed Manned Spacecraft Center. On November 1, 1961, STG was sent to Houston, where it became the Manned Spacecraft Center (MSC).

When STG moved to Houston, the only management package it took along was mission control. Under the pressure of a heavy load of capsule design work, STG had given the network design and deployment job to TAGIU, which was part of Langley. (Figure 3-3) TAGIU, in turn, had asked Goddard to help with computing and communication because Goddard's unmanned satellite programs had already given it a headstart, expertise, and facilities for network communication. Furthermore, Goddard wanted the computing and communication tasks. It could claim with justification that it would be more economical for the government to expand Goddard's staff and facilities rather than build new ones at Langley or Houston.[38] At that time, this made sense, and Goddard got these jobs; although, as we shall see, MSC eventually reclaimed the computing assignment after the control center was transferred there.

The only network package unaccounted for is network operation, with its thousands of operating personnel and international flavor. Goddard was chosen again because it had: (1) considerable talent and facilities already at Goddard; (2) STADAN was also at Goddard; and (3) Goddard was already doing the closely associated computing and communication tasks. "Centralization" was Goddard's major argument. In addition to its close geographical relationship to NASA Headquarters, Goddard also had the advantage that many TAGIU personnel did not want to move to Houston but would consider Goddard. Langley, which had nurtured both STG and TAGIU, was physically too small to contain the manned space flight program and did not have Goddard's experience and facilities in computers and communications. Langley was also rather far removed from major communication trunks and switching centers. In the end, Goddard took over responsibility for everything except mission control and the actual construction of the Mercury Network.[39] After the Mercury Network was completed, many

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[38]Some thought was given to locating the Mercury computers at the Cape, but the Cape was always in a turmoil with its high priority military programs. NASA also wanted to keep its computers separate from DOD equipment at the Cape.

[39]The official transfer of the network operation package was directed in a letter from Abe Silverstein to Harry Goett, dated April 3, 1961, entitled: "Mercury Network Operating Responsibilities."

key TAGIU engineers, such as William Wood, James Donegan, and Chuck Jackson, moved to Goddard to become part of John Mengel's network team.

On May 12, 1961, Floyd Thompson and Harry Goett, Directors of Langley and Goddard, respectively, met at Goddard to arrange the transfer of network operating responsibility. Thompson and Goett established a committee (with a Langley chairman) to oversee the transfer, which was scheduled to take place during the third quarter of 1961.[40] Langley maintained a small "consultant" group of TAGIU personnel until the end of 1961.

The organization charts indicate that the management structure at NASA Headquarters also shifted in the direction of centralizing network functions during the Mercury program. Edmond C. Buckley had headed NASA's network operations ever since he left Langley early in 1958 to become Director of Space Flight Operations, reporting to Abe Silverstein. Buckley consolidated all of NASA's networks (STADAN, MSFN, DSN) under him when the Headquarters Office of Tracking and Data Acquisition (OTDA) was created on November 1, 1961.[41] (Figure 3-4) NASA communications (NASCOM) and data processing also came under OTDA's jurisdiction. One immediately notes a parallel in the consolidation of network responsibilities at Headquarters with that on the operating level at Goddard.

Prior to the formation of OTDA, there was considerable debate at Headquarters about the most effective way to organize Headquarters itself. Some preferred functional management structure (propulsion, space research, etc.), others wanted project-type management with special offices for manned space flight, scientific satellites, and so on.[42] The final decision favored project management, with OTDA being an outstanding exception.

The major argument favoring centralized management of tracking and data acquisition center on the nigh-unsolvable problem of integrating a complex, worldwide activity if re-

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[40]Letter from Hartley A. Soulé to Abe Silverstein, dated Oct. 27, 1961, entitled: "Completion of Langley Research Center's Work on Mercury Tracking and Ground Instrumentation System."

[41]Interview with George B. Graves, Jr., Jan. 26, 1967.

[42]Almost all OTDA personnel came from the disbanded office of Space Flight Programs.

sponsibility and authority were split up among several groups. Major Victor W. Hammond, an Air Force officer assigned to NASA at the time, summarized the things that NASA had to know and integrate:[43]

1. Mission data requirements
2. All facilities and their commitments
3. Ground support instrumentation technology and planned improvements
4. Potential technical advances
5. NASA programming policy

Hammond believed that only "single-point staff responsibility" could provide:[44]

1. Policy guidance and technical direction
2. The requisite planning and reviews
3. Budget derivation and defense
4. Total coordination of all U.S. and foreign agencies
5. Assistance and guidance to industry
6. Ground support instrumentation to DOD and industry

Obviously NASA could not have separate groups calling on foreign countries about the same problem. Neither could NASA afford duplication of expensive facilities for tracking probes, weather satellites, and manned space capsules. The tracking and data acquisition management package was too vital to be split up among the several project offices at Headquarters.

An important philosophical difference between STG and TAGIU involved money. In Soulé's words, STG was composed of "young men willing to spend lots of money." [45] TAGIU, in contrast, was of conservative mien, a trait doubtless inherited from never-rich NACA. Money for man-in-space was not particularly difficult to get in the 1958-1961 period. TAGIU was somewhat of an anomaly in its energetic attempts to cut costs. S-45B, in fact, showed the elimination of the planned Solomon Island station and other economy moves. It is interesting that the Naval Research Laboratory (creator of

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[43]See Hammond's discussion in: "Tracking and Data Acquisition Program Review," October 7, 1961 (no author, no number).

[44]For details of the project vs. functional management issue, see Robert L. Rosholt, *An Administrative History of NASA, 1958-1963*, (Washington: NASA SP-4101, 1966) p. 224.

[45]Interview with Hartley A. Soulé, Jan. 26,1967.

Minitrack) also watched the pennies. (Chapter 2) Nevertheless, the Volksvagen-class Mercury Network and Minitrack Network could not have performed better if they had been in the Cadillac class.

Roles of WECo and Other Mercury Network Contractors. Of the roughly $80 million spent in the construction of the Mercury Network, about $68 million went to WECo and its team of associate contractors.[46] Contractors also figured strongly in the original network studies and in the operation of the completed network.

TAGIU brought in the first outside contractors in the spring of 1959, when it asked MIT, IBM, Aeronutronics, and Space Electronics to help generate network specifications. Relative to the total cost of the Mercury Network, these were very small studies.

The WECo team was the first major contractor. It drew up the detailed design of the network and built it. The chronology of the NASA-WECo relationship runs like this:

April 2, 1959	Preliminary bidders' conference
May 21, 1959	Bidders' conference, S-45 issued, "informal" competition begins
June 22, 1959	Formal competition begins, PR issued
July 30, 1959	WECo awarded a letter contract
January 11, 1960	Definitive contract executed (NAS1-430)
July 1, 1961	Network accepted by NASA

In only 23 months the WECo group put together a global network that performed extremely well during the whole Mercury program.

Upon receiving NASA's letter contract, Western Electric named R.M. (Rod) Goetchius Project Manager and began marshalling its resources and subcontractors to try and meet the original completion date of June 1, 1960.

The WECo team, sometimes called the Systems Engineering Group (SEG), consisted of five separate organizations: these are listed below along with their assigned responsibilites:[47]

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[46] See Appendix E for summary financial data on the Mercury Network and MSFN.

[47] Western Electric, "Project Mercury," Final Report, June 1961.

Western Electric	Managing and directing team members; procurement, production, transportation, installation, and testing of equipment. Design and implementation of ground communication. Training of maintenance and operating personnel.
Bell Telephone Laboratories	Systems analysis and formulation of operations plans and tests. Design of command and control displays at the Cape and Bermuda. (Bell selected Stromberg-Carlson to construct and install the displays.) Provide a simulation system to "exercise" flight controllers and astronauts.
Bendix Corp.	Design and fabrication of telemetry and site display equipment. Systems design, fabrication, and integration of radars not furnished by the government. (Bendix obtained new radars from RCA and Reeves Instrument Corp.)[48] Design and fabrication of all capsule communication equipment.
IBM	Computer programming and operation at Goddard and Bermuda. Maintenance and operation of the launch and display data subsystem at the Cape.
Burns and Roe	Design, engineering, purchasing, transportation, warehousing, logistic support, construction management, and preliminary operation of all nonelectronic equipment.

WECo and its team members, of course, went to other industrial concerns for services and hardware. The many thousand miles of communication lines were usually leased. Mercury guidelines specified maximum use of local materials and contractors; this led to problems in primitive areas where most work was done by hand. Even in advanced countries, such as Australia, WECo ran into "standards" problems, where electromechanical devices from the U.S. just did not

[48]Negotiations between Bendix and RCA for the modification of seven FPS-16 radars were suspended after three months. NASA subsequently handled all RCA contacts directly. (RCA and Bendix were competitors in the radar business.) Six Verlorts were obtained from Reeves with no difficulty.

match local products. In the end, all these problems were solved.

The NASA-DOD Interface. In modern usage, an interface exists between two organizations when, for economic, political, or other reasons, they must work together for the same goals. So it was with NASA and DOD in Project Mercury. It is to the credit of both organizations that the Mercury Network was built in time and operated well.

To NASA, the Air Force was a huge reservoir of experience and facilities that it had to tap if it was to build the Mercury Network on time. NASA also needed DOD from the economic standpoint, because, as Goddard's James Donegan put it "the cost of wiring the world is very high." The desire to work with the Air Force was tempered by the fear that the DOD might engulf NASA's functions and programs.

On the other side, the Air Force felt it had lost the man-in-space program through a technicality -- the decision to make the space program a civilian effort. After all, orbital space operations were logical extension of its legitimate sphere of operations. Despite these feelings, the Air Force wanted to see a successful man-in-space program as much or more than anyone else. There were some hard feelings, but cooperation was the order of the day for Mercury.[49]

Major-General Donald N. Yates, Commander of the Air Force Missile Test Center, made a strong effort to convince the NASA Administrator, T. Keith Glennan, that the Air Force should build the Mercury Network. It had men, experience, and already controlled many of the necessary facilities. Further, Yates believed that the Air Force could do the job without foreign bases--just as it was doing with the Discoverer series --except perhaps for the key Mexican Station. Edmond C. Buckley, Director of Flight Operations at that time, argued that many foreign countries (especially Mexico) would never tolerate U.S. military personnel and equipment within their borders.[50]

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[49]See *This New Ocean, ibid,* for details on other NASA-DOD encounters.

[50]Interviews with Victor W. Hammond, (Lt. Colonel, USAF, retired), April 14, 1967 and Edmond C. Buckley, May 1, 1967.

Buckley proposed that all Mercury stations be divided into four separate groups. Group #1, including the Cape, Grand Canary, etc., should be run by AMR, an Air Force installation; Group #2 should be run by PMR, a Navy installation; Group #3, by White Sands, an Army installation; and Group #4, which included the two Australian stations, by the Australian Weapons Research Establishment (WRE).[51] Of course, some single agency would be needed to coordinate these four disparate groups, and this single agency logically should be NASA. A few months later, NASA cited negotiation problems with foreign countries[52] and argued that five stations should be exceptions and run directly by NASA. These five were: Bermuda, Grand Canary I., Kano, Zanzibar, and Guaymas. The reasoning was obvious. Behind it was the fact that NASA felt that it had to have the network operating job if it was going to be charged with total responsibility for the success of Mercury.[53]

Air Force officers made a final appeal to Richard E. Horner, the new NASA Associate Administrator and former Assistant Secretary of the Air Force for Research and Development, just before the WECo letter contract was signed on July 30, 1959. This attempt failed.

Congress has always been sensitive to the NASA-DOD interface. At NASA budget hearings before Congress, questions about duplication of facilities are as inevitable as the cherry blossoms outside. Congress has insisted that NASA and DOD work closely together from top to bottom in each organization.

At the top, the key NASA-DOD agreement covering a broad scope of activities including the Mercury program was entitled: "Agreement Between National Aeronautics and Space Administration and Department of Defense on Global Tracking, Data Acquisition, Communications, and Data Centers for Space Flight;" it was signed by Neil H. McElroy, Secretary of Defense, and T. Keith Glennan on January 10, 1959. One provision of the agreement was that NASA would provide and operate

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[51] Letter to Neil H. McElroy from T. Keith Glennan, dated May 25, 1959, no title. (In Buckley's DOD letter file)

[52] Letter to General Donald N. Yates from T. Keith Glennan, dated May 20, 1960. Even earlier, Abe Silverstein had sent a letter to Walter C. Williams (dated Feb. 5, 1960) stating that DOD should not imply prospective military management of Guaymas.

[53] Personal interview with Victor W. Hammond, October 6, 1967.

new stations for Project Mercury. Another section directed that a joint technical committee be set up to study and monitor global network problems.[54]

The agreement could not conceal the very real problems that DOD and NASA were having in jointly managing the huge complex at the Cape and the stations downrange. Some equipment and land belonged to NASA; but the Air Force held title to the lion's share. Yet, NASA felt that it should be able to have operational control of the range during one of its missions.

Basically, the Air Force wished to treat NASA like any of its other range "customers." NASA would merely fill out the proper forms and the Air Force would man the sites and do all the work. NASA, of course, wished to have its own equipment and operators. Two events helped NASA obtain the operating environment it desired at the Cape. First, Walter C. Williams personally and persuasively explained NASA's special requirements and philosophy to General Yates.[55] Second, General Bernard Schriever, who then headed the Air Force ICBM program, also insisted on having his own men and equipment at the Cape during his missile tests.[56] General Schriever prevailed, creating a precedent for NASA.

In the middle of 1959, Walker Cisler, a utilities executive from Detroit, was made a special consultant to the Secretary of Defense with the mandate to review the whole problem of NASA-DOD ground environment coordination. The Cisler study found: (1) conflict of interest; (2) duplication of effort; (3) lack of clearly defined responsibilities; (4) lack of correlated plans; and (5) absence of centralized control. Cisler proposed the formation of a joint NASA-DOD office with authority delegated from the Secretary of Defense and the NASA Administrator to provide centralized planning, scheduling, and control. Cisler's proposal was not accepted, although DOD did move to strengthen its

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[54] For the text of this agreement, see: U.S. Congress, Senate Committee on Aeronautical and Space Sciences, *NASA Authorization for Fiscal Year 1960*, 86th Cong., 1st sess. (Washington: GPO, 1959).

[55] Interview with J. Satterfield, June 3, 1971.

[56] Interview with Ralph Hicks, June 9, 1971.

management of its ground environment organizations, creating the new post of Deputy Director for Ranges and Space Ground Support within the Directorate of Defense Research and Engineering.

In late 1959, NASA asked DOD to create an organization that would man and provide equipment for the Mercury launches, network operations, and the recoveries of the astronauts and space capsule. The DOD response was the assigning of a DOD Manager for Manned Space Flight Support, who would be based in Washington and be directly responsible to the Joint Chiefs of Staff. General Yates was the first to assume this position. In addition, a special Manned Space Flight Support Office was established at the Cape to assist NASA.

Action was also taken at the working levels. The "joint technical committee" was established quickly, but it did not function well. A more effective coordinating body was then established by Executive Order. On September 14, 1960, the Aeronautics and Astronautics Coordinating Board was created, with Herbert S. York (DOD) and Hugh L. Dryden (NASA) as cochairmen. Formed under this committee was a Space Flight Ground Environment Panel that was charged with network coordination matters. The Board and its panels functioned well, but several less obvious mechanisms were perhaps of more direct value.

Two methods of bridging the NASA-DOD interface have already been mentioned: the IRIG committees and the assignment of Air Force officers to NASA for tours of duty.

Transferring knowhow is one thing; getting widely separated NASA and DOD stations to operate on a common basis is another. How could NASA and DOD coordinate sixteen stations with three different radars, different time zones, different units of measure, and different operator nationalities? The solution lay in careful, thoughtful documentation. Only jointly agreed upon network standards and operating procedures could make a workable entity out of the diverse NASA and DOD facilities. Here, as with S-45, a definitive document hammered a rather incohate mass into something that could be grasped by the mind. A "bible" was needed that would tell everyone what to do and when to do it. Of course, a most valuable byproduct was that NASA and DOD had to sit down and work it out together.

The so-called Operations Directive (OD) was originally evolved by DOD to make its far-flung range sites compatible in standards and procedures. For example, DID had to be sure that radar data from Ascension and Antigua were taken on the same basis. NASA's problem was identical, and NASA and DOD decided to employ the OD as the Mercury Network "bible."

The first model used was OD-60-1, generated in 1960 by DOD for its range stations, many of which now became elements in the Mercury Network. In the next step, NASA first presented its requirements to DOD in a plan which subsequently served as a basis for mutual discussions.[57] NASA and DOD then drew up OD-61-1, which was subsequently issued by DOD and sent to all Mercury Network sites. OD-61-1 without question helped make the Mercury Network an operational success. It was a negotiated document--the result of many iterations--that helped bridge the NASA-DOD interface.

At higher levels, the situation was not so clear-cut. For example, on August 24, 1961, another key agreement was signed jointly by NASA Administrator James E. Webb and Deputy Secretary of Defense Roswell Gilpatric. This agreement called for a pooling of NASA and DOD resources "in a manner which makes effective use of the services and facilities of the Atlantic Missile Range." Similar vague language diminished the usefulness of the agreement. Although it was stipulated that the launch site would be operated as a joint NASA-DOD venture, it did not say clearly who would be in charge beyond the rather self-contradictory statement that NASA would be responsible for operation of mission facilities for NASA programs while the Air Force would be responsible for range operations.[58] After further review, NASA and DOD agreed that NASA would manage its new facilities on Merritt

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[57]Mercury Implementation Team, "Plan for the Mercury Tracking and Ground Instrumentation System at Atlantic Missile Range," Issue 3, January 29, 1960.

[58]U.S. Congress, Committee on Government Operations, "Missile and Space Ground Support Operations," 23rd Report, (Washington: GPO 1966) p. 31. See next chapter for the 1963 Gemini agreement.

Island. The logic here was that NASA ought to be able to manage facilities it purchased. Despite the ambiguities on paper, NASA and DOD worked well together in practice.

Hardware Problems and Their Solutions. A cornerstone of Mercury Network philosophy was that equipment R&D would be minimized through reliance on off-the-shelf material. Looking back on Mercury now, we can see that this was a rather naive expectation. True, radars, radios, and computers existed, but no one had ever tried to meld them together into a global, real-time satellite network. When TAGIU tried to put the existing electronic pieces of the puzzle together, it found that most did not fit together very well and that some pieces were not even in the puzzle box.

Modification of extant equipment was an easy but frustrating problem. TAGIU purchased commercial transmitters and put them on test. Most did not have the requisite reliability for network operation. WECo had to make many field modifications to bring commercial equipment up to network standards. Sometimes equipment had to be backed up with 100% spares.

Network equipment diverted from military pipelines was considerably more reliable. This was not surprising because military specifications were based on operating conditions similar to those of the Mercury Network. Getting priority military hardware proved the most difficult chore in these cases.

The FPS-16 and Verlort precision or "instrumentation" radars selected for Mercury were well proven. With minor changes the Verlorts were integrated into the network easily. The RCA FPS-16s needed more substantial changes. The FPS-16s at DOD sites did not have adequate displays and controls for acquiring the Mercury capsule within the allotted time. The answer to this problem was the so-called IRACQ (Instrumentation Radar Acquisition) kit designed by Paul Vavra, Barry Graves, and other NASA engineers and built by RCA. The IRACQ kit helped the radar analyze signals returning from the spacecraft and enabled it to lock onto the target sooner.

The original FPS-16s had a range of only 250 nautical miles (460 km), but most of those on DOD sites of interest to NASA had been modified by RCA to reach out to 500 nautical miles (920 km). NASA had RCA make this modification on all Mercury FPS-16s. In addition, NASA added a "1000-mile kit" to the Bermuda station to help with the go-no go decision.

Perhaps the biggest problem NASA had with the FPS-16 occurred in the red-tape area. The Navy held the FPS-16 service contract with RCA, and radar modifications had to pass through Navy procurement and contract people. Serious delays were encountered in this "paperwork loop."[59]

The FPS-16 acquisition problem should not be confused with the *general* target acquisition problem faced by all Mercury radars. The FPS-16 and Verlort beam widths were so narrow that radar operators would have difficulty in finding the capsule with the radar beam. The Active Acquisition Aid (AAA) mentioned earlier was the solution. The AAA's 30° beam easily found the capsule using the acquisition data forecast by Goddard computers before it appeared over the horizon. The design, development, and test of the AAA was a critical schedule problem during Mercury.

Bendix was the member of the WECo team responsible for developing the AAA. Bendix subcontracted the job to Cubic Corp. By April 1960, Cubic had built the first AAA and had shipped it to NASA's Wallops Island Demonstration Site on the Virginia coast. Cubic had taken a DOD AGAVE (Automatic Gimballed Antenna Vectoring Equipment) base and added a quad-helix antenna to it. The AAA worked well at Mercury stations. (Figure 3-10) It would pick up the satellite as soon as it rose over the horizon and pass pointing information on to the radars (which searched independently); within seconds, the radars would lock on to the capsule and have a "valid track."

Radar difficulties were to be expected in tracking high, fast targets the size of the Mercury capsule, but few TAGIU engineers suspected that the high-speed data link between Goddard and the Cape would cause so much trouble. Because the Goddard computers drove MCC displays for the mission controllers, the Goddard-Cape data link had to be highly reliable, high-speed, and accurate. In transmitting the flood of computer data (up to 1000 bits per second), Bell and IBM were plagued with "line equalization" problems. TAGIU, working with a small Miami concern called Milgo Co., finally built some equipment (Milgo 165) that would do the job. Much of the technology for high-speed data links had been developed in the mid-1950s for military programs, such as SAGE and Missile Master.[60]

As soon as a Mercury flight left the Canaveral launch

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[59]Interview with George B. Graves, Jr., Jan. 26, 1967.

[60]Personal interview with Laverne R. Stelter, Sept. 28, 1967.

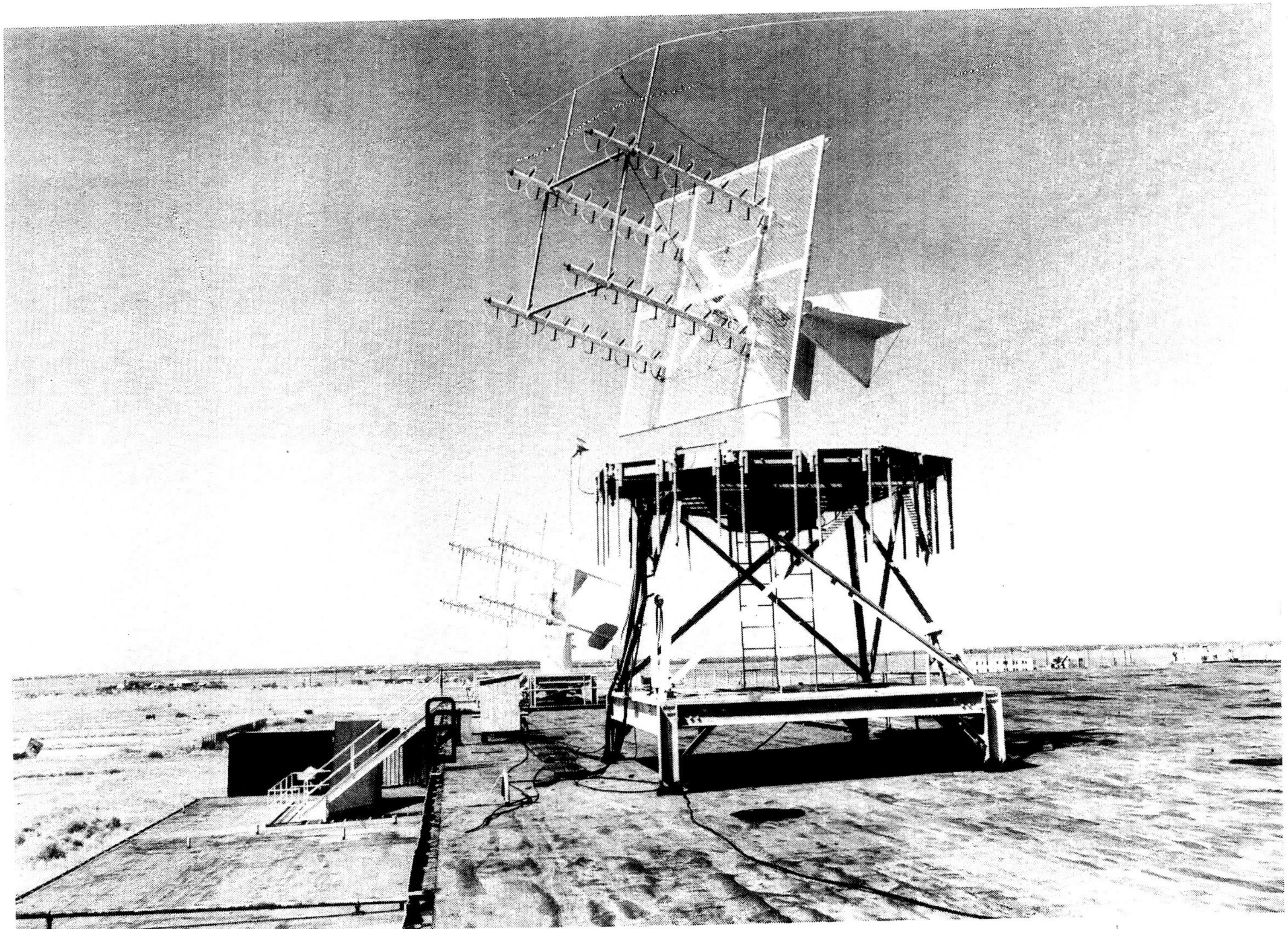

Figure 3-10. The Active Acquisition Aid (AAA) and Yagi telemetry antenna atop hangar at Corpus Christi. (NASA photo)

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pad, data began to converge on the two IBM 7090s running in parallel at Goddard. These data would have piled up behind a bottleneck caused by slow computer input equipment had not IBM hurriedly developed a special "buffering" unit, called the IBM 7281. In effect, the IBM 7281 lubricated the flow of data and helped make real-time operation of the network a reality. In a parallel to the Milgo case mentioned above, IBM was stimulated in finding this solution to the problem by an MIT engineer, Jack Arnow, who came up with an idea that could break the data log jam. IBM subsequently found an even better solution.

So, Mercury Network hardware was hardly "off-the-shelf" as originally prescribed. However, the conservative groundrules did prohibit risky development programs that might have delayed network completion. The small amount of R&D undertaken in the communication and computer areas led to some significant commercial "fallout," particularly in long-line and high-speed data communication.

Cost of the Mercury Network. With the Russians launching Sputniks and Vostoks with infuriating regularity, getting money for the construction and operation of the Mercury Network was never a serious obstacle. If more personnel or a piece of expensive equipment were really needed, Congress was generous.

How much did the Mercury Network cost? Complete cost figures are as follows:[61]

Operations and equipment	$ 71,900,000
Facilities	53,200,000
Total	$ 125,100,000

The network and its operation during Mercury took roughly one-third of the total $400 million charged to Mercury as of the above date. MSFN costs on a fiscal year basis are presented in Appendix B.

It is not unusual for projects on the frontiers of science and technology to cost several times the original estimates. The Mercury Network was spared this fate by avoiding R&D wherever possible. To illustrate, in the November 1959 "Report to the Cisler Committee," NASA estimated that the total capital cost of the network would be about $51 million, with an *annual* operating cost of about $20 million. As aerospace estimates go, this was not far off the mark.

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61 *This New Ocean, ibid,* p. 643.

Deploying the Mercury Network. NASA was fortunate in that DOD had already ringed the world nearly half-way around with tracking stations, although DOD stations could not see all the spacecraft in all of the orbit inclinations planned by NASA. Widening and completing the circle turned out to be as much of a challenge as any of the technical problems. In early 1959, TAGIU and STG had selected seventeen sites, nine of which would be on foreign soil. NASA's oft-iterated position was that non-military space installations would be welcome in these countries.

One of the basic problems of getting the network built on schedule was that of obtaining the timely cooperation of the governments of the foreign countries to allow entry of U.S. personnel and the speedy establishment of the station. The only other comparable U.S. non-military program that preceded this NASA task was the Voice of America's 1949 job of "ringing" the Soviet Union with high power broadcasting stations at Munich, Germany; Salonika, Greece; Colombo, Ceylon; San Fernando la Union, Philippines; and Okuma, Okinawa.[62]

For the NASA effort, Edmond C. Buckley acquired the services of Edward J. Kerrigan on August 4, 1959. Kerrigan had spearheaded the successful negotiations for the Voice of America and came highly recommended by Robert Murphy, Under Secretary of State.

Project Mercury required quick entry into the foreign countries for purposes of site selection and the development of site specifications while formal negotiations were underway. Working through the State Department, TAGIU informed the various countries about the plans and requirements of Project Mercury in July and August 1959. (See Table 3-2 for a complete timetable.) Visits by management and technical teams were requested. Foreign reaction was swift and favorable, except in Mexico where the presentation of the proposition was delayed until late September so that Milton Eisenhower could discuss the idea with the President of Mexico. Further delay in response from the Mexicans was in part due to the already heavy workload of the man assigned by the President, Dr. Nabor Carrillo Flores, President of the University of Mexico, to review the proposition and discuss it with NASA. However, following Mr. Buckley's visit to Mexico City in late January 1960 to explain the need for the station and the specifics of the Project Mercury program negotiations proceeded rapidly and favorably resulting in the agreement of the Mexican Government for the establishment of the Guaymas station.

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[62]Edward J. Kerrigan, personal communication.

Table 3-2. CONTACTS WITH FOREIGN COUNTRIES DURING MERCURY[63]

Station	Foreign Country Informed	Visit Request Made	Technical Visit Made	Agreement Reached
2. Bermuda	7-22-59	7-27-59	8-14-59	3-15-61[a]
5. Kano	7-31-59	8- 8-59	9-21-59	10-19-60[a]
6. Zanzibar	7-31-59	8- 8-59	10- 5-59	10-14-60[a]
8. Woomera 9. Muchea	7-22-59	7-27-59	8- 7-60	2-26-60
10. Guadalcanal	7-22-59	8- 8-59	Station eliminated	
11. Canton Island	7-22-59	8-19-59	9- 5-59	4- 6-61[a]
14. Guaymas	8-12-59	9-21-59	1-20-60	4-12-60
4. Grand Canary I.	8- 4-59	8-10-59	9- 3-59	3-18-60

[a]Construction was started at these stations before the final agreements were signed.

[63]Western Electric, Introduction to Project Mercury and Site Handbook, MG-101, Sept. 1960

To help sell the Mercury stations planned for Africa, NASA asked the National Academy of Sciences for the services of Arnold W. Frutkin, who had considerable contact with various foreign countries during the International Geophysical Year. The African political problems had varied and sometimes strange origins. The most vivid way to describe the African situation is to quote sections from a trip report made by Langley's Ray W. Hooker, who was largely responsible for the preparation of the Mercury Network sites:[64]

> In the case of the Kano and Zanzibar sites, the British have sold the local government on the fact that this is an American experiment, harmless in nature and would contribute to the scientific knowledge of the world. In both the Nigerian and Zanzibar governments there is the general native population which is capable of believing almost anything, and getting quite excited about it. A rumor was circulated in Kano at the time of the siting team's visit there to the effect that the siting team was tied in with the French atomic bomb experiment in some manner.

> The British are trying to end their rule in 1960 in Nigeria on good terms with the Nigerians and most of their action seems to be based on this policy. They have much to gain in future dealings with the Nigerians if they can do this. It would be embarrassing to the British to be in the position of having sponsored a mis-represented project. Much the same situation exists in Zanzibar except that no presently planned British withdrawal is evident. The handwriting is literally on the wall, however, because one sees scrawled on every wall the slogan 'Freedom 1960'!

And last, the most significant quotation of all from the letter:

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[64] Ray W. Hooker, Memorandum for Files, dated October 20, 1959, Subject: Tracking and ground instrumentation systems for Project Mercury; special report on African sites.

> There is one consideration which it is believed should be brought out in this memorandum and that is the fact that, at all of the sites, the statement was made that the National Aeronautics and Space Administration was a civilian scientific organization and that Project Mercury was a scientific experiment being conducted for the purpose of ascertaining the problems of man's existence in space. Furthermore, that the results from this experiment will be made available to all the world.

As soon as each foreign country gave its permission, NASA-WECo siting teams moved in to select the best spot for station equipment. The following criteria were employed:[65]

1. No physical obstructions to the transmission and reception of signals greater than 1°.
2. Existence of adequate separation distance between receiving and transmitting antenna to prevent electrical and physical interference.
3. Minimum outside radio interference.
4. Existence of housing and utilities.
5. Availability of good roads.

There are numerous anecdotes connected with the preparation and operation of each site. In Appendix A, each site is described in more detail and a few of these sidelights presented. Here it is sufficient to list the Mercury Network stations and their major pieces of equipment (Table 3-3) and to illustrate their general configuration and communication facilities. (Figures 3-11, 3-12 and 3-13)

The tight Mercury schedule made it necessary to work on the various sites simultaneously. (Figure 3-14) The first construction operations began on April 29, 1960, and all stations were underway by midsummer. The last staion, Kano, was completed in March 1961.

Most site buildings were made of prefabricated sheet metal supported by rigid steel frames. Besides building for the electronics, most sites also needed power buildings, cooling towers, water chillers, etc. Diesel generators were installed to backup local power sources.

Each site was surveyed carefully to determine true

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[65]"Siting for Project Mercury," Burns and Roe W.O. 1775-02, August 8, 1959.

Table 3-3. EQUIPMENT DEPLOYED AT MERCURY NETWORK SITES.[67]

Station[d]	Station Symbol	Coverage (Passes)	Command Control	Telemetry Reception	Air-Ground Voice	FPS-16 Radar	Verlort Radar	Acquisition Aid	Computer	Ground Communications: Voice	Ground Communications: Telemetry	Ground Communications: Timing
1. Cape Canaveral	CNV-MCC	1,2,3	x	x	x	x		x	B/GE[c] IP7090	x	x	x
a. Grand Bahama Is.[a]	GBI		x	x	x	x				x	x	x
b. Grank Turk Is.[a]	GTI		x	x	x					x	x	x
2. Bermuda	BDA	1,2,3	x	x	x	x	x	x	IBM-709	x	x	x
3. Atlantic Ship	ATS	1,2,3		x	x			x		x	x	x
4. Grand Canary Island	CYI	1,2		x	x		x	x			x	x
5. Kano, Nigeria	KNO	1,2		x	x			x			x	x
6. Zanzibar	AAB	1,2		x	x			x			x	x
7. Indian Ocean Ship	IOS	1,2,3		x	x			x			x	x
8. Muchea, Australia	MUC	1,2,3	x	x	x		x	x		x	x	x
9. Woomera, Australia	WOM	1,2		x	x	x		x		x	x	x
11. Canton Island	CTN	1,2		x	x			x			x	x
12. Kauai Is., Hawaii	HAW	2,3	x	x	x	x	x	x		x	x	x
13. Point Arguello, Calif.	CAL	2,3	x	x	x	x	x	x		x	x	x
14. Guaymas, Mexico	GYM	1,2,3	x	x	x		x	x		x	x	x
15. White Sands, N.M.[b]	WHS	1,2,3				x	x	x		x		x
16. Corpus Christi, Tex.	TEX	1,2,3		x	x		x	x		x	x	x
17. Eglin, Florida[b]	EGL	1,2,3				xMPQ 31				x	x	x
Goddard Space Flight Center	GSFC								IBM-7090 (2)	Communications Center		

[a]No monitoring facilities; downrange antennas for MCC.

[b]Radar tracking station only.

[c]Burroughs - General Electric

[d]See Appendix A for station details.

[67]Adapted from Niles R. Heller et al, "Worldwide Network Support" (Washington: NASA SP-45, 1963), p. 146.

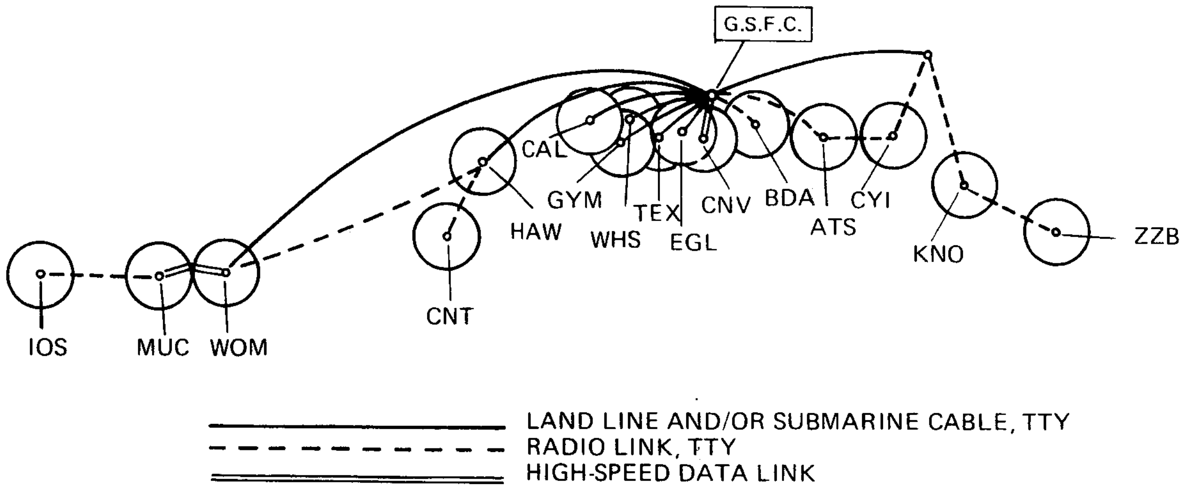

Figure 3-11. The Mercury Network ground communications system, now superseded by NASCOM. See Fig. 3-12.

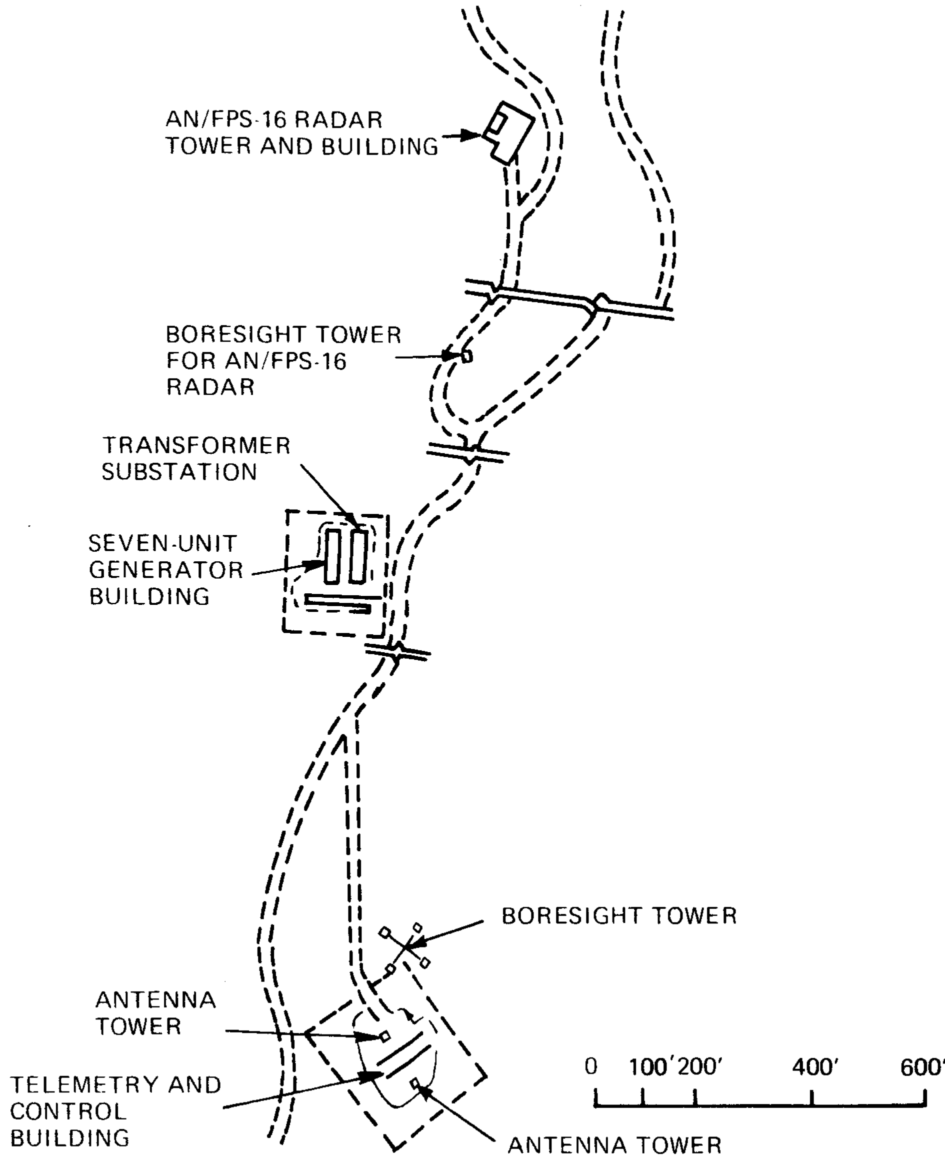

Figure 3-12. Representative station layout. (Kauai, Hawaii)

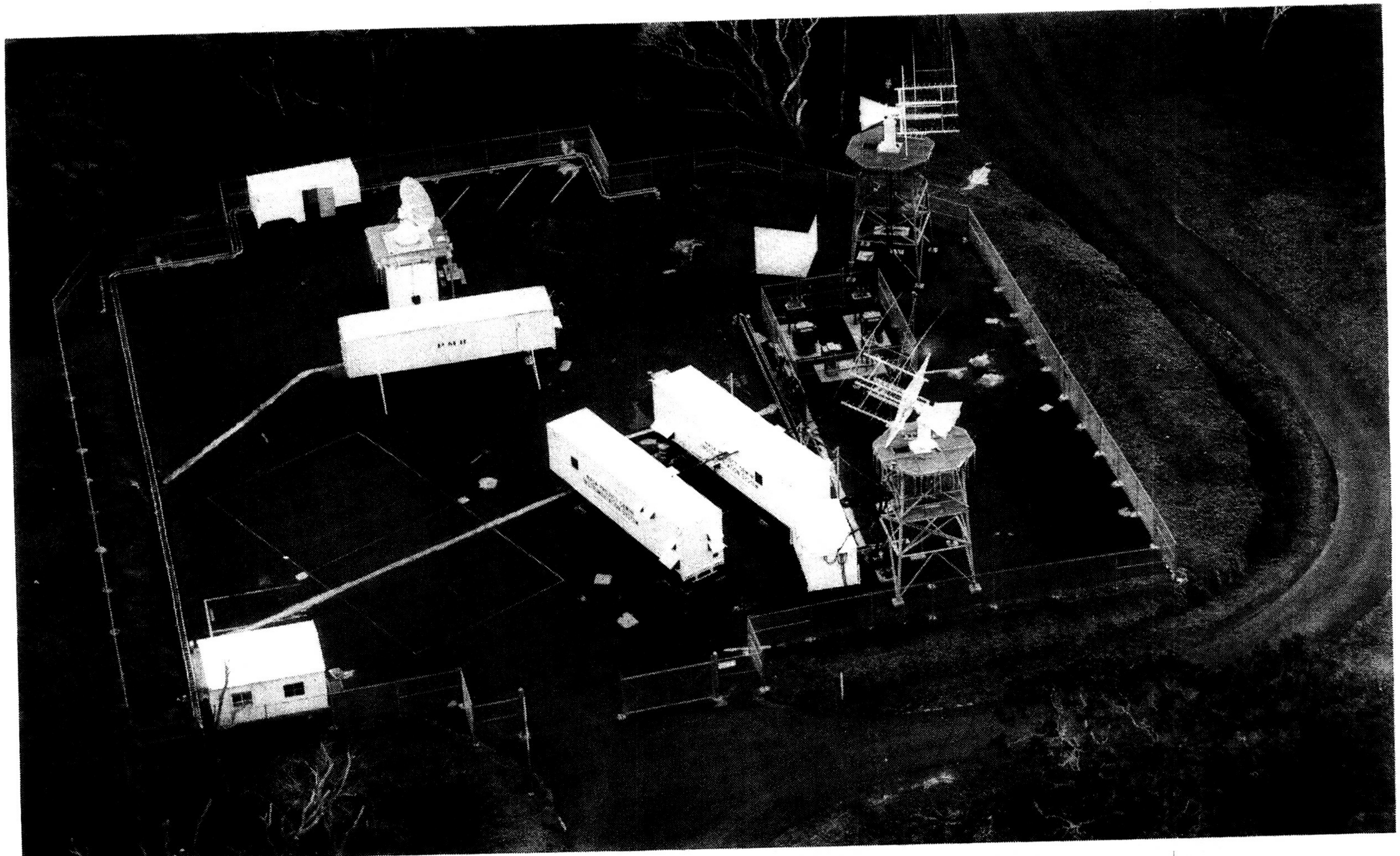

Figure 3-13. Aerial view of the MSFN station located at Kauai, Hawaii. An AAA is shown in the right foreground; the Verlort is on the left; and the command antenna is at the right rear corner.

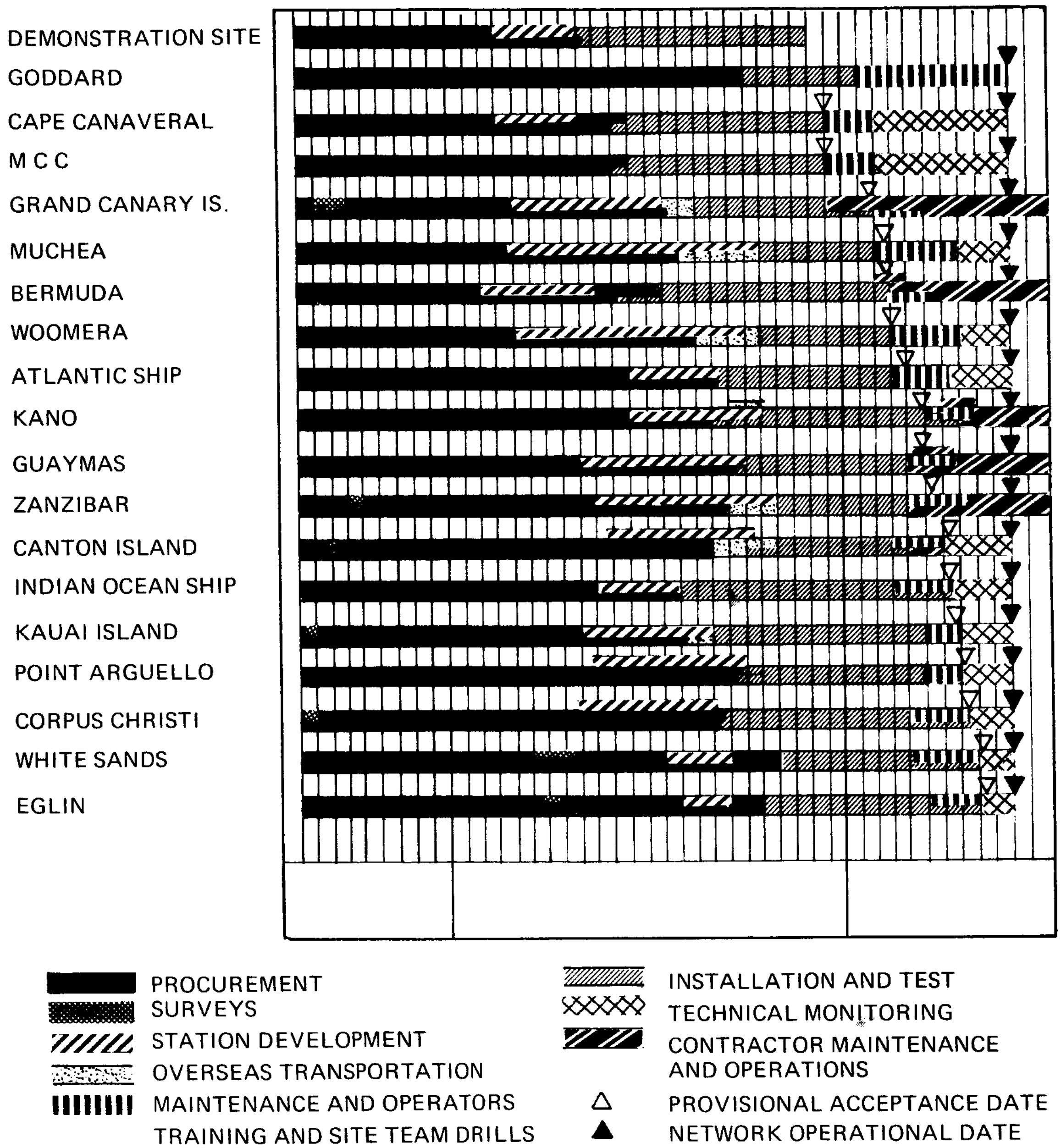

Figure 3-14. The Mercury Network station construction schedule.

latitude and longitude plus elevation. The positions of the radars had to be established within 6 sec of arc.

While the sites were still being built, equipment and installation teams began to arrive. A typical team consisted of the site manager, the team crew chief, technicians, a logistics man, and one or two subcontractors to help with specialized equipment, such as the AAA.

Two depots -- one on each coast of the U.S. -- were set up to provide logistics support for overseas stations and to handle customs problems. These depots served as staging areas for overseas shipments. Stations in the U.S. received their equipment directly from the manufacturer.

One Mercury Network installation that rarely appears on maps and tables was the Wallops Island Demonstration Site. Here, the equipment, different equipment configurations, and operating procedures were tested before being tried in the field. Wallops had an FPS-16 radar prior to Mercury and used it to check out the AAA. Wallops also served as a training ground for stations operators and technicians, much as the Blossom Point station did for Minitrack. Some of the Little Joe test shots using the Mercury Capsule also took place at Wallops.

The early Mercury schedules called for an operational network in early 1960.[66] This conformed to the Mercury flight schedule drawn up in January 1959 that set the date for the first manned orbital flight as April 1960. Numerous revisions of the network operational date followed -- and fortunately Mercury flight schedules slipped independently and more or less in step. The major target dates were: September 15, 1960; November 15, 1960; January 1, 1961; January 25, 1961; and finally, June 1, 1961. (Figure 3-14) The last date was met successfully. The network was ready in ample time for the first manned orbital shot, MA-6, which was launched on February 20, 1962.

Network Operations During Project Mercury

Network Simulations and Tests. Before the Mercury Network could be applied to actual satellites and ballistic capsules, it had to be checked out, first on a station basis and then

[66]Letter from H.J.E. Reid to J.W. Crowley, dated Mar. 9, 1959, called for an operational date of March 1960.

as an integrated network.

One of the most valuable testing tools during network shakedown was the instrumented aircraft. During the equipment-test phase at Wallops Island, small, instrumented airplanes flew over the site to check the tracking accuracy of the AAA. Some AAA design weaknesses were found during these tests. The value of instrumented aircraft was reinforced by their success in calibrating the Minitrack sites. (Chapter 2) NASA therefore decided to procure three aircraft and outfit them with the same electronics gear being built for the Mercury capsule. The objectives of the aircraft tests were:[68]

1. Ensure compatibility between ground and spacecraft systems.
2. Checkout each station and ensure the operational readiness of the equipment and operators.
3. Provide continuous testing and training during the course of the project.

NASA's Mercury aircraft flew over each site many times at predetermined altitudes, speeds, and directions to simulate spacecraft passing overhead. This technique detected a number of minor network deficiencies that had been missed by other tests.

An airplane, however, could check out only a single site at a time. NASA needed something that provided full-scale network "simulation;" i.e., something short of an actual satellite that would "exercise" the entire network.

IBM and James J. Donegan's group, while still at Langley, had conceived of a computer-controlled test procedure that interrogated the different sites via the Mercury communication network. The Goddard computers could analyze the responses and determine the status of each element in the data-flow subsystem. Stations could be checked simultaneously and in depth. Faults could be isolated. This testing procedure is called CADFISS (Computation and Data Flow Integrated Subsystem); and it became an integral part of network simulation. Actually the concept of network simulation was resisted violently until a few simulations had shown the "horrors" of incompletely defined and misunderstood network

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[68]Anonymous, "Historical Summary of the Project Mercury Tracking and Ground Instrumentation Systems," NASA GSFC X-550-63-225, 1963.

functions.[69] (Figure 3-15)

In a sense, network simulations drove the entire network with make-believe data: such as radar inputs, telemetry, and commands. During network simulations, simulated Mercury capsule data were sent to the test sites, such as a sample electrocardiograph. Oxygen loss, power supply degradation, and many other "logical" troubles were faked and kept the station operators and mission controllers at the Mercury Control Center (MCC) on their toes as these data came in over the communication lines. These troubles were superimposed upon a "scenario" of mission events. Radars would be commanded to point at calibrated targets and their replies would be compared with the known answers. Network simulation was not a complete substitute for a real satellite, but, like war games, it was quite realistic. CADFISS did pinpoint weak spots in equipment and procedures. NASA occasionally talked about "manrating" the network, but this term had no meaning in terms of CADFISS or any other performance test. Edmond C. Buckley gave this opinion of network simulation:

> These constant training exercises are the secret, I think, of why the network has worked so well from the very beginning. In actual use on missions these facilities are called upon at widely spaced intervals. But practice maintains stations at high operational quality.

The downrange portion of the Mercury Network was frequently exercised, not only by watching military targets go by, but also by ballistic Mercury test shots, such as MA-1 and MR-1 in the early 1960s, and, of course, Shepard's manned ballistic shot, MR-3, on May 5, 1961. Despite this practice, there was a strong desire within NASA to test the entire network with a small, unmanned satellite carrying Mercury transmitters and radar transponders. This desire took hardware shape as the MNTV (Mercury Network Test Vehicle) launched by the ill-fated Mercury-Scout 1 or MS-1.[70]

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69 CADFISS is often used as a verb. To CADFISS a site means to interrogate it and analyze the responses to see if the site is RED or GREEN. An earlier acronym was CADFIST (Computation and Data Flow Integrated Subsystem Test).

70 See *This New Ocean*, p. 392, for a detailed account of the politics and foreboding surrounding the MS-1 effort.

Figure 3-15. The Mercury computing system at Goddard Space Flight Center. (Courtesy of J.J. Donegan)

The basic MS-1 idea was to take a Blue Scout rocket,[71] mount a battery-powered instrument package on it, and launch it enough in advance of MA-4--the first unmanned orbital Mercury shot--to give the network a good test with an orbital target. To summarize, hardware troubles delayed the payload package's arrival at the Cape until September 20, 1961, a week after MA-4 had been successfully launched. A launch attempt was made on Halloween, but the ignition circuits were faulty. Finally, on November 1, 1961, MS-1 lifted off the pad and promptly began to tear itself apart. After 43 sec of flight, the range safety officer pushed the destruct button. As it turned out, the Mercury Network functioned beautifully without the MNTV.

Mercury Network Operations During the Orbital Flights. The Mercury Network was not a static thing; it changed from flight to flight. Most changes were minor, such as the repositioning of a ship. However, for MA-9, the final Mercury shot, which was scheduled for 22 orbits, the three-orbit "standard" Mercury Network had to be stretched and augmented here and there. Looking back, it is rather remarkable that NASA and DOD were able to pool enough resources and integrate them into the network for MA-9. The extent of the MA-9 modifications is evident from Table 3-4.

The substantial MA-9 augmentation showed that NASA's man-in-space capabilities were expanding rapidly beyond the rather limited, initial Mercury objectives. Just how the Mercury Network was modified to meet Gemini requirements will be covered in the next section.

To illustrate the operating procedures employed during the Mercury Program, some MA-9 events will be described. First came the "precountdown" period, during which CADFISS and other simulations brought the network up to peak operating condition. The MA-9 schedule (abbreviated):[72]

F minus 7 day:	Orbital mission simulation and reentry simulation
F minus 6 day:	Ditto
F minus 5 day:	Two reentry simulations
F minus 4 day:	Detailed system tests

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[71] The particular Scout rocket, developed by NASA and modified by the Air Force, was called a Blue Scout.

[72] Niles R. Heller et al, "Worldwide Network Support," *Mercury Project Summary*, (Washington: NASA SP-45, 1963), p. 148.

Table 3-4. MERCURY NETWORK CONFIGURATIONS

DURING THE ORBITAL FLIGHTS

Flight	Launch Date	Configuration
MA-4 (unmanned)	9-13-61	Standard
MA-5 (Enos)	11-29-61	Standard See Table 3-3
MA-6 (Glenn)	2-20-62	Standard
MA-7 (Carpenter)	5-24-62	No Atlantic ship, Indian Ocean ship reposition in Mozambique Channel off Africa's east coast.
MA-8 (Schirra)	10- 3-62	Six orbits. Atlantic Ship redesignated Pacific Command Ship (PCS) and repositioned south of Japan. Three DOD instrumented ships (*Huntsville, Watertown, American Mariner*) positioned near Midway I. *Rose Knot Victor* received command equipment for MA-8.
MA-9 (Cooper)	5-15-63	22 orbits. *Coastal Sentry Quebec* relocated to 28°N, 130°E. *Rose Knot Victor* relocated to 25°S, 120°W. DOD's *Range Tracker* stationed at 31°N, 173°E. DOD's *Twin Falls Victory* stationed at 31°N, 75°W. DOD Ascension I. site provided with FPS-16 and telemetry recording equipment. DOD East Island, Puerto Rico, site provided FPS-16 tracking. Antigua provided telemetry recording, voice. Voice provided at Wake I., Kwajalein I., and San Nicholas I. Goddard computers converted to IBM 7094s and third computer added. Bermuda radio link supplanted by submarine cable. DOD aircraft relayed voice communications and recorded telemetry in some situations.

F minus 3 day: Equipment maintenance
F minus 2 day: Orbital mission simulation
F minus 1 day: "Patching" (wiring) checks, equipment maintenance. Data flow integrated subsystems tests, especially between Bermuda and Goddard

Actual network countdown began 5 hours and 50 minutes before the rescheduled launch on May 15, 1963. Goddard had prepared a "Network Countdown Document" that specified a series of computer and data-flow checks (using CADFISS), teletype checks, voice checks, and brief system checks. This document also contained "plus-time" events that guided network operators after MA-9 had been launched.

During the MA-9 flight, a site's pre-pass calibrations began about 45 minutes before the capsule appeared over the horizon. About 25 minutes prior to the expected appearance, Goddard would dispatch by teletype acquisition data based on real-time radar data from the preceding site. Better acquisition data would be sent five minutes before the spacecraft's appearance. Radars and AAAs would begin searching the area specified by the Goddard computers. Usually the AAA would locate the capsule first, and all antennas would then be slaved to it. In most passes, the MA-9 capsule could be tracked from horizon to horizon, the pass lasting about seven minutes. About 85 minutes after it disappeared below the horizon, MA-9 would reappear on the opposite horizon. (Figure 3-16)

The only time during Mercury when the network delayed a flight came on May 14, 1963, the day originally scheduled for the MA-9 launch. During the countdown, the Bermuda radar failed to pass the CADFISS tests. At T minus 15 minutes, the Bermuda radar's range data spread exceeded tolerable limits. Two minutes later (T - 00:13:03) the mission was held for 24 hours. According to James J. Donegan, the launch-vehicle crew was also having troubles and was happy to have a postponement.[73] The Bermuda crew replaced a faulty preamplifier and MA-9 was successfully launched the next day.

On all of the Mercury orbital missions, the network experienced minor equipment failures, power outages, and, of course, the human mistakes that cannot be avoided with such a large and tremendously complex machine. Some of these

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[73]The pad diesel would not start and the umbilical cord was inadvertently pulled. Personal communication, Virgil F. Gardner, GSFC, Sept. 1, 1967.

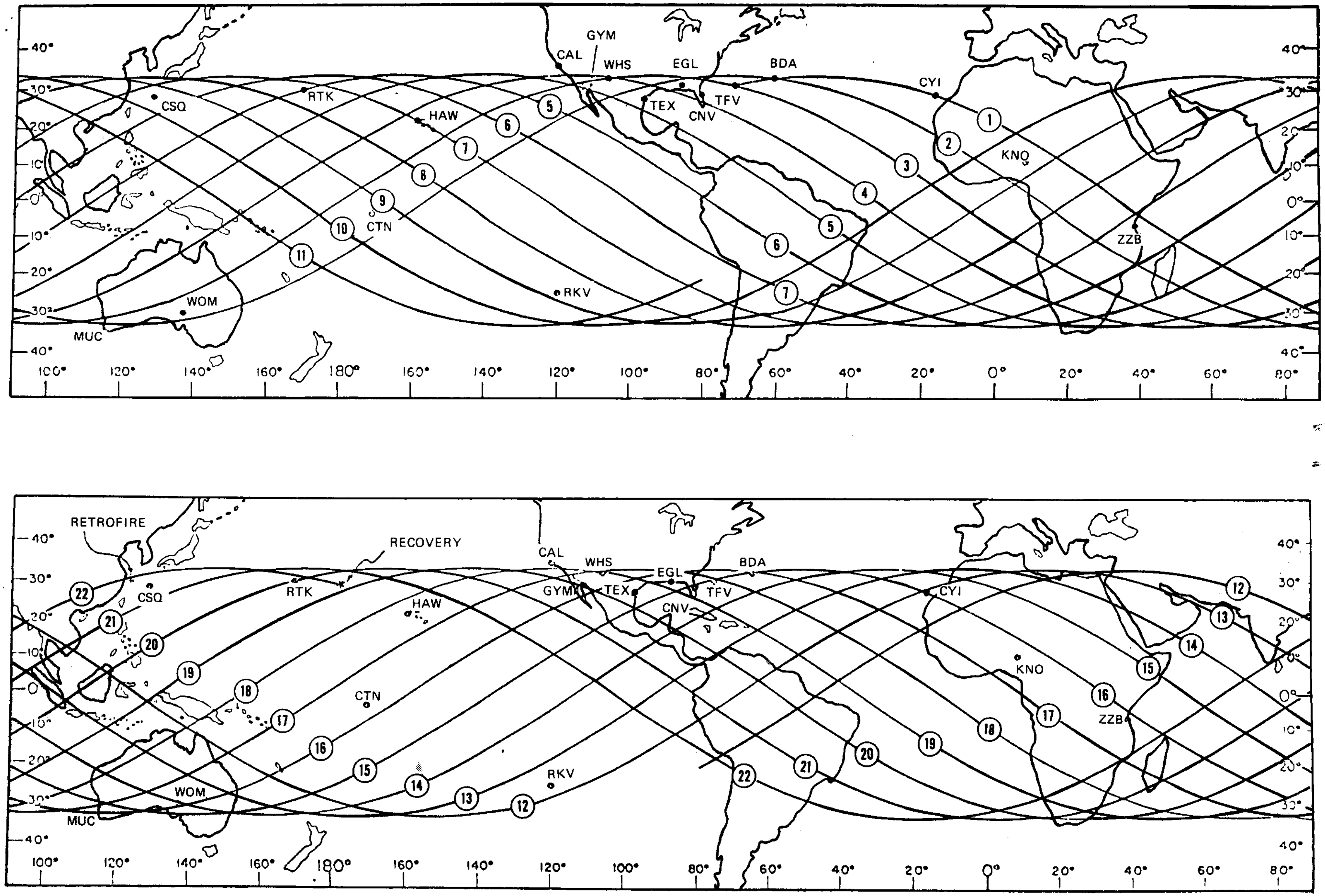

Figure 3-16. Orbital charts for the MA-9 mission.

problems are described below, but it should be emphasized first that the Mercury network was almost always completely GREEN and that missions were never compromised by network problems.[74]

MA-5. On the Enos (a primate) flight, a tractor plowed up a buried cable outside Tucson, cutting off communications with Hawaii and California. The alternate DOD circuits that had been provided in case something happened to NASA circuits were severed at the same time. Just as the satellite was coming in over the Pacific, AT&T was able to reroute NASA communication traffic around the cable break. Chris Kraft, the Flight Director, had just twelve seconds to initiate the reentry sequence.

MA-6. On Glenn's flight, the backup computer at Goddard came in handy. For three minutes the prime computer was out of commission. This was only one instance where the policy of providing "hot spares" proved a wise one.

MA-7. As if to make up for their faltering on MA-6, the Goddard computers correctly indicated Carpenter's 390 km overshoot from California radar data immediately following retrofire. Subsequent MSFN sites confirmed the overshoot, despite some disbelief at the control center.

MA-8. During this flight, solar activity was high and serious radio propagation problems were experienced with the instrumentation ships employed to augment the ground stations. During the fifth orbit, primary power failed at the California site. Fortunately, the backup site on San Nicholas Island was able to provide data. During MA-8, the tracking beacons were turned off during the fourth and part of the fifth orbit to see if the radars could skin track the capsule reliably. They could not.

MA-9. There were fifteen reports of radio interference during this mission. Bermuda, for example, reported hearing the Voice of America, Greenville, N.C., on Mercury channels. DOD frequency controllers were usually able to contact the offending transmitter operators and clear NASA channels On several occasions, amateur radio operators tried to contact the astronauts; but the latter were directed not to respond. More serious were instances where industrial equipment generated excessive radio interference. In most cases, NASA

[74]Detailed accounts of Mercury Network performance can be found in these Goddard internal reports: X-551-62-53, X-551-62-191, and X-551-63-108.

was able to convince the equipment owners to shut it off during actual flights.

The failure of a filament transformer in the backup Guaymas transmitter on MA-9 was more typical of the electronic troubles that afflict any complex electronic system. These sorts of problems had little effect because redundancy was built into the Mercury Network.

Chapter 4. TWO IN SPACE: THE GEMINI NETWORK

Network Modifications for Gemini

Gemini Objectives and New Network Requirements. In late January 1961, over a year before John Glenn made the first manned orbital Mercury flight, the seeds of the Gemini program were sown at a "retreat" held at Wallops Island by STG and NASA Headquarters personnel. The retreat's primary purpose was the discussion of pressing Mercury problems. But, the question of what to do after Mercury could not be ignored; the long lead times associated with spacecraft and launch-vehicle development would not allow it. Rather quietly, the ideas and plans for an "improved" Mercury began to take shape.

What features of Mercury could be readily improved? The spacecraft could be made larger so it could orbit the Earth for longer periods of time and perhaps carry a second astronaut. Both of these changes would support the Apollo program, which became a high-priority national objective when President Kennedy announced it on May 25, 1961. Landing a man on the Moon required more than a bigger capsule with greater endurance; it demanded that NASA demonstrate that orbital rendezvous was technically feasible. Gemini thus became a valuable interim development program between Mercury and the much-more-difficult Apollo. A fourth Gemini objective (dropped in 1964) was the use of a paraglider to bring the capsule to a soft terrestrial landing.[1]

This chapter deals with the network changes resulting from the more ambitious Gemini goals. The $100 million Mercury Network could not be scrapped, but neither could it remain the same. It had to evolve along with the spacecraft it supported.

The network consequences of Gemini were clear to Goddard and to Buckley's office at Headquarters:

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[1]For Gemini details see: James M. Grimwood and Barton C. Hacker, with Peter J. Vorzimmer, "Project Gemini Technology and Operations, a Chronology." (Washington: NASA SP-4002, 1969).

1. More orbits (up to two weeks of flight) meant the capsule would repeatedly stray well beyond the normal limits of the Mercury Network, just as MA-9 had. Either the geographical coverage of the network would have to be increased or communication with the capsule and tracking would have to be reduced.

2. More orbits would increase network reliability requirements. Stations would have to adopt shift-operation during long flights.

3. Spacecraft rendezvous meant doubling many antennas and transmitters to support two spacecraft.

4. The presence of two spacecraft, one of which was larger and more complex than the Mercury capsule, would necessitate expansion of telemetry and ground communication capabilities. The Agena target vehicle required complete new sets of consoles, instruments, operators, etc.

5. Two maneuvering spacecraft would require more ground control displays and command capabilities.

In sum, Gemini network requirements would expand the functions built into the Mercury Network. However, Gemini also represented an opportunity to improve the state of the art in communications, computation, and network automation in preparation for the Apollo program, which was proceeding in parallel with Gemini.

Changes in Network Philosophy. Each change had to carry the network a step closer to Apollo and not away from it. As a result, Gemini philosophy demanded significant engineering development in contrast to Mercury, which utilized mostly off-the-shelf hardware.

During the first week of June 1962, Goddard engineers made their first presentation to Houston personnel, explaining the technical changes they would like to see implemented in the Gemini Network.[2] To Houston engineers, absorbed in the intricacies of designing a complex spacecraft, most of the Goddard suggestions were too advanced---they had enough problems with the spacecraft and did not want more on the ground. Here is what Goddard proposed:

1. Unification of all commands, telemetry, and other radio signals into a single frequency.
2. Conversion from analog to PCM telemetry.
3. Installation of computer-driven alphanumeric displays.

[2]Personal interview with Dale Call, September 18, 1969.

4. Use of two acquisition aids at each station (one for each target) and the ability to slave the radar to either.
5. Conversion to digital UHF up-link command so that the station computer could handle commands as well as telemetry.

The Goddard suggestions taken collectively represented a major synthesis of tracking and data acquisition techniques and bore many resemblances to the Unified S-Band system that was adopted later for Apollo (Chapter 5). Houston quickly agreed to the switch to PCM telemetry but objected to the rest of the "package" on the grounds that complete dependence upon a single concept could lead to total mission failure if part of the system failed. In essence, the bulk of the Goddard proposals were rejected.

On and off during the next year, Goddard tried to convince Houston of the soundness and desirability of the new concept for Gemini. In June 1963, Goddard engineers made a last presentation at Houston, stating that there was no time for further argument if the Gemini schedule was to be met. Goddard reiterated its faith in its proposal but stated that it would accept Houston's decision as final. After the presentation, Houston agreed to the entire Goddard proposal with two stipulations: (1) the station computers would be employed only for telemetry processing, not for commands (Houston feared software errors as much as hardware errors in this restriction), and (2) the unified frequency approach was not implemented.

One Gemini guideline that had a significant effect upon the MSFN was the relaxation of the Mercury ten-minute-dead-time requirement to one contact per orbit. Consequently, the MSFN did not have to spread its resources all over the globe, but rather could heavily instrument a few "primary" sites and spot "secondary" stations with more limited capabilities wherever they were needed for the particular flight at hand.

It had been the assumption during Mercury that some of the communication links between the MCC and the stations would be lost on occasion. This happened only rarely; a fact enabling NASA to remove flight controllers from many stations and centralize control activities.[3] Flight controllers remained at a few primary Gemini sites where there was some doubt about the reliability of communications. This centralization of control also occurred in STADAN (Chapter 2). The great improvements in world-wide, real-time

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[3]Personal interview with Robert J. Coates, GSFC, October 5, 1967.

communication represented a key technological trend--a trend stimulated by NASA's progress. (See Chapter 6).

Another change in network philosophy involved the physical integration of centralized mission computing and mission control. These functions are so closely related that NASA Headquarters felt they should be managed by the same center. In addition, communication problems between Houston and Goddard would be eased by this integration. With the launch of GT-5 (Gemini-Titan 5) on August 21, 1965, the Manned Spacecraft Center took over the mission computing function from Goddard.[4] Goddard computers still remained in backup status and were still employed on purely network matters, such as CADFISSing the network sites.

It was apparent from the start that Gemini, particularly the rendezvous missions, would be too big for the Mercury Control Center at the Cape (MCC-K). Furthermore, during Mercury, the travelling back and forth to the Cape had been time-consuming and a morale problem as well for Houston engineers. NASA decided to construct a new Mission Control Center at Houston (MCC-H) and tie it into the new computing center. (Figure 4-1)[4a] The NASA Administrator announced the move on July 20, 1962.[5] On the GT-5 flight, MCC-H became prime and the MCC-K went into backup status. The control and computing functions have remained at Houston ever since.

Equipment Changes. The question of computers at the primary Gemini sites was a weathervane that showed the drift to network computerization. During most of Mercury, the only network computer outside those at Goddard and at the Cape was the one installed at Bermuda to help make the go-no-go decision if communications to the mainland failed at a crucial time. The added length and complexity of the last few Mercury flights underscored the need for better computation facilities at the sites. Mercury practice included the reading of spacecraft analog data off meters and then the manual plotting of key parameters. Teletype summaries of these reduced data were then sent to the Control Center. To test the utility of a computer in on-site telemetry processing, an AN/UKY-1 computer (8 kilobit memory) was added at

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[4]During GT-4, MSC computers were checked out and placed in backup status with the Goddard computers remaining prime. GT-5 reversed these roles.

[4a]Originally, this facility was called the Integrated Mission Control Center or IMCC.

[5]NASA News Release 62-172, July 20, 1962.

Figure 4-1. The Mission Control Center, Houston, during the Gemini-7 flight.

Bermuda for the MA-8 flight. Operating in parallel with the manual data reduction technique, the computer quickly proved its superiority. Yet, the flight controllers and Houston personnel were concerned over the spectre of software problems added to those they already had. The Bermuda computer again functioned beautifully during MA-9, winning over many former opponents of station computerization.

When telemetry processing plans were laid for Gemini, Houston originally wanted only four groups of parameters to be processed and sent back to the Control Center where they could be monitored. When the decision was made to install computers (UNIVAC 1218s) at the primary sites, almost overnight Houston engineers discovered that they could now ask for many more spacecraft parameters than before and get them more quickly and reliably. Once the "dam" was broken, the rush was on to utilize the computers to the fullest. Commands for Gemini were handled by the special-purpose Digital Command System (DCS). Although this system formatted digital commands, it was not actually a computer in the modern sense.

Mercury's analog telemetry had been selected because of its proven reliability. Gemini presented the opportunity to follow the example of NASA's large scientific satellites and switch to a digital scheme, more specifically PCM (Pulse Code Modulation). PCM was a more flexible and accurate type of modulation; furthermore, it was "computer language" and needed no translation at the computer input. Going digital, like the addition of more computers, was another step toward automation of the entire MSFN. By making all telemetry PCM, spacecraft telemetry equipment was consolidated and lightened. Spacecraft command equipment and other ground instruments were also digitized for Gemini, so that all equipment, on the ground or in orbit, conversed in the same language.

Computers, in other words, assumed more and more importance in a network that was becoming more highly automated with each mission. The addition of station computers and new submarine cables helped make real-time communication throughout the network a reality.

The Mercury acquisition aid, which had been mounted on an old radar pedestal, posed many mechanical problems during Mercury. It was badly balanced and tended to strip gears: it was also not waterproofed. After trying two contractors, Goddard finally designed a new acquisition aid itself with the help of Bendix personnel stationed at Goddard. Another piece of Mercury equipment, the quadhelix telemetry antenna, was also phased out. It was replaced by the TELTRAC antenna, manufactured by Canoga.

In addition to the major changes described above, the following modifications were made for Gemini:

1. Equipment was added at each station permitting the Flight Controllers to communicate directly with the astronauts.
2. Electrocardiogram capability was added, as were displays for medical teams monitoring the astronauts.
3. The *Rose Knot Victor* was given command capabilities prior to MA-8 for the forthcoming Gemini missions.
4. Ditto the *Coastal Sentry Quebec* prior to MA-9.
5. There were many building and ship modifications.

The MSFN ground communication complex was also expanded and refined for Gemini; although this was more evolutionary than abrupt as Mercury phased out and Gemini began to occupy everyone's attention. Long lines and radio links were improved through the addition of new equipment, especially new submarine cables. One measure of the increasing capabilities of the ground communication network is found in the evolution of SCAMA (Switching, Conferencing, and Monitoring Arrangement) which is the switchboard at Goddard that handles all voice communications around the world. In the early days of Mercury, SCAMA could conference only ten worldwide circuits; after MA-9, this number grew to 220.[6] (See Chapter 6)

It is a fact that the state of the art in advanced communications has done much to shape the evolution of the MSFN. The "value" of a station is proportional to both its on-site equipment *and* its ability to communicate with the spacecraft and the control center. "Real-time, wide-band communication is the name of the game."[7]

<u>Gemini Station Changes</u>. In addition to the changes evolving from shifts in technical philosophy and expanded requirements were several minor station changes. The first impression gained from the list of Gemini stations (Table 4-1) is that it is much longer (25 entries) than the comparable Mercury list (Table 3-4). This occurs because secondary supporting stations, such as Ascension and Pretoria, have been added to the basic Mercury Network core. Both the Gemini and Apollo networks show this trend toward a few highly instru-

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[6]Personal interview with Laverne R. Stelter, September 28, 1967.

[7]Personal interview with Ozro Covington, April 10, 1969.

Table 4-1. EQUIPMENT DEPLOYED AT GEMINI NETWORK SITES[10]

	Station Symbol	Real-Time Telemetry to MCC-H	Acquisition Aid	Radar	PCM Telemetry Ground Station	Telemetry Record	PAM Telemetry (FM/FM) Ground Station	Flight Controller Display Consoles	Digital Command Modulation	Radio Frequency Command	Spacecraft Communications (Air-to-Ground)	Voice
Cape Kennedy[b]	CNV											
Mission Control Center	MCC-K	x	x	x	x	x	x	x	x	x	x	x
Grand Bahama I.	GBI	x	x	x	x	x	x			x	x	(a)
Grank Turk I.	GTK	x	x	x	x	x				x	x	(a)
Bermuda[b]	BDA	x	x	x	x	x	x			x	x	x
Antigua	ANT	x	x	x	x	x	x				x	(a)
Grand Canary I.[b]	CYI		x	x	x	x	x	x	x	x	x	x
Ascension I.	ASC			x		x	x				x	(a)
Kano, Africa	KNO		x			x	x				x	x
Pretoria, S. Africa	PRE		x		x	x						
Tananarive, Malagasy Rep.	TAN		x			x	x				x	x
Carnarvon, Australia[b]	CRO		x	x	x	x	x	x	x	x	x	x
Woomera, Australia	WOM		x	x								x
Canton Island[c]	CTN		x			x	x				x	x
Kauai Island, Hawaii[b]	HAW		x	x	x	x	x	x	x	x	x	x
Point Arguello, Calif	CAL		x	x							x	x
Guaymas, Mexico[b]	GYM		x	x	x	x	x	x			x	x
White Sands, N. Mex.	WHS		x	x								x
Corpus Christi, Tex.[b]	TEX	x	x	x	x	x	x	x	x	x	x	x
Eglin, Fla	EGL		x	x		x	x					x
Wallops Island, Va.	WLP		x	x	x	x	x	x	x	x	x	x
Coastal Sentry Quebec (ship)[b]	CSQ		x		x	x	x	x	x	x	x	x
Rose Knot Victor (ship)[b]	RKV		x		x	x	x	x	x	x	x	x
Goddard Space Flight Center	GSFC											x
Range Tracker (ship)	RTK			x		x					x	x

(a) Through Cape Kennedy Superintendent of Range Operations.
[b]Primary sites with flight controllers (MCC-K for GT-1, GT-2, and GT-3 only)
[c]Some flights only

[10]Adapted from Henry E. Clements, Richard L. Holt, and Douglas W. Carmichael, "Mission Control Center and Network," in *Gemini Midprogram Conference*, (Washington: NASA SP-121, 1966) p. 175.

mented primary stations supported by many secondary stations with limited facilities. (Compare similar STADAN trends, Chapter 2.)

Several station changes deserve further comment. The Australian Mercury stations at Woomera and Muchea were combined into a primary station at Carnarvon to consolidate Gemini and Apollo facilities and to better monitor spacecraft rendezvous. (A STADAN station is also located at Carnarvon.) Woomera was part of Australia's missile range, and its radar continued to support Gemini. Command transmitters were installed at Perth, Australia, to transmit re-entry commands to Gemini capsules as they made their final pass over Australia.

The Atlantic and Indian Ocean ships of the Mercury Network were repositioned just south of Japan (*Coastal Sentry Quebec*) and in the South Atlantic off Brazil (*Rose Knot Victor*).

The only significant network change not inspired by changed technical requirements was the transfer of the Mercury Zanzibar functions to Tananarive, in the Malagasy Republic. The nontechnical consideration was the Zanzibar revolution which overthrew the government on January 12, 1964. Because of the threat to American personnel at the Zanzibar station, the U.S. Navy evacuated the station's staff and their dependents on January 12, 1964. On April 7, 1964, at the request of President Abeid Karume of the Zanzibar People's Republic, President Johnson ordered the removal of the $3.5 million tracking station.[8] By August 12, 1964, an agreement had been concluded with the Malagasy Republic that permitted a Gemini MSFN station to be built alongside the relocated station at Tananarive. The Zanzibar coup came as no surprise to NASA, where officials had been apprehensive about the political environment from the beginning.[9]

Changes in Management Philosophy. Goddard took over network operating responsibility from TAGIU during the third quarter of 1961, well before Glenn's MA-6 flight. Ahead of Goddard

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[8]According to the *Kansas City Star*, January 20, 1964, Communist China was after U.S. classified equipment!!

[9]Interview with Hartley A. Soulé, Jan. 26, 1967.

in 1961 lay the immense task of converting the Mercury Network into the Gemini Network and, in addition, the even bigger task of designing and constructing a network to handle the Apollo lunar landing. To help cope with this assignment, Goddard brought Ozro M. Covington to Greenbelt from White Sands in mid-1961.[11] At White Sands, Covington had been Technical Director of the Signal Corps group established at White Sands in early 1946. His experience in setting up the White Sands missile instrumentation (noted in an earlier section) proved invaluable to the deployment and successful operation of the MSFN during Gemini and Apollo. The infusion of White Sands experience through the transfer of Covington and other White Sands personnel represented the most significant change in NASA expertise and management structure in the tracking and data acquisition area since Langley and NRL personnel were transferred to Goddard early in its history.

As the Gemini program took shape in 1961 so did the interface between Goddard and Houston. As described earlier, intercenter discussions about Gemini and Apollo requirements began in early 1962. During this period, Goddard and Houston personnel worked hand-in-hand. Ozro M. Covington, drawing on his White Sands background, helped establish good communications with MSC personnel and convince them of Goddard's desire to operate on a "customer-supplier" basis. These informal contacts were probably more important than the formal ones in building an amicable MSF-GSFC interface. (Figure 4-2).

In the early days of Gemini, the question of which center should have the network operation package was reopened, particularly with respect to the forthcoming Apollo missions. This renewed debate was finally settled by a letter from NASA Associate Administrator Robert C. Seamans reiterating Goddard's role as the center of NASA expertise in tracking and data acquisition.[12] This letter and its attachment "Management Plan for the Manned Space Flight Network" were based on a draft submitted to Seamans by Edmond C. Buckley on July 12, 1962. Because of the definitive nature of this letter, it is reproduced in Appendix B.

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[11]Covington's official position at Goddard during Gemini was Deputy Assistant Director for Tracking and Data Acquisition.

[12]Letter from Robert C. Seamans to Harry Goett, March 11, 1963.

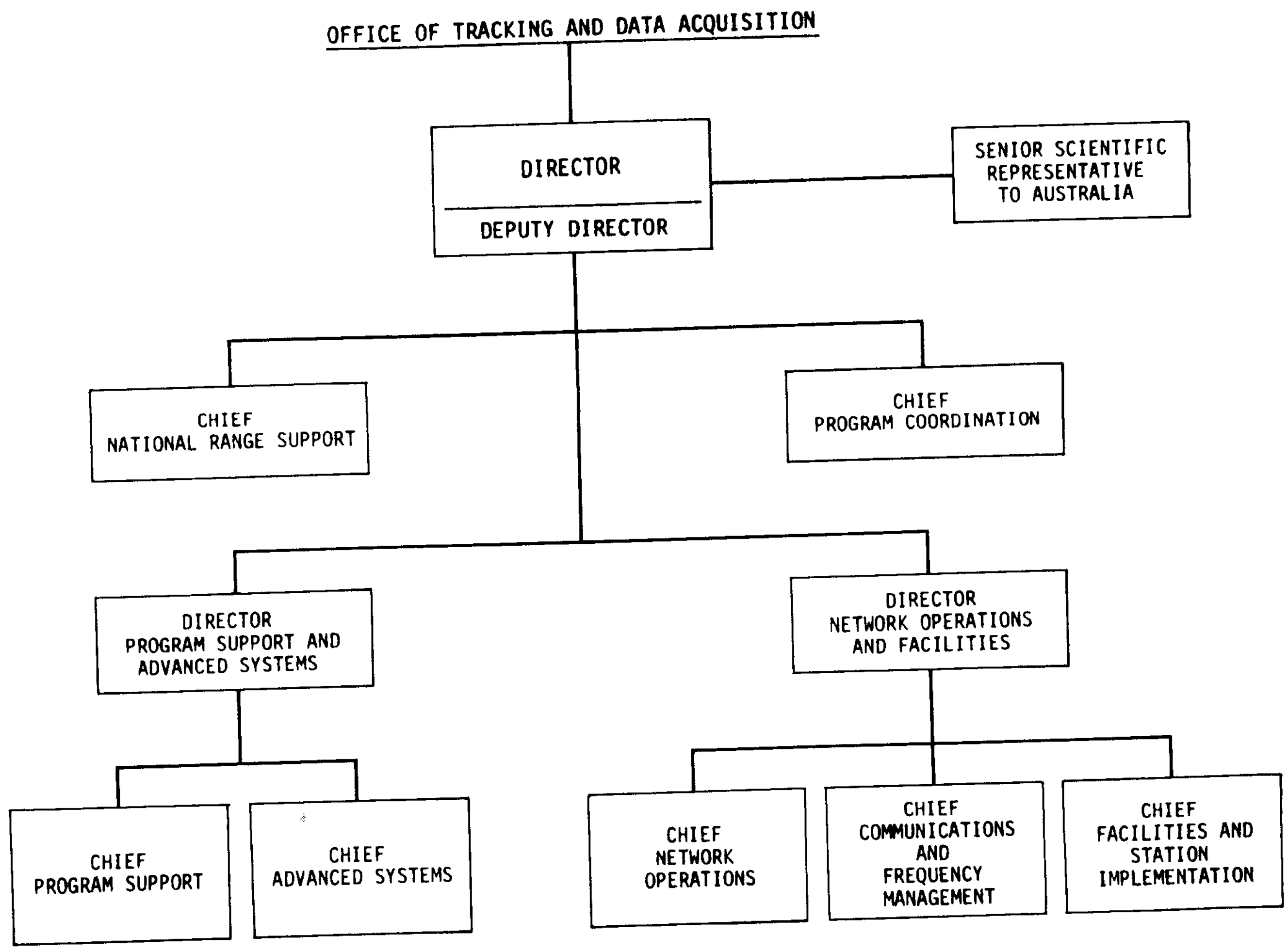

Figure 4-2. Organization chart for tracking and data acquisition during Gemini

In a nutshell, Goddard was assigned the management and technical operation of the network. Goddard had to certify a GREEN network before and during a manned space shot. This certification included DOD and Australian sites. Intrinsic in these responsibilities were the implementation and manning of the stations, the communication lines between them and the Mission Control Center, and the mission computations.[13]

MSC was responsible for the success of the manned space programs. As the responsible party, MSC set requirements before the missions and maintained actual operational control of the network during each flight.

MSC and Goddard responsibilities were reflected upwards to two NASA Headquarters organizations: the Office of Tracking and Data Acquisition (OTDA) and the Office of Manned Space Flight (OMSF). (Figure 4-2) Summarizing, OTDA had the "management responsibility for the generation, direction, and execution of the ground implementation plan for the Manned Space Flight Network." Further, OTDA had to provide for the technical operation of the network, which, of course, was delegated to Goddard. OMSF, in turn, was assigned the responsibility for generating the ground instrumentation requirements, which it delegated to Houston.

OTDA oversees all of NASA's network operations, including NASCOM. Edmond C. Buckley, Associate Administrator of OTDA from 1961 to 1967, stated the objectives of his office in these terms:

> Our role, in brief, is to perform the integrated management and administration of the worldwide ground instrumentation and associated operational communications networks, including the resources required to plan, develop, implement and operate them.

One of OTDA's most difficult tasks was the assembly of a total picture of network requirements for each mission. During Gemini, Houston generated its spacecraft support requirements, Marshall Space Flight Center (MSFC) drew up ground support needs for its Saturn launch vehicles, and Kennedy Space Center had become an important factor in activities at the Cape. All three organizations had different ways of requesting ground support from the network through OTDA. Because it was the responsibility of OMSF to present OTDA with

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[13]Computing responsibility was transferred to Houston with the GT-5 flight.

a complete, coherent set of network requirements, Major-General Samuel C. Phillips, OMSF's Apollo Program Director, recommended that a new organization be set up at NASA Headquarters to coordinate all these requirements. To this end, B. Porter Brown, who was with MSC but based at the Cape, was called to Washington in early 1965 to set up the Operations Support Requirements Office (OSRO).[14] OSRO helped OTDA immeasurably by coordinating MSC, MSFC, KSC, and the Air Force. These organizations as well as JPL, Goddard, and OTDA were all represented in the OSRO organization. In Brown's words, "It was a United Nations." Despite the great diversity of views within OSRO, a universal scheme for documenting ground support requirements was created. Just having the support problem defined in a consistent, complete fashion was a major step forward for Gemini and, in particular, the much more complex Apollo Program, which was rapidly gathering momentum in 1965.

Defining network requirements has been such a critical phase of the manned space flight effort that a brief summary is in order. During Mercury, STG and TAGIU were both located at Langley and could work out Mercury's relatively simple ground support requirements conveniently and informally. (Chapter 3) Gemini was more complex, but many of the requirements were hammered out informally between Goddard and Houston--often without going through OTDA and OMSF at all. These informally made decisions were then written up in a Program Instrumentation Requirement Document (PIRD).[15] The program office and NASA Headquarters reviewed and signed off on the PIRD, and it then became the definitive document levying network requirements.

With the formation of OSRO in 1965, the PSRD system came into being. (PSRD = Program Support Requirements Document) When an upcoming mission was adequately defined, the various NASA centers involved would submit their support requirements to OSRO, which would then negotiate and remove obvious conflicts.[16] The integrated requirements were then disseminated in the PSRD. The PSRDs were really "scoping" documents and invitations for assessments of the impact of each mission in terms of money, time, and facilities. Each center responsible for providing support (Goddard, KSC, the Air Force, etc.) responded with a Network Operations Directive (NOD) or its equivalent. Additional conflicts became apparent at this stage, and a general meeting would be called to work them out. Finally, when all disputes and inconsistencies were resolved, the centers were told to go ahead with

[14] Interview with B. Porter Brown, June 30, 1971.

[15] Interview with Charles Beers, June 3, 1971.

[16] Interview with B. Porter Brown, June 30, 1971

the implementation phase. Each center then issued its plans for meeting mission requirements. These plans were made in sufficient detail so that engineers could begin designing and procuring hardware.

DOD Support During Gemini. NASA and DOD pooled their network resources to create the Mercury Network in 1959-1961. They did the same for Project Gemini.

The Webb-Gilpatric NASA-DOD agreement signed during the Mercury Program was renewed and extended during Gemini. Only the most important of these will be mentioned here. On January 17, 1963, James E. Webb and Robert S. McNamara signed an "Agreement Between DOD and NASA Regarding Management of the Atlantic Missile Range of DOD and the Merritt Island Launch Area of NASA." Expanding this document was another, signed May 22, 1965, entitled "NASA-DOD Agreement Regarding Land-Based Tracking, Data Acquisition, and Communication Facilities."[17] Robert C. Seamans, Jr., NASA Associate Administrator, said about the May 1965 agreement:

> This agreement delineated the policies for coordination of planning, for management of instrumentation facilities and support functions at collocated stations, and for cross-servicing between the operating facilities of both agencies--all designed to achieve a maximum of mutual assistance and economy.

The coordination of NASA and DOD network support at the working level was well-mechanized by the time Gemini became operational. The DOD-originated Operations Directive (OD) and later the NASA Network Operations Directive (NOD) was the primary tool used to ensure coordination, as discussed in an earlier section. During Gemini, Goddard took over the responsibility for preparing this key document--the network "bible."

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[17]The text of the May 1965 agreement may be found in U.S. Congress, *Missile and Space Ground Support Operations*, Hearings before the Subcommittee on the Committee on Government Operations, GPO, (Washington: GPO, 1966), pp. 158-161.

Network Operations During Project Gemini

Some Generalities. Gemini MSFN operations followed the Mercury pattern except, of course, for the longer flights, the critical rendezvous maneuvers, and the less-frequent voice contacts with the astronauts. Save for minor electromechanical troubles, which were negated through the use of redundant equipment, the MSFN worked well.

Prior to the first Gemini flights, each MSFN station was checked out and exercised by instrumented aircraft. These aircraft, two C-121G Super Constellations on permanent loan from the Air Force, helped calibrate station equipment and simulated the passage of a satellite overhead. In addition, the entire network was checked out and exercised with CADFISS, the computer-controlled interrogation scheme described previously.

The detailed configurations of the MSFN and NASCOM varied slightly as the Gemini flight program progressed. The changes were not significant enough to record here.[18] To give the reader the flavor of operations during Gemini, the Gemini-11 mission has been selected for discussion in depth. First, however, the twelve Gemini flights are recapitulated in the following table and narrative. (Table 4-2)

GT-2. This ballistic unmanned shot was tracked by CNV, MIA (Merritt Island), MCC, BDA, RKV, CSQ, PAT, GBI, GTK, ANT, and four telemetry-recording aircraft. (See Table 4-1 for code key.) As with some Mercury flights, beacon modulation was noticed. Radio propagation problems were encountered with RKV and CSQ, the tracking and data acquisition ships). Because of a partial power loss at MCC-K ten messages from the spacecraft were lost temporarily.

GT-3. During this flight, the Gemini "real-time patching tape" was found to have errors.

GT-4. A typical human error cropped up during this flight: an astronaut had thrown the beacon switch to the wrong position. As a result, no C-band beacon was picked up at PRE. In addition, heavy rains at CRO and the resultant seepage into antenna connectors prevented this site from passing the

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[18]Details concerning the operational performance of the MSFN during Gemini can be found in the following Goddard internal reports: X-552-64-206, X-552-65-204, X-552-65-424, X-550-66-251, X-552-66-242, X-552-66-390, X-552-66-438, X-552-66-589, X-552-66-590, and X-552-67-36.

Table 4-2. The Gemini Flights

Flight	Launch Date	Remarks
GT-1 (unmanned)	4-8-64	Orbital test flight
GT-2 (unmanned)	1-19-65	Suborbital test flight
GT-3 (Grissom and Young)	3-23-65	Three orbits
GT-4 (McDivitt and White)	6-3-65	66 orbits -- roughly four days. First U.S. walk in space.
GT-5 (Cooper and Conrad)	8-21-65	128 orbits -- roughly 8 days. Rendezvous maneuvers.
GT-7 (Borman and Lovell)	12-4-65	220 orbits -- roughly two weeks. Rendezvoused with GT-6.
GT-6 (Schirra and Stafford)	12-15-65	17 orbits -- just over one day. Rendezvoused with GT-7.
GT-8 (Armstrong and Scott)	3-16-66	6.5 orbits -- 10.7 hours. Had to reenter early because of malfunctioning spacecraft thruster.
GT-9 (Stafford and Cernan)	6-3-66	47 orbits -- about 3 days. Walk in space. Rendezvous with unmanned target.
GT-10 (Young and Collins)	7-18-66	46 orbits -- about 3 days. More rendezvous experiments.
GT-11 (Conrad and Gordon)	9-12-66	47 orbits -- about 3 days. High apogee: 853 miles.
GT-12 (Lovell and Aldrin)	11-11-66	63 orbits -- about 4 days. More walks in space.

CADFISS test. Just prior to GT-4, the submarine cable from San Salvador ruptured. Before the rocket lifted off on January 3, 1965, DOD had San Salvador back in the network with rented cables via Puerto Rico.

GT 5. This Gemini flight encountered serious fuel cell problems. To conserve power, the beacons were turned off for long periods, forcing the radars to skin track the capsule. WHE experienced severe radar maintenance problems during this flight. A possible cause was the change in maintenance and operating (M&O) contractor personnel before the mission.

GT-10. During this flight, there was difficulty in transmitting data from PRE to the control center.
GT-11. See the next section.
GT-12. ASC and PRE could not track the GT-12 capsule on the first orbit because of erroneous data received from the Real-Time Computing Center (RTCC). It turned out that there was a bad computer input.

Actually, the problems enumerated above were minor in character and did not compromise the operation of the network. Of course, there were other difficulties of even less importance. The policy of building redundancy into the MSFN made it possible to rectify, bypass, or otherwise compensate for equipment failures and human errors. Gemini operations were generally routine and uneventful. This is the best compliment a ground-support operation can receive.

Some Details of the GT-11 Mission. The GT-11 and the Atlas-Agena target vehicle were successfully launched into their orbits on Sept. 12, 1966. The primary objective of GT-11 was the rendezvous and docking of the GT-11 with the target vehicle. This was achieved one hour and 34 minutes after the liftoff of GT-11. Retrofire occurred on Sept. 15, when GT-11 was over Hawaii. Splashdown took place in the Atlantic at 13:59:54 GMT. During the entire mission the MSFN performed well. GT-11 will be used as an example of a Gemini mission.

The specific network configurations employed during GT-11 is shown in Table 4-3.

Prior to lift off, a long series of tests took place. Since these tests are typical of the preparations that occurred before a MSFN Gemini operation, a few illustrations are given below.

Table 4-3. MSFN CONFIGURATION DURING GT-11[19]

Stations \ Systems	Acq. Aid	C-Band Radar	Biomed Remoting	RF Command	S-Band Radar	Teletype	Voice
MCC-H						X	X
MCC-K	X		X			X	X
A/C							
ANT	X	X	X	X			
ASC		X					
BDA	X	X	X	X	X	X	X
CAL	X	X			X	X	X
CNV		X[a]		X	X		
CRO	X	X	X	X	X	X	X
CSQ	X		X̲	X		X	X
CTN	X					X	X
CYI	X	X	X	X	X	X	X
EGL	X	X				X	X
GBI	X	X	X	X	X		
GTK	X	X		X	X		
GYM	X				X	X	X
HAW	X	X	X	X	X	X	X
KNO	X					X	X
MIA		X					
PAT		X					
PRE		X					
RKV	X		X̲	X		X	X
WHE	X	X				X	X
TAN	X					X	X
TEX	X		X	X	X	X	X
LIMA						X	
WHS	X	X				X	X
WOM	X	X				X	X

[a]Wind profile measurements in support of recovery operations

Ship Positions:
CSQ: 125°E20°N
RKV: 39°W19°S
WHE: 175°W25°N

X̲ Post-pass biomedical remoting

[19]Adapted from "Network Performance Analysis for the Gemini GTA-11 Mission," Goddard Space Flight Center, X-552-66-590, Dec. 29, 1966.

F Minus 8 day	Skin tracking of Agena target vehicles. Detail systems tests at all stations. Bermuda high-speed data interface test.
F Minus 7 day	More skin tracking and detail systems tests.
F Minus 6 day	More skin tracking. CADFISS tests begin. ANT fails radar-slew CADFISS tests.
F Minus 5 day	More skin tracking tests. Final Flight Simulation Flight test at MCC-H and MCC-K.
F Minus 4 day	Network Simulation at CRO, CSQ, CYI, HAW, ASC, MCC-K, MCC-H and TEX.
F Minus 3 day	More skin tracking tests on Agena targets.
F Minus 2 day	Computation and Data Flow Integrated Subsystems Tests. More CADFISS tests.
F Minus 1 day	More skin tracking. Air/ground remoting test. Launch rescheduled for Sept. 10, 1966.
F Minus 0 day	GT-11 rescheduled for Sept. 12, 1966.
F Minus 0 day (Sept. 12,1966)	GT-11 launched. MSFN GREEN. CADFISS tests.
F plus 1 day	More CADFISS tests, with minor problems showing up at ASC and GBI.

CADFISS tests continued through F plus 4 day. The following table (Table 4-4) illustrates some of the postlaunch problems encountered during GT-11. In general, the minor failures recorded were typical of those encountered during Gemini. Note the speed with which each trouble was repaired. At no time did these failures compromise MSFN effectiveness.

Table 4-4. MSFN STATION STATUS DURING GT-11[20]

Station	Status
CNV	The Impact Predictor computer was reported RED at 1240 GMT, September 15. It was reported GREEN at 1320 GMT the same day.
PAT	All systems were reported GREEN.
MIA	The radar was reported RED due to water cooling problems at 1359 GMT, September 14. It was reported GREEN at 1430 GMT the same day.
MCC-K	The Teltrac acquisition aid was reported RED due to a frozen spinner motor at 1405 GMT, September 14. This item could support the mission even though it remained RED.
GBI	Command antenna No. 2 was reported RED at 1812 GMT, September 13. It was GREEN at 2109 GMT the same day.
	The radar was reported RED due to power failure at 1225 GMT, September 14. Power was restored and reported GREEN at 1234 GMT the same day.
	The TPQ-18 radar was reported RED for azimuth channel errors at 1056 GMT, September 15. It was reported GREEN at 1102 GMT the same day.
GTK	The command antenna was reported RED at 1444 GMT, September 12. It was reported GREEN at 1610 GMT the same day.
ANT	The radar was reported RED at 1458 GMT, September 14, because it was locked in azimuth and elevation. It was reported GREEN at 1525 GMT the same day.
ASC	All systems were reported GREEN.
PRE	All systems were reported GREEN.

[20]Adapted from "Network Performance Analysis for the Gemini GTA-11 Mission," Goddard Space Flight Center, X-552-66-590, Dec. 29, 1966.

Table 4-4 (continued)

BDA	The FPS-16 radar was reported RED at 0620 GMT, September 14. It was reported GREEN at 0818 GMT the same day.
	Acquisition Aid No. 2 was reported RED due to azimuth preamp failure at 0848 GMT, September 14. It was reported GREEN at 0943 GMT the same day.
	The FPS-16 radar was reported RED due to faulty digital data output at 1208 GMT, September 14. It was reported GREEN at 1301 GMT the same day.
	The FPS-16 radar was reported RED due to a defective data transmitter at 1437 GMT, September 15. It was reported GREEN on September 16.
CYI	All systems were reported GREEN.
KNO	All systems were reported GREEN.
TAN	All systems were reported GREEN.
CRO	UHF air/ground communications were reported RED due to a faulty preamplifier at 0820 GMT, September 13. It was reported GREEN at 1018 GMT the same day.
	The Verlort radar was reported RED due to faulty ranging at 0913 GMT, September 13. It was reported GREEN at 0934 GMT the same day.
WOM	All systems were reported GREEN.
CTN	All systems were reported GREEN.
HAW	The RSDP was reported RED due to a defective 1259 TTY adapter at 1119 GMT, September 15. It was reported GREEN at 1302 GMT the same day.
CAL	The FPS-16 radar was reported RED due to auto-lock problems at 1158 GMT, September 15. It was reported GREEN at 1200 GMT the same day.

Table 4-4 (continued)

GYM	The Verlort radar was reported RED due to elevation drive problems at 1658 GMT, September 12. It was reported GREEN at 1720 GMT the same day. Air/ground communications were reported RED due to amplifier problems at 1741 GMT, September 12. They were reported GREEN at 1937 GMT the same day. The acquisition aid was reported RED due to a defective preamplifier at 1106 GMT, September 16. It was reported GREEN at 1112 GMT the same day.
WHS	All systems were reported GREEN.
TEX	Command transmitter No. 2 was reported RED at 1856 GMT, September 12. It was reported GREEN at 2200 GMT, September 13. RF command was reported RED due to a faulty transmitter at 0800 GMT, September 15. It was reported GREEN at 1008 GMT the same day. The Verlort radar was reported RED due to a defective magnetron at 1820 GMT, September 15. It was reported GREEN at 1820 GMT the same day. RF command was reported RED due to a faulty transmitter at 1820 GMT, September 15. It was reported GREEN at 1915 GMT the same day.
EGL	All systems were reported GREEN.
RKV	All systems were reported GREEN.
CSQ	All systems were reported GREEN.
WHE	All systems were reported GREEN.

Chapter 5. ASSIGNMENT MOON: THE APOLLO NETWORK

The Apollo Program

The Apollo Program predates Gemini. In October 1958, shortly after the official start of the Mercury Program, NASA formed the "Goett committee," headed by Dr. Harry Goett, who would soon become the Director of the new Goddard Space Flight Center. The committee was charged with recommending a manned space flight program to follow Mercury. In May 1959, the Goett committee recommended a manned lunar landing as a logical follow-on. The giant Apollo Program grew from these small beginnings.

At first, Apollo, as the Mercury/Gemini follow-on program was soon named, was conceived only as an intermediate step toward the future goals of landing men on the Moon and ultimately the planets. According to early thinking in the Apollo Program, there would first be orbital flights around the Earth, followed by circumnavigation of the Moon, *but no landing*. The Apollo spacecraft would return to Earth orbit where it would do double service as an orbiting laboratory.[1] Apollo was a "far-out" program; the main preoccupation in 1959 was getting a U.S. astronaut into space aboard a Mercury capsule.

The rather leisurely pace of Apollo was accelerated rapidly when, on May 25, 1961, President Kennedy proposed that the United States should try to land a man on the Moon within the decade. Thus, Apollo was redirected and became the major U.S. space program rather than a somewhat vague follow-on to Mercury and Gemini.

Beginning of the Apollo Network

New Network Requirements. The Apollo mission was obviously much more than just an extension of Mercury and Gemini. The *new* mission phases included:

1. Insertion of the spacecraft into a lunar transfer orbit from its Earth parking orbit
2. Transit from Earth orbit to the vicinity of the Moon with midcourse correction(s)

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[1]George M. Low, statement before the Committee on Aeronautical and Space Sciences, February 28, 1961, in NASA Scientific and Technical Programs (Washington; GPO, 1961), p. 152.

3. Insertion of the spacecraft into lunar orbit
4. Lunar orbiting and adjustment of the orbit as required
5. Descent to the lunar surface
6. Data acquisition from the landed spacecraft and mobile astronauts
7. Ascent from the lunar surface and rendezvous in lunar orbit[2]
8. Insertion of the spacecraft into an Earth transfer orbit from lunar orbit
9. Return to Earth with midcourse correction(s)
10. Reentry of the Earth's atmosphere within a narrow corridor at speeds much higher than those encountered during the Mercury and Gemini programs
11. Long-term data acquisition from scientific experiments left behind on the Moon.

It was apparent long before President Kennedy's redirection of Apollo that the Mercury and Gemini Networks, though suitable for operations in Earth orbit, could not be stretched to cover the trip to the Moon and the critical phases of the mission occurring there. The Space Task Group (STG), which was managing the Mercury Program at Langley established an Apollo Technical Liaison Group for Instrumentation and Tracking in 1960 specifically to work out the problems of tracking, commanding, and communicating with a manned lunar spacecraft. The first meeting of this key group was held at Langley on January 6, 1961. Goddard Space Flight Center and the Manned Spacecraft Center were not represented at this first meeting because the MSFN had not yet been assigned to Goddard and MSC. However, the Jet Propulsion Laboratory (JPL) was represented by Eberhardt Rechtin, indicating that NASA was already considering the use of JPL's experience in and facilities for deep space tracking and data acquisition.[3] There was, in fact, a strong tendency at this early meeting to think in terms of a near-Earth network based on the Mercury and Gemini Networks and a separate, but coordinated, lunar network for the lunar phases of the Apollo mission.

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[2]The critical and controversial decision to rendezvous in lunar orbit rather than Earth orbit was announced by NASA Administrator James E. Webb at a press conference on July 11, 1962. Early tracking studies were usually based on the assumption that rendezvous would be in Earth orbit rather than in lunar orbit where it would be much harder to resolve two small radio targets.

[3]F.M. Flanagan, P.S. Goodwin, and N.A. Renzetti, "Deep Space Network Support of the Manned Space Flight Network for Apollo" (Pasadena: JPL TM 33-452, Vol. I, 1970).

This division of the tracking chore, primarily arising from technical facts of life, obviously posed important questions for program managers as well as the engineers who might have to insure the compatibility of radically different tracking and data acquisition techniques.

The technical facts of life were these: the radars of the Mercury and Gemini Networks obviously could not track two spacecraft orbiting the Moon a quarter-million miles away: neither could the small MSFN telemetry antennas hope to pick out the telemetry and voice messages in the weak signals arriving from the vicinity of the Moon. Translated into network hardware terms, Apollo would require at least the following changes in the MSFN:

1. A range and range rate tracking system, such as GRARR (Chap. 2) or the JPL range and range rate system, would have to be incorporated to accurately track the distant spacecraft while it was out of radar range.
2. Large dish antennas with high gains, such as the 26-m paraboloids employed in STADAN and the DSN, would have to be added to the MSFN to track and communicate at lunar distances.
3. Extant MSFN stations could not properly monitor the very critical mission phases when the spacecraft was inserted into its lunar trajectory and when it plunged into the narrow reentry corridor on the return trip. The result was that the MSFN had to be extended with ships, aircraft, and additional land sites.
4. Small paraboloidal antennas would have to be added at some MSFN sites to communicate with the Apollo spacecraft while it was still below the horizon for the 26-m dishes (below about 16,000 km) but beyond the range of the Gemini telemetry antennas.
5. The communication traffic during the Apollo missions would be several times that planned for Gemini. NASCOM lines would have to be augmented.

Early Apollo Network Studies. 1961 and 1962 were years devoted to broad technical studies that "scoped" the Apollo Network; that is, the major technical decisions were made during this period. It was a time of turmoil because the Apollo mission was still not completely defined. Earth orbital rendezvous was still the most likely way to go,[4] and

[4]Typical of these very early studies was one authored by Robert D. Briskman entitled "Ground Instrumentation Study," and dated August 3, 1961. Based on Earth orbital rendezvous, the study described the need for four "chaser vehicles" in low parking orbits to obtain complete telemetry coverage. It is interesting to note, however, that the actual Apollo missions did use communication satellites to improve communications.

there was talk of developing the huge Nova booster for launching the Apollo spacecraft. The basic organization of NASA was still in a state of flux. Goddard Space Flight Center was being formed primarily from Langley and Naval Research Laboratory personnel, and STG was moving to Houston to create a nucleus for the Manned Spacecraft Center. Nevertheless, NASA had been challenged with the Apollo mission and there had to be a network to support it.

To map out definitive plans for the Apollo Network, Edmond C. Buckley, Director, Headquarters Office of Tracking and Data Acquisition, established an Apollo Task Group in 1962. The leader of this group was Gerald M. Truszynski. Some other Task Force members were:

Headquarters	Goddard	JPL
R. D. Briskman	J. T. Mengel	W. Victor
	D. W. Call	L. Randolph
	F. O. Vonbun	
	E.J. Habib	

Apollo Network studies began at Goddard early in 1962 in the Tracking and Data Systems Directorate of John T. Mengel. By summer, a rough picture of the network had emerged.[5] By fall, a more refined picture was available.[6] These definition studies at Goddard were carried out subject to the following constraints:

1. The Apollo ground support network should place no restrictions on the planned missions; i.e., the network should not compromise the mission
2. Maximum utilization should be made of the existing MSFN
3. The augmentation of the MSFN for Apollo should not interfere with Gemini or other programs
4. The network should be tested and evaluated under operational field conditions prior to actual Apollo flights
5. New equipment must be backstopped with proven equipment until it proves itself. For example, C-Band radar and UHF communications were used until the Apollo

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[5]J. T. Mengel, F.O. Vonbun, and W.P. Varson, "An Integrated NASA Tracking Network for Apollo," NASA GSFC X-520-62-134, August 23, 1962.

[6]Goddard Space Flight Center, Tracking and Data Systems Directorate,"A Ground Instrumentation Support Plan for the Near-Earth Phases of Apollo Missions," NASA GSFC X-520-62-211, November 23, 1962.

AS-204 flight after which the USB was considered proven.[7]

The early Goddard studies are fascinating to read in the light of today's MSFN. First, it was obvious that the MSFN radars would have to be used for Earth-orbital support. They were well placed to follow the Apollo capsule during the vital parking orbits (similar to the Mercury and Gemini orbits) while the spacecraft was being checked out prior to its insertion into a lunar trajectory. The mission and national economy both dictated that the Apollo Network would have to be built around the Gemini Network radar station core. Thus, the Apollo Network would not be built from scratch.[8] The augmentation of the Gemini Network with range and range rate equipment (either JPL's or Goddard's) and the application of big antennas for portions of the mission far from Earth were technical facts accepted early in the Goddard studies. Also in the air during those days--like "a ripe plum," as Vonbun has put it--was the integration of all communication and tracking signals into a single conceptual framework based on: (1) digital coding (PCM) for most signals; (2) conversion of all transmissions to higher frequencies (the S-band specifically); and (3) the use of one ground antenna for all transmission and reception. More will be said about the Unified S-Band (or USB) approach shortly, but it is interesting to note that it was not a concept created for Apollo; rather it was an idea already being explored by others. JPL had already pioneered the concept at L-band as well as S-band frequencies. Thus, it seems as if the major technical features of the Apollo Network were almost unavoidable; in other words, there were good technical solutions already at hand.

Two Crucial Decisions

Two of the most important decisions made during the evolution of the Apollo Network involved JPL. These were the decision to employ the so-called Unified S-Band (USB) concept of communication and tracking, to which JPL scientists and engineers had contributed much, and the decision to capitalize on JPL expertise and extant JPL tracking facilities. The two actions were not unrelated. Perhaps it goes too far

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[7]The first four constraints were stipulated in Goddard's report X-520-62-211, while the fifth was obtained from Ozro M. Covington during a personal interview on April 10, 1969.

[8] There was no absolute requirement that the Apollo Network be built around the Gemini Network, just that extant MSFN equipment should be employed where feasible. Personal interview with Friedrich Vonbun, March 12, 1969.

to say that JPL involvement was dependent upon adoption of its USB ideas or that the USB concept would have been impossible to implement in time without JPL involvement; but technically and politically, there is some truth in each statement.

Adoption of the USB for the Apollo Network. Today, few people question that the adoption of the USB was a great step forward for the Apollo Network. In the early 1960s, however, it was "an uphill fight" against the conservative view of "Why try something new?"[9]

Much more will be said about USB technology later. For the moment, it is enough to know that the USB represented a major advance in spacecraft technology. Signals for tracking, telemetry, voice, television, and command were integrated into a single radio carrier. In a single stroke, the many various separate transmitters, receivers, and antennas of Mercury and Gemini were consolidated. USB meant economy and simplicity on the spacecraft and on the ground.

The USB concept consisted of four technical elements --each with its own alternatives, champions, and/or rationales. We must know these elements to understand the history of Apollo USB.

1. Unification of carriers. There was little debate about the ultimate desirability of the "U" in USB. Mercury and Gemini had relied upon many carriers--too many from the standpoints of spacecraft weight and simplicity. But Mercury and Gemini techniques were successful. Again that old question cropped up: "Why change to something new?" Yet, the change to unified systems had already been accomplished within the DSN by JPL in the early 1960s. Channel unification was a relatively new concept but the advantages far outweighed the risks. NASA developed the USB system concept during 1962 and 1963. Meanwhile (1963 and 1964), DOD moved ahead with its SGLS system, which was essentially a USB system. During these nearly parallel development programs, NASA and the Air Force were discussing the situation at meetings of the Plans Subpanel of the Space Flight Ground Environment Panel of the AACB. Late in 1964, DOD proposed that the USB and the SGLS be made compatible; and they were to a large extent.[9a]

[9] Interview with Robert Briskman, July 7, 1971.

[9a] The USB and SGLS are both coherent S-band systems with similar (but not identical) ranging codes. Both use phase modulation. Both NASA and the Air Force use the same frequencies and can receive each other's transmissions. However, the Air Force, which requires "secure" communications, has special subcarriers which NASA does not.

2. The move to the S-band. The desirability of going to the higher frequency S-band (around 2000 MHz) provoked little argument either, especially in view of the fact that the VHF band was crowded and the FCC wanted to see space communications move to higher frequencies. JPL was going to the S-band on its Mariner and Surveyor programs because of the better signal-to-noise ratios. Furthermore, only above 1000 MHz was there sufficient room in the spectrum to use subcarriers on a single carrier for all information. In this sense, the "U" and the "SB" are inseparable.
3. The phase-lock loop. This concept of electronically "locking" a transmitter and receiver together via a coherent radio signal had been under development at JPL during the 1950s for its missile and deep space work.[10] Eberhardt Rechtin, Robert Jaffe, and Walter Victor, all at JPL, helped bring this fairly old idea to practical fruition.[11] Although there had been much controversy in the 1950s about the basic workability of the phase-lock concept, the JPL group soon applied it to Army missiles and the Microlock satellite tracking network. (Chapter 2)
4. Inherent but not essential to the JPL USB approach was pseudorandom noise ranging. Some opposition developed to this concept; first, because it is rather esoteric and hard to understand, and, second, because Goddard engineers wanted to see their concept of sidetone ranging (part of the GRARR idea) introduced into the Apollo USB system.

The swing to USB by NASA gathered most of its momentum at Houston, where a decision had been made by Joseph F. Shea, Deputy Director of Manned Space Flight for Systems, that the Apollo spacecraft should have an S-band transponder. This decision forced other decisions-domino-like--in the direction of USB.[12] During 1962 North American Aviation, which was designing the spacecraft for Houston, and Bellcomm, a consulting firm on Apollo, had recommended this step. A communication modulation study group headed by Lorne Robinson at North American was already adapting Surveyor S-band

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[10]R.C. Tausworthe, "Theory and Practical Design of Phase-Locked Receivers" (Pasadena: JPL TR-32-819, 1966).

[11]R.M. Jaffe and E. Rechtin, "Design and Performance of Phase-Lock Circuits Capable of Near Optimum Performance Over a Wide Range of Input Signals and Noise Levels, *IRE Transactions on Information Theory*, Vol. IT-1 (March 1955) pp. 66-76.

[12]Interview with Walter Victor, March 23, 1971.

technology for the Apollo spacecraft.[13] In this way, Houston, working with North American, decided that spacecraft communications should utilize the USB concept based on performance, low weight, and simplicity. The Apollo Network was forced to follow the lead of the spacecraft. It was not a reluctant step, however, for OTDA, Goddard, and JPL all recognized the advantages to be gained. In fact, it was Walter Victor, acting as a JPL "consultant," who helped swing many Houston engineers in the USB direction.

More controversial was the selection of JPL's pseudorandom noise concept for the Apollo USB. Goddard was developing sidetone ranging for tracking its geostationary and highly elliptical satellites and would have liked to see its ideas adopted in the USB. The GSFC/JPL interface was rather sensitive because both coveted the assignment of scientific missions into lunar and deep space. No serious confrontation occurred, however, because in early 1963 the subject was argued out at NASA Headquarters under an "OTDA umbrella."[14] In the end, Goddard went along with the JPL pseudorandom noise approach. The most obvious reason why the JPL scheme was favored over that of Goddard was that it was the better proven system in 1962. Either approach would doubtless have worked. However, separate from the technical arguments was NASA's desire to bring JPL's talents and facilities into the Apollo program. If JPL's facilities, which already used the pseudorandom noise technique, were to be useful in Apollo, Apollo equipment (including the MSFN) would have to be compatible with JPL's Deep Space Network.

<u>The Involvement of JPL</u>. JPL's official role in the Apollo Program began when it was invited by NASA to become a member of the Apollo Technical Liaison Group. For roughly two years, JPL acted as a consultant. Eberhardt Rechtin and Walter Victor were JPL's primary contacts with Apollo during this period. In addition to the consultative role (with Houston, in particular), JPL kept the Apollo Program informed about the rapidly developing Deep Space Network (DSN), because it was already tacitly assumed by many that JPL and its DSN would be used in Apollo. For example, in May 1961 Robert M. Gilruth requested that JPL supply a DSN information package for an August 1, 1961, Apollo bidders' conference. Despite these activities, JPL remained on the fringes of the Apollo effort until early 1963. In fact, there was

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[13]Lorne Robinson, "Interim Report, Apollo Modulation Technique Study, Cislunar Communications" (Downey: July 1962). Robinson moved to OTDA, NASA Headquarters, in 1963.

[14]Interview with Ozro M. Covington, April 10, 1967.

considerable reluctance at JPL to become involved any further. JPL was already heavily committed to scientific programs, such as Ranger and Mariner. Many JPL personnel did not want to get swept into the immense Apollo "engineering" effort.

Nevertheless, JPL's background in space telecommunications and tracking was unparalleled inside or outside NASA. It also had the equipment and foreign sites. Houston forced the issue in October 1962, when Walter C. Williams, Associate Director of the new Manned Spacecraft Center, dispatched a memo to Edmond C. Buckley, Director of OTDA (also a new organization), emphasizing the expanded requirements of Apollo and stating that:

> The MSC desires to make use of the facilities of Jet Propulsion Laboratories, both current and planned, to assist in meeting these requirements...[15]

OTDA then requested "JPL assistance in the planning and implementation of ground instrumentation for the lunar missions of the Apollo program."[16] JPL now had to decide how deeply it would get involved in Apollo.

The initial JPL reluctance to become heavily involved in Apollo stemmed from several sources:

1. JPL wished to maintain a scientific image
2. The people working on unmanned spacecraft projects feared that they might be "squeezed out" by a huge manned program.
3. JPL and its facilities were already heavily committed
4. There was genuine doubt at JPL that a manned lunar landing was feasible within the Apollo time frame.

Eberhardt Rechtin spoke out strongly for a larger JPL role in Apollo. "Apollo would be important," he reasoned, "It was a national effort and JPL could make important contributions." NASA had already negotiated for the use of land in foreign countries for DSN sites and Apollo could move right in. JPL could "assist" Apollo with "backup" stations. In the end, Rechtin's view won the day, and JPL became an important part of Apollo tracking and data acquisition. Subse-

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[15]Memo from Walter C. Williams to Edmond C. Buckley, October 3, 1962.

[16]Letter from Edmond C. Buckley to William H. Pickering, October 31, 1962.

quently, JPL was identified as a major element in Apollo in the "Management Plan for the Manned Space Flight Network" approved by Associate Administrator Robert C. Seamans, Jr., on March 11, 1963.

To formalize JPL's role further, Eberhardt Rechtin sent a preliminary Memorandum of Understanding to Edmond C. Buckley on March 21, 1963.[17] William H. Pickering, Director of JPL, transmitted the final Memorandum of Understanding to Buckley with a cover letter dated May 1, 1963. The Memorandum is reproduced in its entirety in Appendix B. It clearly defines the extent to which JPL management was willing to participate in the Apollo effort. In general the effort requested of JPL by OTDA consisted of:[18]

1. Systems design and engineering for the Unified S-Band ground system to be used in support of Project Apollo
2. Procurement, delivery, and qualification of Unified S-Band systems as required by station implementation plans
3. Operation of the deep space network as part of the Manned Space Flight Network during test, training, and flight missions
4. Engineering assistance in the area of transponder compatibility.

When JPL assumed a more active part in the Apollo MSFN work, the interface between JPL and Goddard became more important--in fact, a harmonious interface was critical to MSFN success. As pointed out earlier, both organizations competed for unmanned space missions. It was natural that there was some apprehension at both centers. Goddard did not want JPL telling it how to track spacecraft, and JPL did not want Goddard installing equipment at their DSN sites and controlling their big antennas. OTDA top management was very effective in bridging this critical interface.[19] More important at the working level was a meeting at JPL between Eberhardt Rechtin and Walter Victor, both from JPL, and John Mengel and Ozro Covington, from Goddard. The thrust of this famous meeting was, "Let's get the job done and ignore intercenter politics." With these formal and informal agreements, the Apollo Network began to take shape.

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[17]The preliminary document was dated March 19, 1963.

[18]Letter to W.H. Pickering from Edmond C. Buckley, June 26, 1963.

[19]Interview with Eberhardt Rechtin, May 20, 1971.

How the Network Evolved

Houston Sets the Requirements. Apollo Network requirements varied as the program moved from unmanned flight tests, through the first manned lunar landing, to the later lunar rover missions with their higher scientific contents. Of course, the Apollo Network had to evolve right along with the missions. As the Apollo program drew to a close, there was intense pressure for economy. At this point, it is practical to describe only the very general requirements levied by Houston on the MSFN relatively early in the program. Even these sketchy descriptions are so bulky that they have been consigned to Appendix C. Taken from a 1964 Program Instrumentation Requirements Document published by Houston, these requirements represent a distillation of considerable discussion and negotiation between NASA Headquarters, Houston, Goddard, JPL, and Marshall Space Flight Center. Each specific mission was preceded by much more detailed support requirements and by the MSFN's response, issued as a Mission Support Plan. For the operators at the NASA and DOD sites, there was, of course, the Network Operations Directive and a Mission Supplement issued prior to each flight. At the moment, though, the general requirements specified in Appendix C will suffice, for they reveal the major evolutionary pressures on the MSFN. Important changes in requirements will be covered later in this chapter when actual mission operations are discussed. Meanwhile, for the general reader who does not wish to read through Appendix C, the sheer magnitude of the Apollo tracking and data acquisition task is apparent in the following quotation from a paper of Howard C. Kyle:[20]

> The requirements for Apollo communications have been derived in some measure from Mercury and Gemini experience, and also from experience with unmanned lunar and planetary probes. Basically, there will be voice, telemetry, tracking, and up data. It became obvious quite early in the planning that none of the systems used in these earlier programs would adequately support Apollo. The requirements soon developed for a high-data-rate telemetry system, a precision trajectory measuring system, a voice system, and a real-time, moderately high-resolution television system. To these were later added (as the mission planning evolved) a telemetry and voice record and

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[20] H. C. Kyle, "Manned Spaceflight Communications Requirements," *Advances in Communication Systems*, Vol. II, (New York, 1966), p. 211.

playback system, a high-capacity up-data link system, and additional channels of biomedical and scientific data. During certain critical phases, almost the entire capability is desired simultaneously.

General Philosophy Employed in Network Design and Operation. A machine as large and as complex as the Apollo Network cannot be built without some general guidelines or "design philosophy," to use the language of the engineers. The overriding factor controlling MSFN technical development and operation has always been reliability: The Network had to be GREEN during a manned flight or the lives of the astronauts might be compromised. To this end, MSFN designers evolved the following elements of design philosophy:

1. Maximum use should be made of instrumentation systems already proven in the Mercury and Gemini programs and in NASA's unmanned satellite and deep space programs. (Primarily the radars and JPL equipment)
2. Redundancy should be provided by backing up critical systems and routing alternate communications circuits to each station. (In practice this meant reducing the "single points of failure" to the 9-m antennas employed in Earth orbital coverage but not the 26-m antennas for lunar coverage).
3. Stations should be placed to guarantee coverage during critical mission periods, including potential deviations from nominal missions. (In the early phases of Apollo, the Network had to cover greater areas than during later missions because engineers did not know just how punctual Saturn launches would be or how accurate reentry trajectories would be.)
4. The Network should be kept in a reliable state of readiness through continued testing, operational simulations, and practice with unmanned spacecraft.

Early Evolution of the Network Configuration. The MSFN has never been a static construction. Not only does it respond to changing requirements, but network engineers work continuously to make it more effective and cheaper to operate. When stations are no longer needed, they are dropped from the network. The general pattern followed in the Apollo Program was: (1) a buildup to maximum network coverage that would accommodate the maximum expected deviations from launch vehicle and spacecraft operations; and (2) a paring back of stations and coverage as actual flights demonstrated that launches and spacecraft operations could indeed be carried out with great precision. In this section, only the early buildup to maximum size for the first manned flights to the Moon will be described. The streamlining of the network during later flights will be covered in the section on actual network operations.

Appendix C illustrates clearly that Apollo was an order of magnitude more complex than Mercury and Gemini. Well before Goddard received the first Program Instrumentation Requirements Document (PIRD) from Houston on April 23, 1963, network engineers were studying different configurations of stations to cover the first Saturn tests, the unmanned and manned Earth orbital flights, and the later trips to the Moon.[21] Several combinations of existing and planned stations appeared promising. For example, the Goddard study of August 23, 1962, suggested that the JPL and Goddard large antenna sites be utilized cooperatively for the far-from-Earth phases of the mission. (Fig. 5-1). To wit:

Proposed Site	Proposed Antenna(s)	Remarks
Fairbanks, Alaska	26-m	STADAN site
Rosman, N.C.	26-m	STADAN site
Orroral, Australia	26-m	STADAN site
Quito, Ecuador	12-m	STADAN site
Santiago, Chili	12-m	STADAN site
Johannesburg, R.S.A.	12-m	STADAN site
Goldstone, Calif.	26-m, 64-m	DSN site
Eastern Australia	26-m, 64-m	DSN planned site
Johannesburg, R.S.A.	26-m	DSN site
Southern Europe[22]	26-m, 64-m	DSN, planned site

Suggested for the near-Earth mission phases were the MSFN stations already in being at Bermuda, Carnarvon, Kauai, Guaymas, and Cape Canaveral, and three ships in the Atlantic, Pacific, and Indian Oceans.

Except for the MSFN core of radar sites, the first delineation of Apollo Network sites bore little resemblance to the Apollo Network of 1971. By the fall of 1962, the decision had been made to divorce STADAN from the Apollo net-

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[21]Three important requirements documents subsequent to the formal PIRD were: (1) Letter from Walter C. Williams to G.M. Low, dated September 6, 1963, Subject: "Preliminary Information on the Program Instrumentation Requirement for the Saturn/Apollo S-1, S-1B and S-5 Program," (2) Engineering Instrumentation Requirements Document (EIRD) for Saturn I Block II missions, November 15, 1963, (3) Engineering Instrumentation Requirements Document (EIRD) for Saturn V missions, February 6, 1964.

[22]Izmir, Turkey, was under consideration at this time.

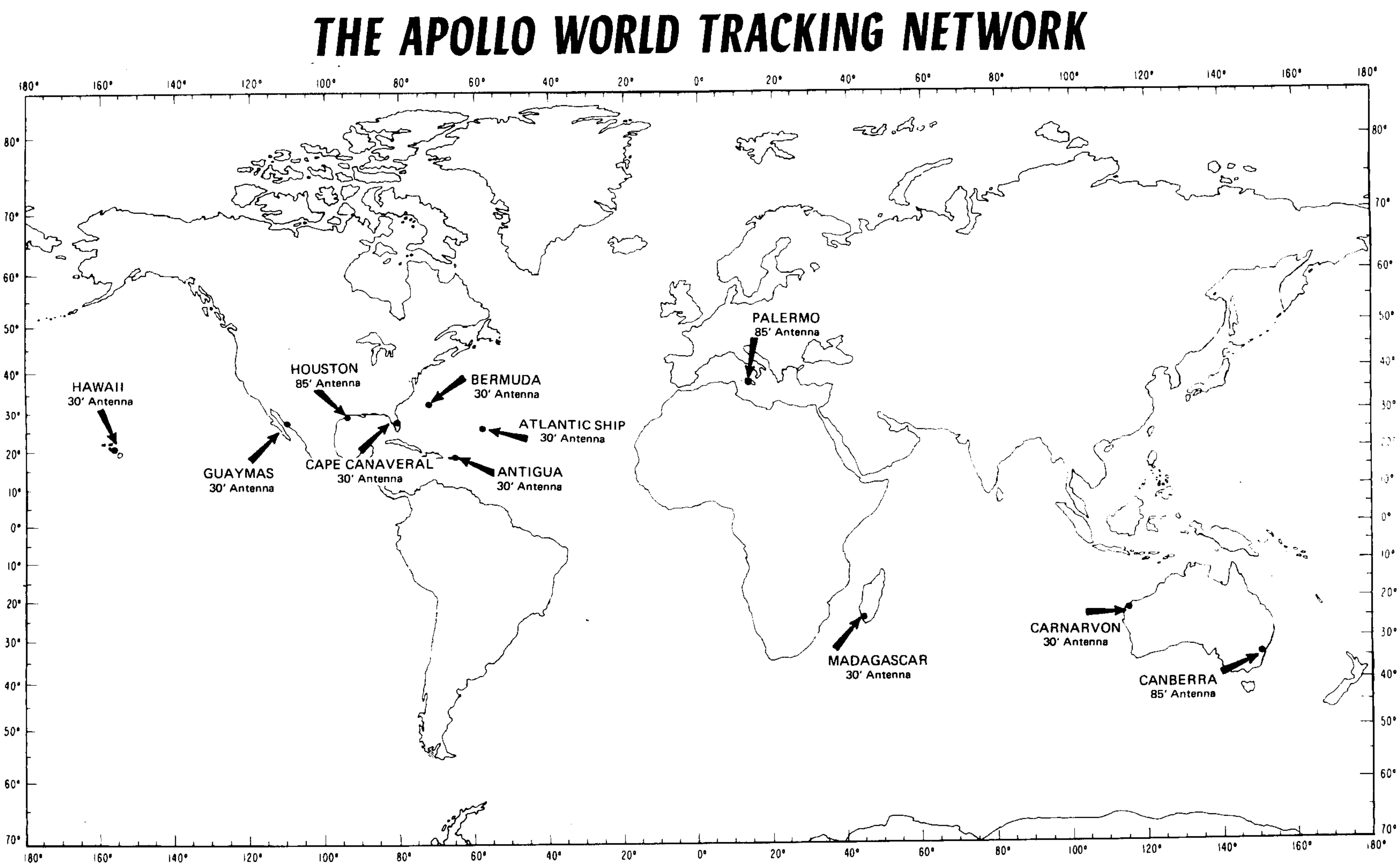

Figure 5-1. The Apollo Network as visualized in 1962.

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work completely.[23] STADAN would be fully occupied with the many forthcoming scientific and applications satellites; and, in addition, operations during periodic manned missions are distinctly different from those included in tracking and acquiring data from a steady parade of unmanned spacecraft.

The Goddard report of November 23, 1962, was more thorough and in greater depth. The basic technical solutions had not changed. The Unified S-Band (USB) System was made the official name of the integrated tracking and communication scheme in this report. The proposed site locations, however, had changed a great deal. The 12-m STADAN antennas had been replaced by new 9-m USB antennas generally located at selected extant MSFN sites. (Table 5-1) Five ships, but no aircraft, were considered necessary for adequate coverage. In these aspects, the network configuration began to look more like its final version at the time of Apollo 11.

The large antenna facilities contemplated at Houston, Canberra, and Palermo seem out of place though. In theory, three large antennas (26-m dishes or bigger) are sufficient for lunar tracking and communication if they are spaced approximately 120° apart in longitude. JPL was planning such a site in Southern Europe; and, in late 1962, Palermo, Italy, was the choice. With the Apollo Integrated Mission Control Center planned for Houston, it also seemed reasonable--technically and politically--to locate a big dish nearby. (Fig. 5-2) Of course, 26-m antennas were never installed at Houston or Palermo for reasons which will be explained presently.

It is pertinent now to present a distillation of Goddard thinking about the character and expected evolution of the Apollo Network as it existed in late 1962 after the Apollo Task Group studies:[24]

1. Step one: Augmentation of the present Mercury network to provide PCM telemetry and digital command for Gemini. This augmentation is now in process at eight of the seventeen Mercury stations and should be completed by mid-1963. Later augmentation will add the on-site data processors and high-speed data transmission circuits.

[23] STADAN and the MSFN are to be merged into a single network beginning in the mid-1970's.

[24] Goddard Space Flight Center, "A Ground Instrumentation Support Plan for the Near-Earth Phases of Apollo Missions," Goddard Rpt. X-520-62-211, Nov. 23, 1962.

Table 5-1. EARLY PLANNING OF THE APOLLO NETWORK[25]

Prime Stations	Mercury Support	Gemini Support	Early Earth Orbital Apollo Mission[a]	Late Earth Orbital Apollo Mission[b]	Lunar Apollo Missions[c]
Cape Canaveral	x	x	x	x	x
Bermuda	x	x	x	x	x
Canary Islands	x	x	x		
Kano, Nigeria	x	x			
Zanzibar	x	x			
Indian Ocean Ship	x	x			
Muchea, Australia	x	x			
Woomera, Australia	x	x			
Canton Island	x	x			
Hawaii	x	x	x	x	x
Point Arguello	x	x			
Guaymas, Mexico	x	x	x	x	x
White Sands, N. Mex.	x	x	x		
Corpus Christi, Tex.	x				
Eglin A.F.B.	x				
Mercury Ship, Pac. Ocean	x	x	x		
Carnarvon		x	x	x	x
Madagascar				x	x
Apollo Ship #1, Atl. Ocean				x	x
Apollo Ship #2, Ind. Ocean					x
Apollo Ship #3, Ind. Ocean					x
Apollo Ship #4, Pac. Ocean					x
Apollo Ship #5, Pac. Ocean					x
Antigua					x
Large Antenna Facilities:					
Houston					x
Canberra					x
Palermo					x

[a]These were then called Saturn flights SA-111 through SA-114. This network was informally called the I-B Network.

[b]These are Saturn flights SA-201 through SA-205. This network was informally called the V Network.

[c]These are Saturn flights SA-508 and following.

[25]As visualized in NASA GSFC X-520-62-211, the Goddard contribution to the Apollo Task Group study, published November 23, 1962. 9-m USB antennas were to be placed at the MSFN sites carried over from Gemini; with 26-m antennas at Houston, Canberra, and Palermo. No aircraft were contemplated at this time.

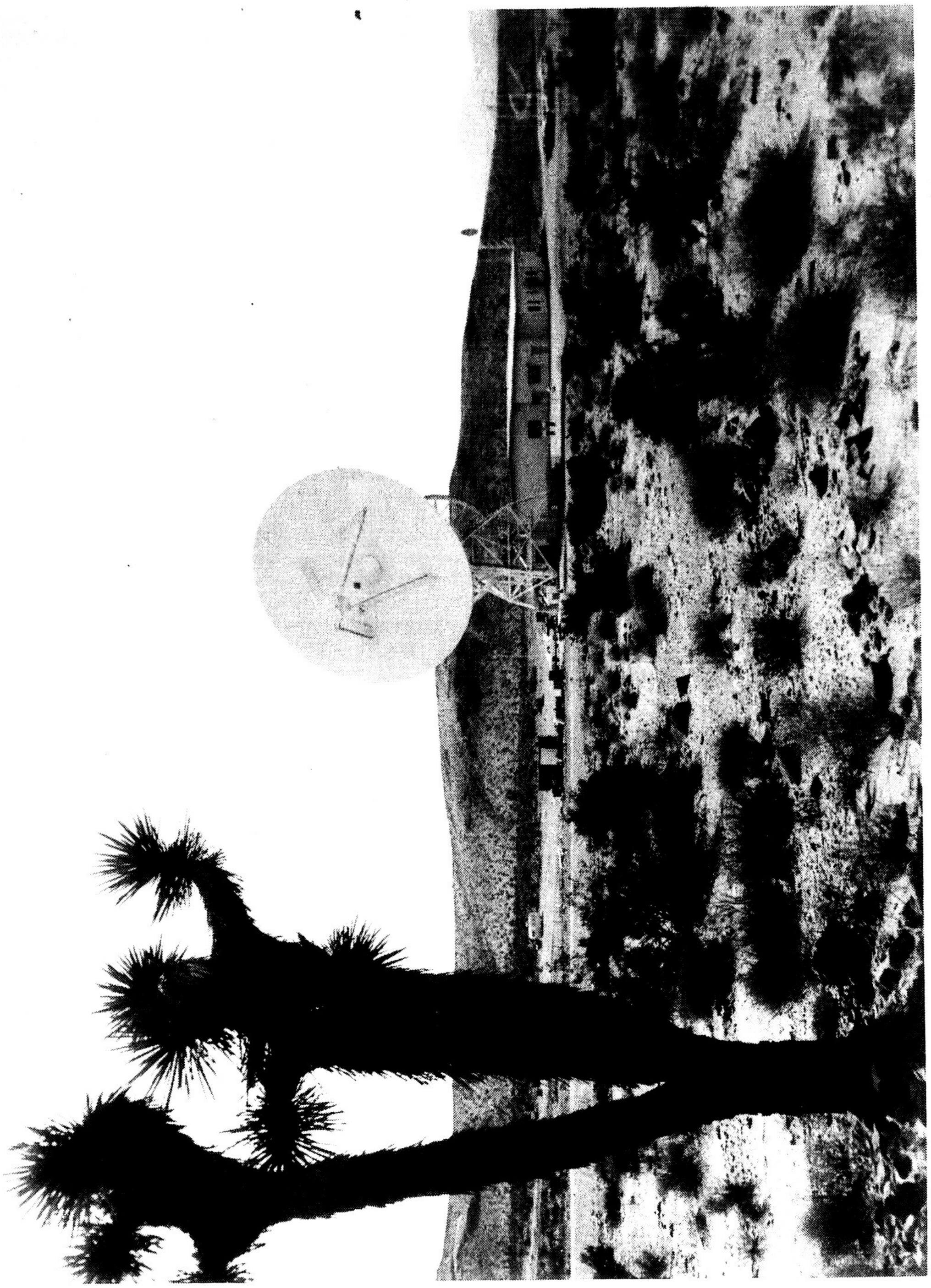

Figure 5-2. One of the 26-m dishes at Goldstone.

2. Step two: Addition of the Unified S-Band System at two stations (Bermuda and Carnarvon) and test equipment at Cape Canaveral for evaluation and qualification of this system during the early earth-orbital flights. This step, requiring completion by mid 1965, must be started by late 1963.
3. Step three: The provision of a tracking-communication-command ship east of Bermuda to support the C-1 and C-1B launches. This step, with a required availability of mid 1965, must be started not later than mid 1963.
4. Step four: Addition of the Unified S-Band System at Guaymas, Hawaii, Antigua, and Madagascar, and at the three large antenna facilities required for lunar coverage. Completion of this step, to provide coverage of all phases of the Apollo missions with the exception of complete coverage of re-entry tracking, must be accomplished by mid 1967, requiring initiation by late 1964.
5. Step five: Provision of four tracking-communication-command ships to cover re-entry tracking during a lunar return reentry. These ships will be located along the reentry path, typically two in the Indian Ocean and two in the Pacific Ocean. These ships must be operational by mid 1967, requiring procurement initiation by late 1964.

The early Goddard studies pinpointed fairly accurately sites to be used during the near-Earth phases of the Apollo mission. This is apparent from the comparison of Tables 5-1 and 5-2, which show the 1962 and 1968 "snapshots" of the MSFN. The so-called "prime" stations were little different. However, many secondary, support-role stations are shown in Table 5-2. Just as it did during the various Gemini missions, NASA pooled its own and DOD equipment to extend and augment the basic Apollo Network where necessary. (Note that some STADAN equipment finally did serve the MSFN.) Further, five ships and eight aircraft were to be employed in the 1968 "standard" version of the network. However, instead of the one insertion ship and four re-entry ships envisioned in the GSFC Nov. 23, 1962 report, the five Apollo ships consisted of three identical ships for insertion and translunar injection coverage and two ships designed specifically for re-entry coverage.

The major difference between the snapshots taken six years apart is in the location of the 26-m antennas so vital to tracking and communication during the lunar phases of the mission. The main technical requirement here was three stations separated by about 120° of longitude. With a DSN 26-m antenna already located at Goldstone, and a 9-m dish at Corpus Christi, there seemed little apparent justification for the expense of another 26-m antenna at Houston just some

29° to the east. Goddard Engineers, however, preferred the Houston site because it would have eliminated the Corpus Christi and Guaymas sites.[26] The growing need for two 26-m antennas at three sites made OTDA decide to add just one new one at Goldstone, where backup dishes were already in place.[27] The proposed Canberra station (also called Honeysuckle Creek) was retained and also collocated with a DSN site.[28] The third site had to be in the European area. Considerations involved such factors as economy of operations, accessibility, security, and last but not least, the receptivity of the foreign government involved. On January 28, 1964, the United States and Spain announced that a DSN station would be constructed about 48 km west of Madrid. To be collocated at the DSN Madrid site was the third 26-m MSFN antenna. Spain and the United States had already negotiated an agreement for a DSN site; the MSFN requirement was satisfied under the same basic agreement.

The construction of the MSFN 26-m antennas near DSN sites which each already possessed a 26-m dish conferred two advantages:

1. The DSN antenna could be used instead of the MSFN antenna in cases of equipment breakdown -- a classical example of what an engineer means by "redundancy."
2. The two antennas at each site could be used simultaneously to track and communicate with two spacecraft; a situation that would exist when the Lunar Excursion Module (LEM) separated from the Apollo spacecraft for its descent to the Moon.

Although many of the Apollo sites retained the names they received during Gemini, changes were often so extensive that they could be considered brand-new stations. Some representative "modifications":

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[26]See for example, Harry Goett's "strong" memo to Edmond C. Buckley of June 8, 1964, entitled "Locating 85-foot Antenna MSFN Station in Texas."

[27]In retrospect, the choice of Goldstone was fortunate because it turned out that its 64-m antenna was needed for Apollo TV coverage.

[28]Although some DSN and MSFN 26-m sites are termed "collocated," they are usually several miles apart. This separation helps reduce radio interference between transmitting and receiving equipment.

Table 5-2. STANDARD APOLLO CONFIGURATION OF THE MSFN AS OF 1968[29]

Prime Stations	Code	USB antennas 3.7-m	USB antennas 9-m	USB antennas 26-m	Radar	Acquisition Aid	Telemetry USB	Telemetry VHF	Command USB	Command UHF	Purpose
Antigua	ANG		x			x	x		x		Monitors S-IVB cutoff, near-space support
Ascension I.	ACN		x			x	x	x	x		Near-space support
Bermuda	BDA		x		x	x	x	x	x	x	Monitors S-IVB cutoff, near-space support
Grand Canary I.	CYI		x		x	x	x	x	x	x	Validates Cape and Bermuda orbital tracking data, near-space support
Canberra	HSK			x			x		x		Lunar support
Carnarvon	CRO		x		x	x	x	x	x	x	Nearspace support, long-range radar covers post-injection phase
Corpus Christi	TEX		x			x	x	x	x	x	Orbital support
Goldstone	GDS			x			x		x		Lunar support
Grand Bahama I.	GBM		x			x	x		x		Launch and orbital support
Guam	GWM		x			x	x	x	x		Near-space support
Guaymas	GYM		x			x	x		x		Near-space support
Hawaii (Kauai)	HAW		x		x	x	x	x	x	x	Near-space support
Madrid	MAD			x			x		x		Lunar support
Merritt I.	MIL	x			x	x	x	x			Prelaunch, launch, orbital, and near-space support
USNS *Huntsville*	HTV	x			x	x	x	x			Reentry, orbital, and/or near-space support
USNS *Mercury*	MER		x		x	x	x	x	x	x	Injection, reentry, orbital, and/or near-space support
USNS *Redstone*	RED		x		x	x	x	x	x	x	Injection, reentry, orbital, and/or near-space support
USNS *Vanguard*	VAN		x		x	x	x	x	x	x	Injection, reentry, orbital, and/or near-space support
USNS *Watertown*	WTN	x			x	x	x	x			Reentry, orbital, and/or near-space support
Aircraft (8) (Fig. 5-3)	ARIA						x	x			Injection and reentry support
MSFNOC	MSFNOC										Support during all phases

Table 5-2. STANDARD APOLLO CONFIGURATION OF THE MSFN AS OF 1968 (cont.)

		USB antennas					Telemetry		Command		
NASA Support Stations	Code	3.7m	9-m	26-m	Radar	Acquisition Aid	USB	VHF	USB	UHF	Purpose
Canberra (DSN)	CNBX			x							Lunar support
Goldstone (DSN)	GDSX			x							Lunar support
Madrid (DSN)	MADX			x							Lunar support
NTTF (GSFC)	NTTF		x			x	x	x	x	x	Test, training, and checkout
Tananarive (STADAN)	TAN				x	x					Orbital support
DOD Support Stations											
Antigua	ANT				x	x				x	Orbital support
Ascension	ASC				x	x					Orbital support
Cape Kennedy	CNV				x	x					Launch and injection support
Grand Bahama I.	GBI				x	x		x		x	Launch and injection support
Merritt I.	MLA				x	x					Launch and injection support
Patrick AFB	PAT				x						Launch and injection support
Pretoria	PRE				x						Orbital support
Vandenburg AFB	CAL				x	x					Orbital support
White Sands	WHS				x	x					Orbital support

29 Extracted from: NASA, "Manned Space Flight Network Ground Systems," Goddard MG-401, (Greenbelt: Sept. 1, 1967). See Appendix A for additional information on each site.

Figure 5-3. An Apollo Range Instrumentation Aircraft (ARIA).

Merritt Island (MIL)	MCC-K was not expanded. Instead, new facilities were opened on Merritt Island, and MCC-K was turned into a museum.
Grand Canary (CYI)	At the request of the owner of the land who feared the tracking station would detract from a resort area he was developing, the equipment was moved about 8 km to a less obtrusive location (still owned by the same person).
Hawaii (HAW)	Consideration was given to moving from Kauai to South Point (on Hawaii). Stayed at Kauai but moved Verlort radar and command antenna, added USB equipment.

One station deserving the special mention is the Network Test and Training Facility (NTTF), located at Goddard Space Flight Center. The NTTF, in essence, served roughly the same role during Apollo preparations as the old Blossom Point Minitrack station did in the early days of the space program. In addition to the testing and training functions stipulated in its title, the NTTF served as a surrogate MSFN site, where real and potential problems could be solved. To a spacecraft, the Houston Mission Control Center (MCC), and NASCOM; the NTTF "looked like" a real MSFN site. Here, problems could be simulated and worked out with the full facilities of Goddard within a stone's throw.

How did the Gemini and Apollo networks compare? First, from the standpoint of network configuration, NASA continued the trend toward better instrumented, NASA-owned "prime" stations, with support drawn as required from "secondary" NASA and DOD sites. For example, at Ascension, Antigua, and Grand Bahama, formerly exclusively DOD sites, NASA had acquired its own facilities and had upgraded them to prime status.[30] After surveys that also included Saipan and Tinian, the Guam prime site was built specifically for Apollo. And, of course, the new 26-m antenna sites were located near with DSN facilities. On the other side of the ledger, Kano and Canton Island, which had been secondary sites during Gemini, were phased out completely. The *Coastal Sentry* and *Rose Knot*, the venerable instrumentation ships from Mercury and Gemini days, were replaced by five new ships fitted with 3.7-m and 9-m USB gear as well as FPS-16 radars, although

[30]The NASA stations were equipped to provide the Unified S-Band support, whereas the DOD stations were designed for the more conventional launch vehicle telemetry and C-Band radar support. At these down range locations, DOD provided base support services such as motor pool service, mess hall service, etc.

the older ships did serve in the network on early Saturn I flights. Finally, the eight Apollo/Range Instrumentation Aircraft (ARIA) were added to the Apollo roster. All in all, the Apollo Network in its final form was one of the biggest, interconnected, synchronized machines built by man. It possessed more primary and secondary sites than the Gemini Network and was better instrumented and more highly automated.

The Apollo Ships. Instrumented ships have been an integral part of the MSFN ever since Project Mercury. The world's oceans do not contain enough islands for adequate terrestrial coverage of all phases of a manned lunar mission. In Apollo, particularly, lunar trajectory insertion and reentry constituted critical maneuvers that could be monitored best by ships and aircraft. On top of these maneuvers was the variable launch azimuth that dictated wider coverage.

The original Apollo plans called for five ships (Table 5-1). In the 1962 time frame, two of these ships were to be assigned to the Indian Ocean, two to the Pacific, and one to the Atlantic. Ships, being mobile, could be moved around with much more facility than land stations as mission plans changed. In early 1966, three insertion injection ships were contemplated, one each for the Atlantic, Pacific, and Indian Oceans; two reentry ships were to be stationed in the Pacific; making a total of five.

The insertion and injection phases of the Apollo mission had to be monitored with great precision. NASA therefore acquired three T-2 tanker hulls and converted them into highly instrumented vessels equivalent in many respects to a prime terrestrial station.[31] Each ship possessed the same C-band radar, the same 9-m USB dish, and much of the other gear common to the Apollo prime stations. (Fig. 5-4). Because of the greater uncertainty of reliable communications with the insertion injection ships, NASA also planned to install flight control consoles in them--a move counter to the general MSFN trend toward centralizing all control functions at Houston. The control consoles were never used operationally because communication reliability improved with the addition of Intelsat communication links to the ships.

The two reentry ships were acquired by major modifications to two ships from the Pacific Missile Range (PMR) fleet of instrumentation ships.

The Concept of the DSN Wing. Another critical step in the evolution of the Apollo Network came in 1965 with the advent of the DSN Wing concept. Originally, the participation of DSN 26-m antennas during an Apollo Mission was to be limited

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[31]One factor degrades the utility of an instrumented ship: its geographical coordinates are necessarily less precise than those of a well-surveyed terrestrial station.

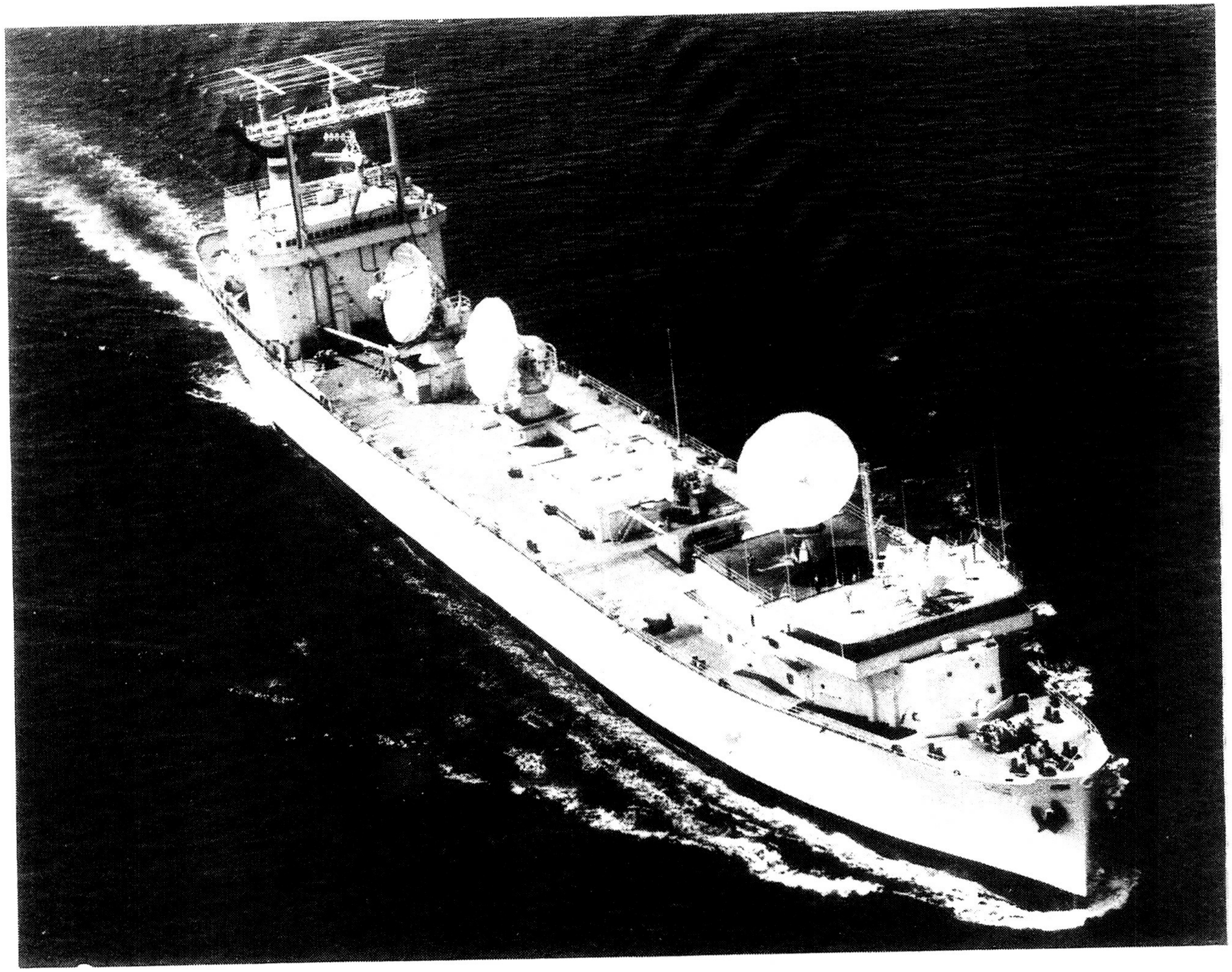

Figure 5-4. The USNS *Redstone*, an Apollo instrumentation ship. Note the 9-m antennas and the FPS-16 radar.

to a backup role. This was one reason why the MSFN 26-m sites were collocated with the DSN sites at Goldstone, Madrid, and Canberra. However, the presence of two, well-separated spacecraft during lunar operations stimulated the rethinking of the tracking and communication problem. One thought was to add a dual S-band RF system to each of the three 26-m MSGN antennas, leaving the nearby DSN 26-m antennas still in a backup role. Calculations showed, though, that a 26-m antenna pattern centered on the landed Lunar Module would suffer a 9-to-12 db loss at the lunar horizon, making tracking and data acquisition of the orbiting Command Service Module difficult, perhaps impossible.[32] It made sense to use both the MSFN and DSN antennas simultaneously during the all-important lunar operations. JPL was naturally reluctant to compromise the objectives of its many unmanned spacecraft by turning three of its DSN stations over to the MSFN for long periods. How could the goals of both Apollo and deep space exploration be achieved without building a third 26-m antenna at each of the three sites or undercutting planetary science missions?

The solution came in early 1965 at a meeting at NASA Headquarters, when Eberhardt Rechtin suggested what is now known as the "wing concept."[33] The wing approach involves constructing a new section or "wing" to the main building at each of the three involved DSN sites. The wing would include a MSFN control room and the necessary interface equipment to accomplish the following:

1. Permit tracking and two-way data transfer with either spacecraft during lunar operations.
2. Permit tracking and two-way data transfer with the combined spacecraft during the flight to the Moon
3. Provide backup for the collocated MSFN site passive track (spacecraft to ground RF links) of the Apollo spacecraft during translunar and transearth phases.

With this arrangement, the DSN station could be quickly switched from a deep-space mission to Apollo and back again. GSFC personnel would operate the MSFN equipment completely independently of DSN personnel. Deep space missions would not be compromised nearly as much as if the entire station's equipment and personnel were turned over to Apollo for several weeks.

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[32] F.M. Flanagan, P.S. Goodwin, and N.A. Renzetti, "Deep Space Network Support of the Manned Space Flight Network for Apollo 1962-1968" (Pasadena: JPL TM 33-452, 1970), p. 67.

[33] Interview with E. Rechtin, May 20, 1971.

In summary, the DSN wing concept represented one of those technical and political compromises that helped bring JPL capabilities and facilities to bear on the Apollo program.

Apollo Network Computers. In view of the eventual smoothly functioning Apollo Network, it is difficult to conceive of all the various technical ideas that were explored and argued (sometimes passionately) pro and con. The question of station computers fell in the "controversial" category at one time. In Mercury days, Bermuda was the only field station possessing a large, general purpose digital computer. (It was needed to help make the vital go-no-go decision should the communication link with the mainland computer center be ruptured.) The fundamental network plan, however, was that the spacecraft and ground stations would transmit raw, unprocessed (or slightly processed in the case of Gemini telemetry) data back to a central computing complex, which was located first at Goddard and moved to Houston early in the Gemini program. The expansion of NASCOM capacity made this a feasible goal. With Apollo, though, data rates increased several-fold and live television was added to the data stream. Two Univac 642B data-processing computers were substituted for the Gemini Univac 1218 computers at most Apollo Network stations; one for telemetry processing and the other for command processing.

The obvious advantage of the remote, on-line computers was the much larger quantity of data that could be handled. There were disadvantages, too, that made the computer decision seem less logical:[34]

1. The computers added complexity, with a possible decrease in network reliability.
2. Software errors, involving cards, tapes, and humans, could be made anywhere in the network rather than just at the central computing center.
3. Operators and flight controllers were isolated one step further from the raw data.

The data traffic planned for Apollo made computers essential despite these potential disadvantages. There was, in fact,a several-level hierarchy of computers:computers on the spacecraft itself, computers at the remote MSFN stations, communication processing computers, and computers at the Mission Con-

[34]Personal interview with Ozro M. Covington, April 10, 1969.

trol Center at Houston (MCC). During an actual Apollo mission, all three types of computers conversed with one another in a sort of digital round robin. Thus, NASA became one of the pioneers in large-scale multi-computer data systems.

The Question of Flight Controllers. Another closely related technical problem has already been mentioned in the Mercury and Gemini chapters: the problem of flight controllers and decision making at the remote sites. The Mercury sites used flight controllers at all prime stations, because worldwide, real-time communication was still in the developmental stage and its reliability was in question. NASA had to give each site the means with which to make critical decisions in the case of a communication failure. The trend towards centralization of mission control began with Gemini and reached its completion during Apollo. Nine sets of Apollo flight control consoles were built for the ships and some stations.[35] They were used during the very early unmanned Apollo flights. The consoles were gradually phased out as communications improved and the Intelsats became operational. The advent of a reliable communication satellite was of major importance in MSFN design philosophy.[36] The Intelsats permitted station automation to move ahead more rapidly.

Reentry Tracking. Another particular concern of Apollo mission planners was reentry tracking; that is, locating the position of the spacecraft during the communication blackout that prevails while the spacecraft is surrounded by a heat-induced plasma sheath. Because the spacecraft transponders are also blacked out during this period, the MSFN radars lose this tracking aid. Of course, the radar waves are partially reflected from the plasma sheath created by the spacecraft, but acquisition is more difficult and tracking data are degraded. Acquisition and tracking of Apollo spacecraft returning from the Moon are more difficult than for vehicles returning from orbit because reentry may occur over a wider geographical area and, in addition, the spacecraft first plunges into the atmosphere and then skips out before making its final descent into the recovery area.

During the early 1960s, the acquisition problem was considered potentially serious, and a radio interferometer

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[35]Carnarvon, Ascension, Guaymas, Goddard, Houston (2), and the ships (3).

[36]Lorne Robinson, "Telecommunication Support for the Apollo Programme," *Electronics and Power*, Vol. XVI (July, 1970), p. 244.

was proposed as a solution.[37] The interferometer, which would have been passive like the Minitrack interferometers described in Chapter 2, would have possessed a much broader acceptance pattern than the radar acquisition aids. It could pinpoint the spacecraft prior to the black out period.[38]

Another acquisition scheme suggested by Goddard would have utilized infrared detectors onboard the Apollo aircraft to locate the hot spacecraft during re-entry. In the end neither the interferometers nor infrared acquisition aids was employed because it became apparent that the trajectory of the incoming spacecraft would be known well enough for shipboard radar to acquire and skin-track the spacecraft without difficulty. To this end, a special skin-tracking radar was designed and installed on the *Huntsville*.

Equipment in the Standard Apollo Network. Having discussed some of the more important technical problems that arose during the design of the Apollo Network, let us now take a quick look at the equipment that was assigned to the various sites for the first manned missions--those requiring the full resources of the network. Neither the network configuration nor the site equipment remained the same from mission to mission. As we shall see in the later section on Apollo operations, some stations were eventually dropped and various equipment changes were made. For example, 64-m antennas were called into service to receive television signals from the Moon, and the ALSEP scientific equipment left behind on the Moon necessitated equipment changes. But for the purposes of history, some details of the standard or "reference" Apollo network, as configured in Table 5-2 and existing in 1968 will be presented.

Network engineers customarily break the MSFN down into several "systems" based on functions performed. There is the C-band radar system, for example, used for launch, orbital, and reentry tracking. The full complexity of the Apollo Network can be comprehended only when all of these systems are delineated and their functions listed. Since this is a history and not a technical report, the description must be sketchy. But in perusing Tables 5-3 and 5-4,

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[37]F. O. Vonbun, "Reentry Network Concept for APOLLO," working paper dated June 21, 1963. F. O. Vonbun, "Apollo Entry Tracking: A Shipboard Unified S-Band Interferometer System." (Washington: NASA TN D-2880, 1965). An interesting aside: the earlier paper still assumed that the spacecraft would be recovered *on land* at either San Antonio or Woomera!

[38]H.L. Richard, "Apollo Infrared Acquisition and Tracking System," (Washington: NASA TN D-3362, 1966).

the reader should pause to consider the myriad technical interfaces between the systems, the geographical extent of the network, and how the millions of parts and millions of miles of wires must be put together properly and kept operating reliably for Apollo to be a success. With an appreciation of these two tables, we are ready to discuss how the network was built; that is, how it was "implemented," in management language.

Implementation of the Apollo Network

The configuration of the Apollo Network and the major site equipment was fairly well established by the end of 1963. The task ahead of OTDA, Goddard, and JPL could be separated into six general categories:

1. The expansion of seven Gemini stations to include the 9-m Apollo USB equipment
2. The construction of four brand new 9-m USB stations at Merritt Island, Ascension, Antigua, and Guam
3. The construction of three new MSFN 26-m USB stations at Goldstone, Canberra, and Madrid
4. The addition of DSN wings to the collocated JPL stations at Goldstone, Canberra, and Madrid
5. Conversion of five ships to provide USB and C-band radar support
6. Conversion of eight jet aircraft to provide VHF/UHF and USB support.

This was what had to be done. Getting it done within a prescribed time frame--that is, network implementation--was very different and every bit as difficult as roughing out the network configuration and the major equipment.

Plans and Schedules. During 1963, only the broadest mission guidelines were available to guide network engineering. The first PIRD from Houston was dated April 23, 1963, but, as Appendix C demonstrates, the Apollo support requirements were not really known in depth; in addition, mission schedules and requirement details kept changing as this formulative stage of Apollo drew to a close. This period of shifting sands, tradeoff studies, and long meetings was typical of the early stages of any engineering project. Still, a network had to be built in just a couple of years, and one could not wait until the last requirement was spelled out in detail.

Toward the end of 1963, there was considerable discussion about network augmentation for Apollo at Headquarters, at the various centers, and within the many joint working groups. OTDA began the transition from the discussion phase to the hardware phase by drawing up an "Apollo Network Im-

Table 5-3. APOLLO NETWORK SYSTEMS[a]

System	Typical Equipment[b]	Basic Functions
USB system	Antennas, acquisition aids, communication equipment (Fig. 5-5)	Spacecraft acquisition, determination of range and velocity, two-way communication (telemetry, TV, voice, biomedical data), transmission of commands, and recording and monitoring
Radar and tracking system	VHF acquisition aids, C-band radars, Azusa and Glotrac systems	Locate and track the spacecraft and launc vehicle during launch and, during orbit flight and reentry, the spacecraft
Telemetry system	Antennas for telemetry acquisition and receiving, receivers and transmitters (Fig. 5-6)	Telemetry receiving
Telemetry decommutators/simulators system	Decommutators and simulators	Decommutate the various telemetry signals received and test the capabilities of the system
Remote Site Data Processor (RSDP) system	Two Univac 642B computers	Process telemetry and commands
Other data processors	Various computers (Table 5-4)	Communications switching, antenna and radar position programming, etc.
Command control system	Univac 642B computer	Transmit flight control signals to spacecraft
Display system	Various consoles and displays (Fig. 5-7)	Monitor the spacecraft
Recorder system	Tape recorders, strip chart recorders, etc.	Record telemetry, voice, etc.
Timing system	Timing equipment	Synchronize network stations.

[a]See Table 5-4 for the disposition of these systems among the various sites and for a listing of miscellaneous, self-explantory systems.

[b]John H. Painter and George Hondros, "Unified S-Band Telecommunications Techniques for Apollo, Volume I--Functional Description" (Washington: NASA TN D-2208, 1965). Goddard Space Flight Center "Proceedings of the Apollo Unified S-Band Technical Conference," (Washington: NASA SP-87, 1965).

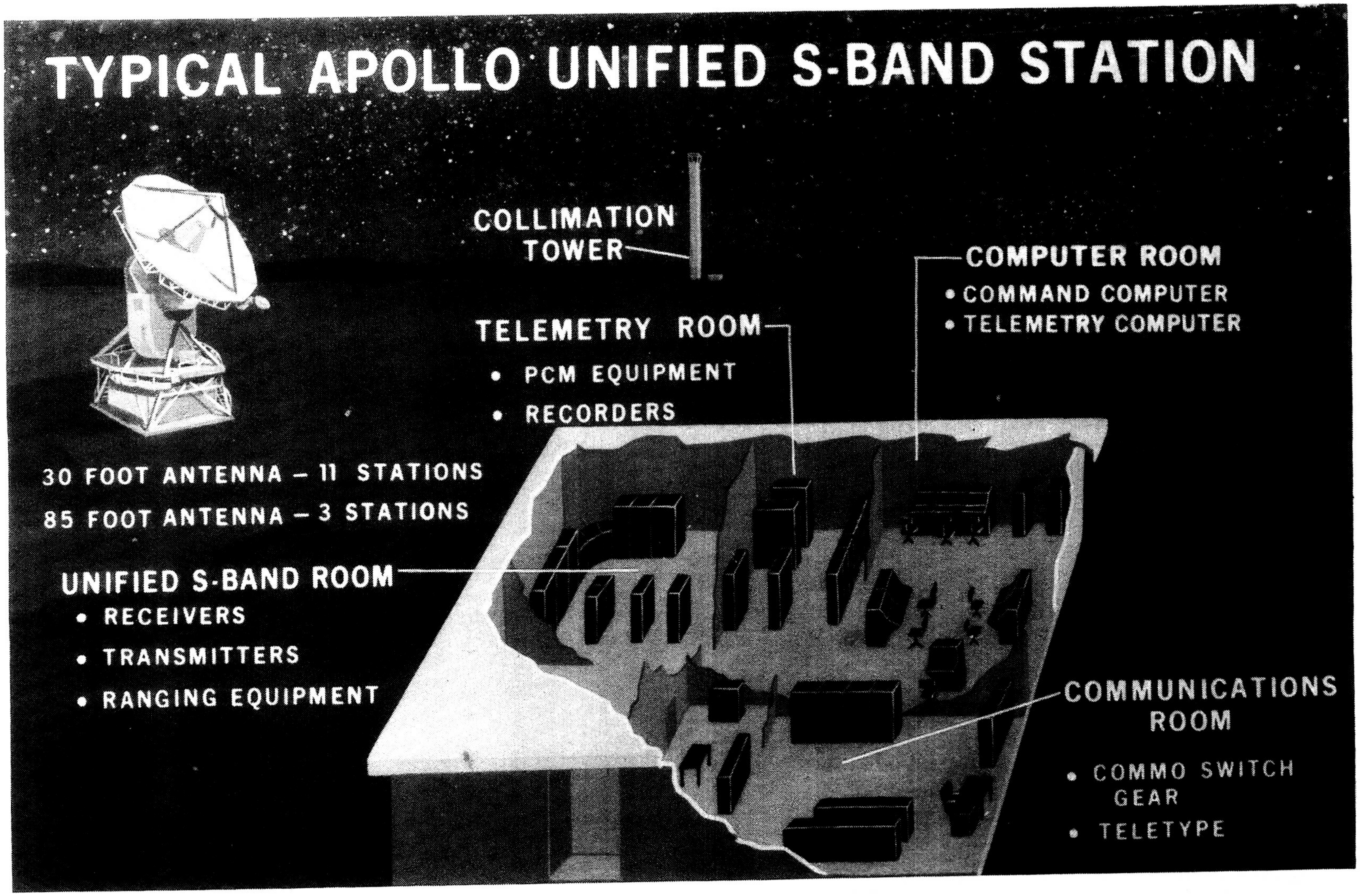

Figure 5-5. A typical Apollo USB station arrangement.

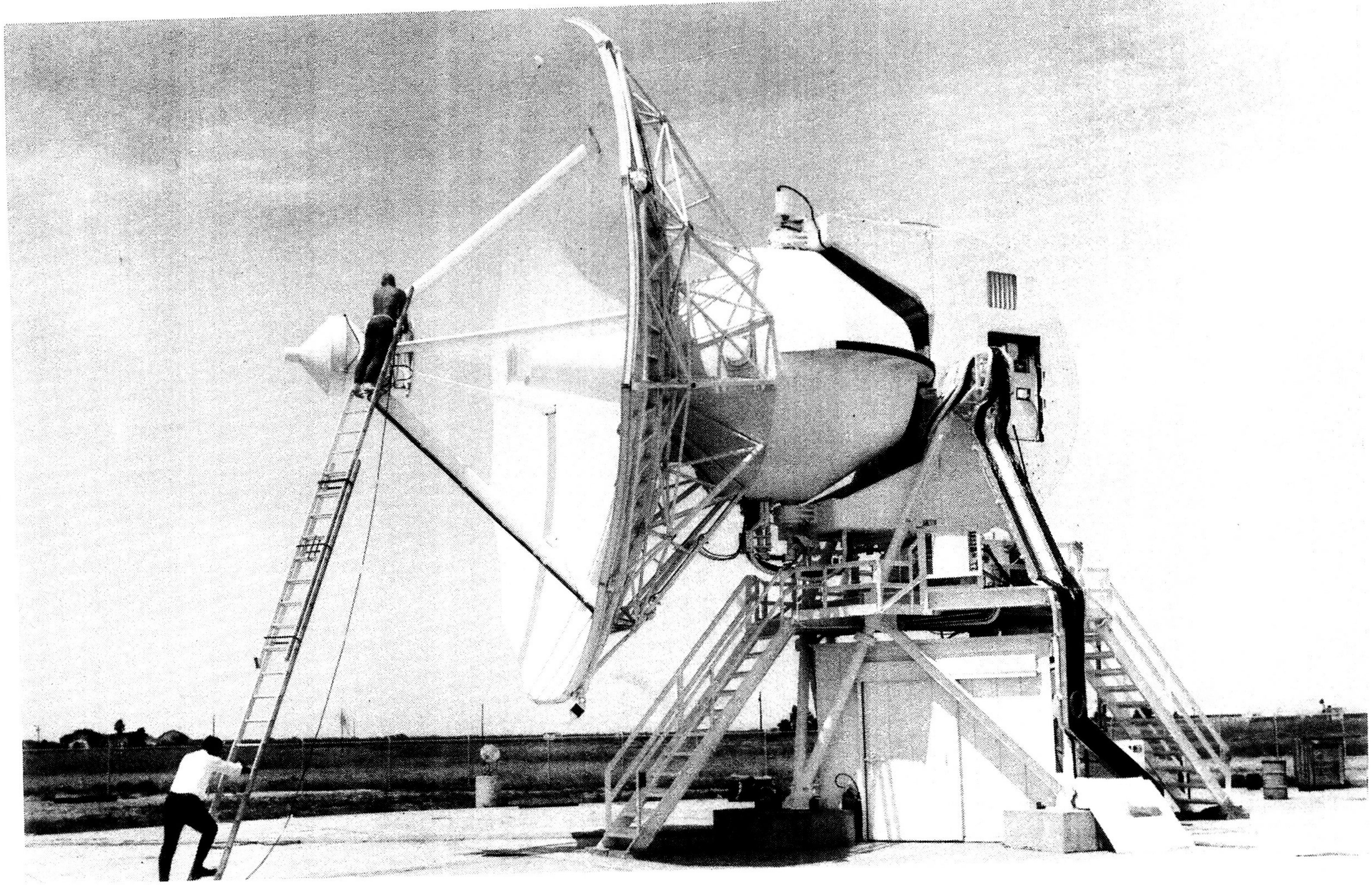

Figure 5-6. The Apollo USB 9-m antenna at Corpus Christi.

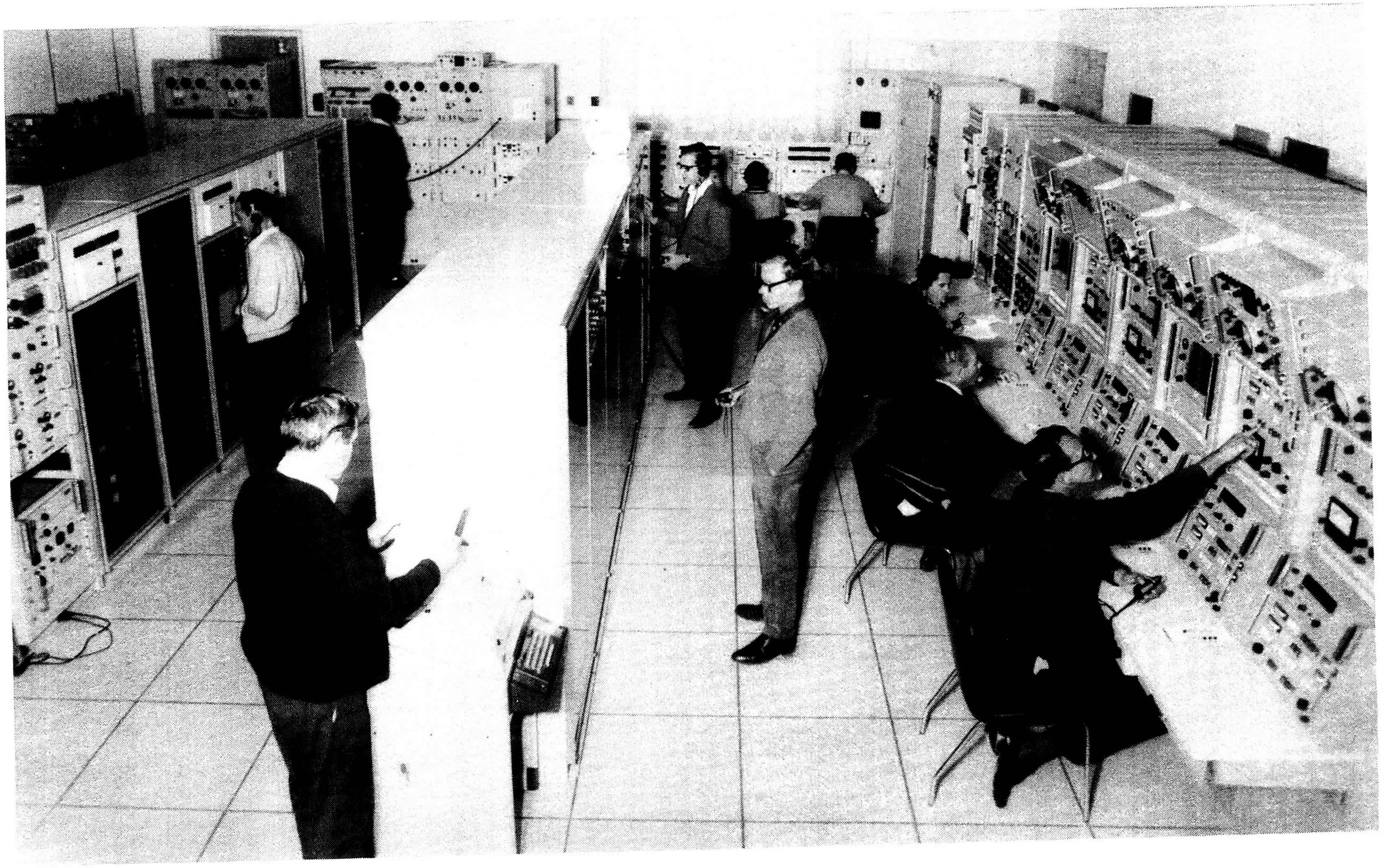

Figure 5-7. The consoles at the MSFN Madrid station.

Table 5-4. MAJOR SYSTEMS AND EQUIPMENT AT APOLLO NETWORK STATIONS[39]

STATIONS

System	Equipment	MCC-H-MSC	CNV	PAT	TEL IV	CIF	MIL	MLA	MSFNOC	ANG	ANT	ACN	ASC	BDA	CAL	CRO	CYI	GSFC-NTTF	GBI
Unified S-Band System	12-Foot Antenna																		
	30-Foot Antenna (Single System)									X				X			X	X	
	30-Foot Antenna (Dual System)						X					X				X			
	85-Foot Antenna																		
Radar	Optical Tracker		X																
	Offset Doppler (ODOP)		X																
	C-Band Radar		X	X				X			X		X	X	X	X	X		X
	Azusa-Glotrac		X											X					
Telemetry Acquisition Aid Antennas					X		X			X	X	X	X	X	X	X	X	X	X
Telemetry Antennas (Non-Acquisition)					X						X		X	X					
Telemetry Systems	USB						X			X		X		X		X	X	X	
	VHF				X		X				X	X		X		X	X	X	X
Telemetry Decommutators	PCM	X					X		X	X		X		X		X	X	X	X
	PCM Simulator	X					X		X	X		X		X		X	X	X	
	PAM/PDM						X							X		X	X	X	
	FM/FM Discriminator						X			X		X		X		X	X	X	
Remote Site Data Processing System	Telemetry Computer (Univac 642B)						X			X		X		X		X	X	X	
	Command Computer (Univac 642B)	X					X			X		X		X		X	X	X	
	Expanded Memory Unit						X			X		X		X		X	X	X	
Data Processing Systems	Univac 1218 Computer	X					X		X	X	X	X		X		X	X	X	X
	IBM 360 Computer	X							X										
	RCA 4101 Computer						X				X			X		X			X
	TRW-130													X					
	Univac 494 (CCATS)	X																	
	AN/USQ-20B																		

System	Equipment	GBM	GDS	GWM	GYM	HAW	HSK	MAD	PRE	TAN	TEX	WHS	RTK	VAN	MER	RED	HTV	WTN	ARIA
Unified S-Band System	12-Foot Antenna																X	X	
	30-Foot Antenna (Single System)	X			X						X								
	30-Foot Antenna (Dual System)			X		X								X	X	X			
	85-Foot Antenna		X				X	X											
Radar	Optical Tracker																		
	Offset Doppler (ODOP)																		
	C-Band Radar					X			X	X		X	X	X	X	X	X	X	
	Azusa-Glotrac																		
Telemetry Acquisition Aid Antennas		X		X	X	X				X	X	X	X	X	X	X			
Telemetry Antennas (Non-Acquisition)																			
Telemetry Systems	USB	X	X	X	X	X	X	X			X			X	X	X	X	X	X
	VHF			X		X					X			X	X	X	X	X	X
Telemetry Decommutators	PCM	X	X	X	X	X	X	X		X	X			X	X	X	X	X	
	PCM Simulator	X	X	X	X	X	X	X			X			X	X	X	X	X	
	PAM/PDM			X	X	X				X	X		X	X	X	X	X	X	
	FM/FM Discriminator				X	X				X	X	X	X	X	X	X			
Remote Site Data Processing System	Telemetry Computer (Univac 642B)	X	X	X	X	X	X	X			X			X[3]	X[3]	X[3]	X[3]	X[3]	
	Command Computer (Univac 642B)	X	X	X	X	X	X	X			X			X	X	X			
	Expanded Memory Unit	X	X	X	X	X	X	X			X			X	X	X			
Data Processing Systems	Univac 1218 Computer	X	X		X	X	X	X			X			X	X	X			
	IBM 360 Computer																		
	RCA 4101 Computer																		
	TRW-130																		
	Univac 494 (CCATS)																		
	AN/USQ-20B												X						

[39]Goddard Space Flight Center, "Manned Space Flight Network Ground Systems," (Greenbelt: MG-401, September 1, 1968), pp. 2-2 to 2-4.

Table 5-4 continued

System	Equipment	MCC-H-MSC	CNV	PAT	TEL IV	CIF	MIL	MLA	MSFNOC	ANG	ANT	ACN	ASC	BDA	CAL	CRO	CYI	GSFC-NTTF	GBI	GBM	GDS	GWM	GYM	HAW	HSK	MAD	PRE	TAN	TEX	WHS	RTK	VAN	MER	RED	HTV	WTN	ARIA
Command Systems	USB						X			X		X		X		X	X	X		X	X	X	X	X	X	X			X			X	X	X			
	UHF		X								X			X		X	X	X	X					X					X			X	X	X			
Apollo Display System	Apollo Consoles and Displays	X					X			X		X		X		X	X			X	X	X	X	X	X	X			X			X	X	X			
	(MOC & SOC)																																				
	Special Consoles and Displays						X							X																							X
Recorders (Apollo) (Magnetic Tape, Strip Chart, and X-Y Recorders)	Wideband	X					X			X		X		X		X	X	X		X		X	X	X	X	X			X			X	X	X	X	X	X
	Narrowband						X			X		X					X	X			X	X	X	X	X	X		X	X			X	X	X			
	Voice									X				X	X	X	X	X		X	X	X	X	X	X	X		X	X			X	X	X			X
	Analog						X			X		X		X				X			X	X	X	X	X	X		X	X		X	X	X	X	X	X	
Timing Systems	Apollo						X			X		X		X		X	X	X		X	X	X	X	X	X	X			X								
	Gemini													X	X	X	X	X					X	X				X	X	X							
	Eastern Test Range (ETR)																										X										
TV Monitor							X	X	X	X		X		X		X	X	X		X	X	X	X	X	X	X			X			X	X	X			
Air/Ground Spacecraft Communications	USB						X			X		X		X		X	X	X		X	X	X	X	X	X	X			X			X	X	X	X	X	X
	VHF						X			X	X	X		X	X	X	X	X	X	X		X	X	X				X	X		X	X	X	X	X	X	X
	Tone Key Remoting	X					X		X	X		X		X	X	X	X	X		X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X
Ground Communications	HF Radio											X				X											X	X			X	X	X	X	X	X	
PBX and Intercommunications Systems		X					X		X	X		X		X	X	X	X	X		X	X	X	X	X	X	X			X			X	X	X	X	X	

Table 5-44 continued

System	Equipment	MCC-H-MSC	CNV	PAT	TEL IV	CIF	MIL	MLA	MSFNOC	ANG	ANT	ACN	ASC	BDA	CAL	CRO	CYI	GSFC NTTF	GBI	GBM	GDS	GWM	GYM	HAW	HSK	MAD	PRE	TAN	TEX	WHS	RTK	VAN	MER	RED	HTV	WTN	ARIA
Public Address System							X			X		X				X	X	X		X		X	X	X	X	X	X		X			X	X	X	X	X	
Satellite Communications (SATCOM) Terminals												X				X	X															X	X	X			
Microwave Transmission Links														X							X				X	X											
Tropospheric Scatter Link																X																					
VHF Transmission Link																							X														
Solar Particle Alert Network Equipment		X														X	X	X						X													
General Information	Telemetry Receiving and Recording				X				X	X		X		X	X	X	X		X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X
	Spacecraft Telemetry Transfer				X				X			X		X	X	X	X		X	X			X	X				X	X		X	X	X	X	X	X	X
	Transmission Receiving																																				
	Apollo Launch Data System		X	X	X	X	X	X			X			X					X																		

plementation Plan." The plan itself is dated November 11, 1963, and it was transmitted to George Mueller, the new Associate Administrator for Manned Space Flight, with a covering memo by Edmond C. Buckley.[40]

The essence of the implementation plan was a three-step augmentation of the existing Gemini Network synchronized to the expanding Apollo requirements. The steps are summarized below:

Step 1. Provide complete support of Launch Vehicle tests (Apollo flights SA-201, 202 and 203) and partial support of the Command Module on Saturn IB missions.

Step II. Provide post-injection coverage of lunar missions with additional 9-m USB stations. (9-m stations at Guam, Ascension, and Antigua; and a third USB ship).

Step III. Provide full mission support for the Lunar Module and Command Module for the Saturn IVB and Saturn V missions. (Two reentry ships, aircraft for coverage of injection phase, use of DOD capability at Grand Turk, and dual-receiver capability at Guam, Hawaii, Ascension, and on one injection ship.)

The addition of the three 26-m USB stations at Goldstone, Madrid, and Canberra was not specified in the three steps enunciated above; however, they appear in the composite implementation schedule presented in Fig. 5-8 as part of Step "0". One can also see from the schedule of key Apollo flights on Fig. 5-8 that flight dates and the missions themselves changed markedly in subsequent months. Nevertheless, the OTDA implementation plan acted as a strong focussing agent for those building the network and for the spacecraft groups at Headquarters and Houston, who now had to concur with or disagree with specific plans for ground support.

Houston replied quickly to OTDA's initiative with an analysis of the implementation plan and further information

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[40]The plan itself was drafted by Lorne M. Robinson. It asked for "concurrence" by the Office of Manned Space Flight. The purpose of the memo and plan was, of course, to focus the discussions on a specific plan.

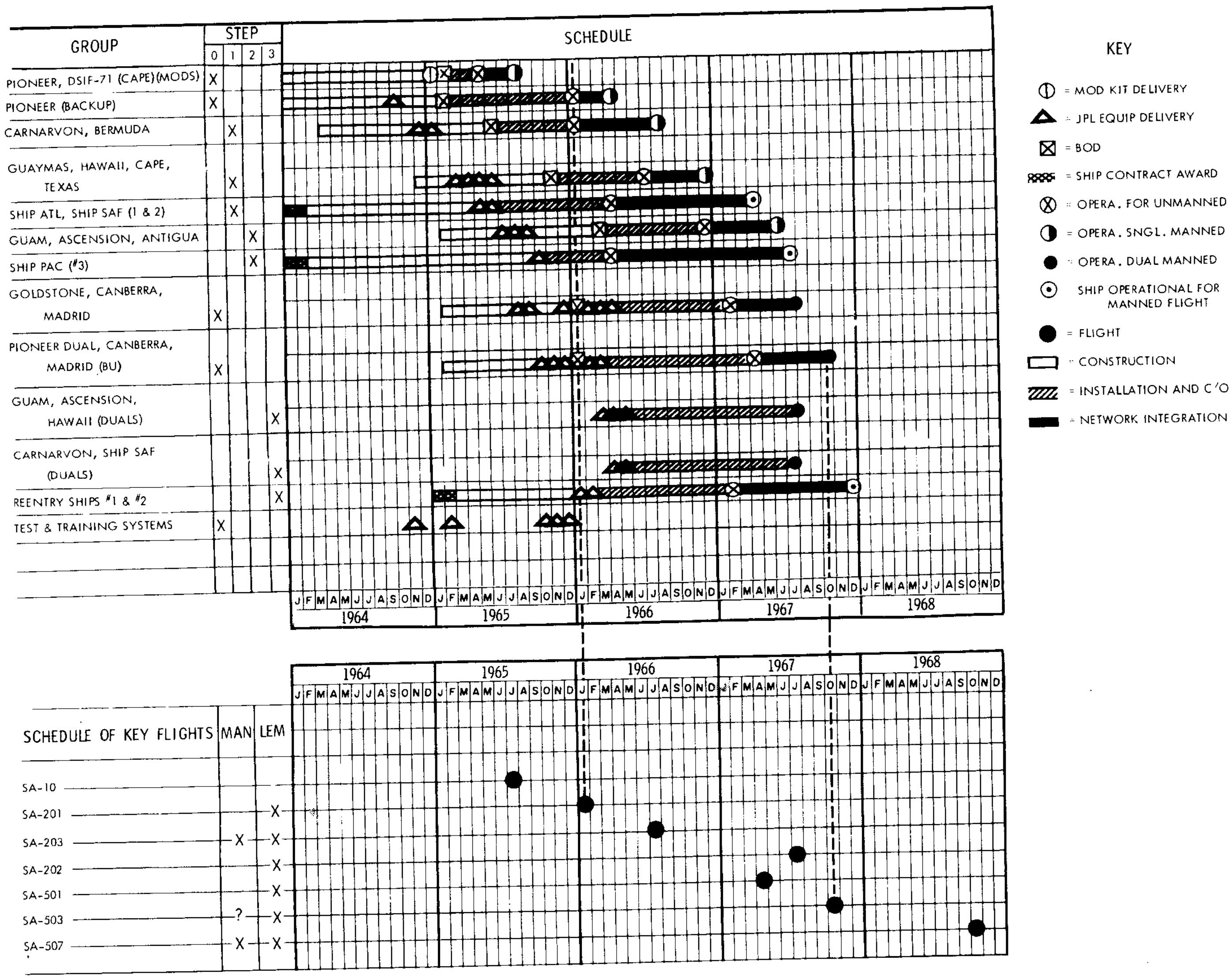

Figure 5-8. Composite implementation plan for the MSFN at the end of 1963.

on Apollo requirements.[41] The major points made in the response were:

1. Unmanned Saturn IB long-duration Earth orbital flights would require additional ground command capabilities. (Due primarily to the addition of unmanned missions with maneuvering capabilities.)
2. Early implementation of the Texas USB station was requested to aid in establishing total system performance and compatibility testing in the initial test and evaluation phase. (At this time, a 26-m station near Houston was still desired by MSC.)
3. The implementation of Johannesburg as an Apollo USB station was recommended strongly. (Johannesburg was later vetoed for nontechnical reasons.)
4. The whole Apollo flight schedule had been accelerated.

In usual engineering fashion, OTDA prepared a second iteration.[42] The revised implementation plan provided for a schedule improvement of about six months for stations needed for the first flight tests. The complete schedule of operational dates for the MSFN stations is presented in Table 5-5. There were further iterations, of course, but they became increasingly detailed as the network requirements clarified. The 1964-1967 period was one of procurement, testing, equipment integration, and network simulation. The final operational dates for the network stations are presented in the final column of Table 5-5. Some highlights from this period follow.

The Procurement Phase. The Apollo Network, being one of the largest machines ever constructed by man, contains many millions of parts ranging from simple resistors to the 26-m antennas. Most government purchases of "high technology" projects involve the factors of cost reduction, tight schedules, and high performance--all three incompatible objectives. Such incompatibilities can be resolved by good management and hard work. To illustrate Apollo Network procurement problems and how they were overcome, the purchase of the so-called RER (receiver-exciter-ranging) USB equipment will now be described.

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[41]Letter from Christopher C. Kraft, Jr., to Walter C. Williams, dated February 6, 1964, subject: "Apollo Network Instrumentation Plan." Attached to this letter were several Houston documents containing additional details on ground instrumentation.

[42]Office of Tracking and Data Acquisition, "Apollo MSFN Implementation Plan," April 20, 1964, with a cover memorandum from Edmond C. Buckley to George E. Mueller, dated April 21, 1964.

Table 5-5. Planned and Actual Operational Dates of Apollo Network Stations

Station	OTDA Plan of 12-27-63	OTDA Plan of 4-20-64	OTDA "Optimistic" Plan of 4-20-64	Actual Operational Date
Carnarvon	July 1966	July 1966	June 1966	Sept. 1966
Bermuda	July 1966	July 1966	July 1966	Sept. 1966
Texas	Dec. 1966	Aug. 1966	Aug. 1966	Dec. 1966
Cape Kennedy	Dec. 1966	Dec. 1966	Sept. 1966	Nov. 1966
Hawaii	Dec. 1966	Dec. 1966	Nov. 1966	Nov. 1966
Guaymas	Dec. 1966	Jan. 1967	Oct. 1966	Nov. 1966
Guam	June 1967	May 1967	Dec. 1966	Sept. 1966
Ascension	June 1967	June 1967	Jan. 1967	Jan. 1967
Antigua	June 1967	Oct. 1967	Feb. 1967	Feb. 1968
Goldstone (MSFN)	July 1967	Mar. 1967	Mar. 1967	Apr. 1967
Goldstone DSN (wing)	July 1965	June 1966	July 1965	Apr. 1967
Madrid (MSFN)	July 1967	Apr. 1967	Apr. 1967	July 1967
Madrid DSN (wing)	Oct. 1967	June 1967	Mar. 1967	July 1967
Canberra (MSFN)	July 1967	May 1967	May 1967	Apr. 1967
Canberra DSN (wing)	Oct. 1967	July 1967	Apr. 1967	Apr. 1967
Grand Canary[a]	a	a	a	Sept. 1967
Grand Bahama[b]	b	b	b	June 1967
Ship #1	June 1967	July 1966	July 1966	Oct. 1966
Ship #2	June 1967	Oct. 1966	Oct. 1966	July 1967
Ship #3	July 1967	Jan. 1967	Jan. 1967	Aug. 1967
Ship #4	Dec. 1967	Nov. 1966	Nov. 1966	Sept. 1967
Ship #5	Dec. 1967	Jan. 1966	Jan. 1966	Nov. 1967

a - Grand Canary added to plan in late 1965.

b - Grand Bahama added to plan in 1965.

The RER equipment had been developed by JPL for the DSN in the early 1960s and was slated for use in the Apollo Network. Because JPL had had a great deal of experience with the RER, NASA decided that JPL should procure the necessary equipment and supply it to Goddard for installation in the network. In March 1963, JPL awarded a contract to Motorola for the construction of three RER units. By December 1963, NASA had decided to purchase 46 additional units for the network. Costs for each Motorola unit then exceeded $1 million---a figure considered too high by JPL and NASA personnel.[43] Furthermore, the Apollo flight schedule had been accelerated and the RERs had to be procured more rapidly. Negotiations with Motorola brought the unit cost down to $727,000, but this was still considered too high. Consequently NASA decided to procure seven more units from Motorola on a sole source basis and obtain competitive bids from industry for additional units. Westinghouse in Baltimore won the competition as the second source in March 1965 with a fixed unit price of $325,375. It seemed that costs had been cut by a factor of three and that the Apollo schedule would still be met easily.

Westinghouse, however, encountered serious problems in using the Motorola drawings and adapting the Westinghouse semiautomatic production plan to the many design changes that were required as the RER design was improved. JPL sent a "tiger team" to Westinghouse to help solve the problems because the schedule was slipping and costs rising. JPL even threatened to send Westinghouse units to their competitor, Motorola, for fixing. The pressure on Westinghouse produced results. Eventually, the RER units were delivered without compromising the network implementation schedule and with an overall cost saving of roughly $9 million.[44]

Two of the largest procurement actions taken for the Apollo Network were those for the ships and aircraft. Instrumented ships have been an integral part of the MSFN ever since Mercury days. The world's oceans do not contain enough islands to cover all phases of the manned lunar flights. Furthermore, ships and aircraft provided the geographical flexibility impossible with land stations. If mission plans changed or a launch azimuth were off or some failure necessitated emergency action, ships and aircraft could react quickly.

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[43]For explanations of the NASA and JPL positions on the RER procurement see the following two references: Lorne Robinson, "Memorandum for Record, Revision of References," no date but circa 1965. Letter to G.M. Truszynski from Eberhardt Rechtin. "Westinghouse MSFN Receiver Delivery Problem," October 18, 1965.

[44]Interview with Lorne Robinson, September 28, 1971.

NASA interfaced with the Navy and Air Force on the Apollo ship program. (See later discussion concerning DOD interactions.) By NASA-DOD agreement, the ship conversion task was the responsibility of the Instrumentation Ships Project Office (ISPO), which reported directly to the Chief of Naval Material. This was a tri-party office, under Navy management, with NASA and Air Force participation. The ships were operated by the Air Force Western Test Range.

As mentioned earlier, ISPO, on NASA's behald, procured three T-2 tanker hulls for conversion into Apollo ships. The contract for the conversion of the T-2 tankers was awarded to the Electronics Division of General Dynamics in September 1964. The hulls were towed from the James River Reserve Fleet area to a construction drydock at Quincy, Massachusetts, where the conversion and installation of instrumentation were performed.

On March 1, 1965, Ling-Temco-Vought was awarded the contract to convert two World War II Victory ships, previously used by the Navy on old Pacific Missile Range (which later became the Western Test Range), into Apollo reentry ships. The shipyard work was done at the Avondale Shipyard, New Orleans. The reentry ship program was set back several months when Hurricane Betsy struck the New Orleans area in September 1965. (Damage repair costs exceeded $2 million.) Nevertheless, all ships were on station for the Apollo missions.

The Apollo Range Instrumentation Aircraft (ARIA) were designed to supplement the voice and telemetry coverage obtained from the Apollo ships and nearby MSFN land stations. Essentially, they served as communication relays. Without these highly mobile "stations," twenty to thirty additional surface stations would have been required to maintain communications with the Apollo capsule in all of the potential injection areas. Actually, some early studies by Houston indicated that if all lunar insertion opportunities in both oceans were to be covered, 30 propeller or 16 jet aircraft would be needed.[45] By covering only one ocean and cutting back on coverage, eight jets were found to be sufficient.

The ARIA were Air Force C-135 jets modified for MSFN duty under the overall management of the Air Force's National Range Division, in accordance with NASA-furnished specifications (Fig. 5-3). The project was assigned to the Air Force Electronics System Division at Hanscom Field, Massachusetts. The jets were modified and instrumented by an industrial team composed of Douglas Aircraft Corporation and the Bendix

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[45]Letter from Christopher C. Kraft, Jr., to W. C. Williams, "Mission Requirements for Aircraft in Support of the Insertion and Injection Phases of the Apollo Program," January 7, 1964.

Corporation's Radio Division. The contract was awarded in October 1965. The resulting aircraft were redesignated as EC-135Ns. During the Apollo missions the ARIA were operated for NASA by the Air Force Eastern Test Range. The Air Force also installed additional optical equipment for use with DOD missions.

Equipment Integration. Once the JPL range and range rate approach had been selected, it fell to Goddard to install the new antennas and electronic hardware. On July 14, 1964 Goddard awarded the USB prime contract to the Collins Radio Company. Collins subcontracted the new 9-m USB dishes to Blaw-Knox, the makers of the 26-m MSFN antennas. The first USB equipment was shipped to Guam--the brand new MSFN station--in mid-1965. About one station per month was outfitted after that.

The task of integrating the new Apollo equipment turned out to be a formidable one, particularly since the twelve Gemini missions overlapped the Apollo equipment deployment schedule. Goddard decided to integrate station equipment itself. From cost and time standpoints it would have been almost impossible to write the multitude of contracts necessary to handle all the interfaces, schedules, and complexities of the integration job.[46]

The installation and checkout of Apollo equipment was phased to take place between Gemini missions. Still, some scheduling conflict was inevitable. For example, Houston (MSC) agreed to waive support from the Guaymas station for Gemini, if absolutely necessary, during the installation of Apollo equipment.

Tests and Simulations

To help insure that the network would perform well during actual flights, NASA employed: (1) exhaustive ground testing of equipment; (2) network simulations; and (3) active network exercises involving actual spacecraft.

The MSC Telecommunications Laboratory. No matter how carefully equipment design is coordinated, when the pieces of a large machine arrive for integration, some part inevitably will not fit properly. To identify such problems early, NASA built a Flight Compatibility Test Laboratory at Houston to test Apollo spacecraft and ground support equipment under realistic environments. JPL and Goddard sent almost-complete ground stations to Houston for these compatibility tests.

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[46]Personal interview with Ozro M. Covington, April 10, 1969. However, Collins Radio Co., maker of much of the USB equipment, did integrate the USB gear.

Likewise, vendors were able to send prototypes or early models of their equipment to see how they performed in an integrated situation. These compatibility tests proved invaluable for they identified problems that could not have been anticipated early enough so that modifications could be made.[47] (Table 5-6)

The prime objectives of the test program at Houston were:

1. To prove the compatibility of the two-way communication links between spacecraft and the network
2. To verify that the integrated system met performance requirements
3. To determine the maximum capabilities of the integrated system
4. To evaluate designs and provide preflight integration tests
5. To perform mission simulation for the evaluation and study of possible problem areas
6. To study and evaluate the compatibility of advanced communication and tracking techniques with existing network systems.

Network Tests and Simulations. Once the network equipment has been installed, it must be tested again on a station basis and, before missions, on a network basis. In the Apollo program station testing occurred on a four-level basis: (1) subsystem tests; (2) systems tests; (3) integrated systems tests; and (4) station readiness tests. Station system tests were performed prior to each manned mission and otherwise as the situation dictated. Station readiness tests were normally part of the premission tests and were also mandatory when a station was returning to active status from an extended down period during a mission. The overall purpose of these tests was to assure that each station was ready to perform successfully during a mission; that is, help determine whether it was RED or GREEN.

Station tests were also carried out using instrumented aircraft--not the ARIA, but specially instrumented aircraft containing spacecraft equipment so that they would "look like" an Apollo spacecraft from the electronic standpoint. These aircraft visited each MSFN station periodically to evaluate ground station equipment and conduct operational readiness tests. A special test conductor aboard the aircraft ran tests that simulated actual, real-time manned flights. The aircraft, however, could not test the network

[47]Interview with Howard C. Kyle, June 2, 1971.

Table 5-6. Types of Tests Performed with Spacecraft and Network Equipment at Houston.[48]

Type of Tests	Equipment tested	Tests conducted
Up-link data channel quality	All subsystems involved in up-link command system both S-band and UHF	1. Error rate 2. Message rejection rate 3. Probability of accepting erroneous message 4. Varying simulated conditions and operation modes for each of the above
Up-link voice channel quality	All subsystems involved in up-link voice communication system, include S-band, VHF, and HF	1. Voice intelligibility 2. Output signal noise 3. Distortion to tone 4. Varying simulated conditions and operational modes for each of the above
Down-link PCM channel quality	All subsystems involved in down-link PCM telemetry system both S-band and VHF	1. Bit error rate 2. Word error rate 3. Event error rate 4. Word rms error percentage 5. Recorded PCM tests 6. Effects of up-link signal level 7. Varying simulated conditions and operational modes for each of the above
Down-link voice channel quality	All subsystems involved in down-link voice communication system, includes S-band, VHF, and HF	1. Intelligibility 2. Output signal to noise 3. Distortion to tone 4. Emergency modes (key and voice) 5. Varying conditions and operations modes for each of the above
Ranging tests	All subsystems involved in the pseudo-random ranging process. S-band only	1. Acquisition time 2. Acquisition threshold 3. Ranging accuracy 4. Varying simulated conditions and operational modes for each of the above

Table 5-6 (cont.)

Type of Tests	Equipment Tested	Tests conducted
Mission profile	Entire integrated system	1. Acquisition procedure tests 2. Tracking data accuracy (doppler and angle information) 3. Effects of mode switching 4. Reacquisition (after loss of lock) 5. Emergency conditions 6. Perform the above tests for various phases of a nominal lunar mission.

[48]H.C. Kyle, "Manned Spaceflight Communications System,s" *Advances in Communications Systems*, Vol. II (1966) pp. 249-250.

as a whole and check important actions such as handover procedures.

The CADFISS tests[49] did exercise the entire network under conditions as real as electronic signals could make them. As described in Chapter 3, the CADFISS program simulated the flow of real-time operational data in the network and compared the resulting data and displays with those expected. CADFISS also took roll calls and checked the performances of each station prior to and during missions. If a station did not pass CADFISS tests, the CADFISS operator at Goddard could select CADFISS diagnostic routines which helped pinpoint the trouble.

The Use of Unmanned Spacecraft as Network Targets. Instrumented aircraft and the CADFISS-created electronic targets do not simulate all of the characteristics of an active spacecraft. In particular, there was no opportunity to test the capability of the network and the computers at Houston to generate precision orbital information from raw tracking data. It was obvious that the best way to exercise the Apollo Network would be with real spacecraft that possessed the electronic and orbital characteristics of the projected Apollo spacecraft. None of the dozens of U.S. unmanned spacecraft displayed the right characteristics; so, a small, special purpose satellite was proposed. The same idea had almost reached fruition during Mercury days in the form of the MS-1 spacecraft. For Apollo, a series of four TETR (Test and Training) satellites was planned.[50]

Quoting from the Goddard TETR *Project Development Plan*:

> The TETR provides an active orbiting target for training of ground system personnel and for mission simulation. It provides the most economic means for premission and prepass verification of station radio-frequency (RF) operational capability for mission support. Only a satellite-borne transponder is capable of traversing MSFN stations at sufficient altitude to be simultaneously viewed by paired USB systems and handed over from station to

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[49]CADFISS = Computation and Data Flow Integrated Subsystem. For a detailed description, see: Federal Systems Division, IBM, "CADFISS Real Time System Engineering Manual (Gaithersburg: MO-301, May 1, 1967).

[50]These satellites are also called TTS rather than TETR in some of the literature.

station. The development and verification of acquisition and handover procedures for the USB system also require an orbiting transponder.

The TETRs belong to TRW Systems family of small polyhedral satellites. The TETR is octahedral, about 28 cm on a side.[51] (Fig. 5-9) The satellite weights vary between 20 and 27 kg. Each TETR carries an S-band transponder and provides VHF telemetry and command links for checking out the MSFN stations. The MSFN, however, does not control the satellite; commands and housekeeping telemetry are handled by STADAN. The TETRs were launched piggyback on the Delta rocket.

The primary objectives of the TETR flights were: (1) premission checkout of MSFN stations; (2) training and cross-training of MSFN ground-system personnel; (3) routine mission simulations; and (4) development and verification of acquisition and handover techniques.

The TETR launch schedule was as follows:

Satellite Designation	Launch Date	Companion Spacecraft
TETR-A	December 13, 1967	Pioneer 8
TETR-B	November 8, 1968	Pioneer 9
TETR-C	August 27, 1969 (Launch vehicle failure)	Pioneer E
TETR-D	September 30, 1971	OSO 7

TETR-A was launched just before Apollo 5, a Lunar Module development orbital flight; and TETR-B went into orbit two weeks before Apollo 8, the first manned orbital flight. Generally speaking, the first two TETRs were not as useful as had been hoped originally, for two reasons: first, they were not in operation long enough; and, second, the timing was off; for example, TETR-B was orbited too close to the Apollo-8 flight to thoroughly exercise the network before it went on "mission status." It is too early to evaluate the performance of TETR-D, the last of the series.

While the TETRs were useful in testing the network in the area of satellite acquisition and handover, they of course could not simulate the lunar phases of the Apollo mission--and these were the most difficult from the stand-

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[51]H.J. Horn, "Test and Training Satellites for the Manned Space Flight Network, System Description Document," (Redondo Beach: 06834-6008-R000, September 1968).

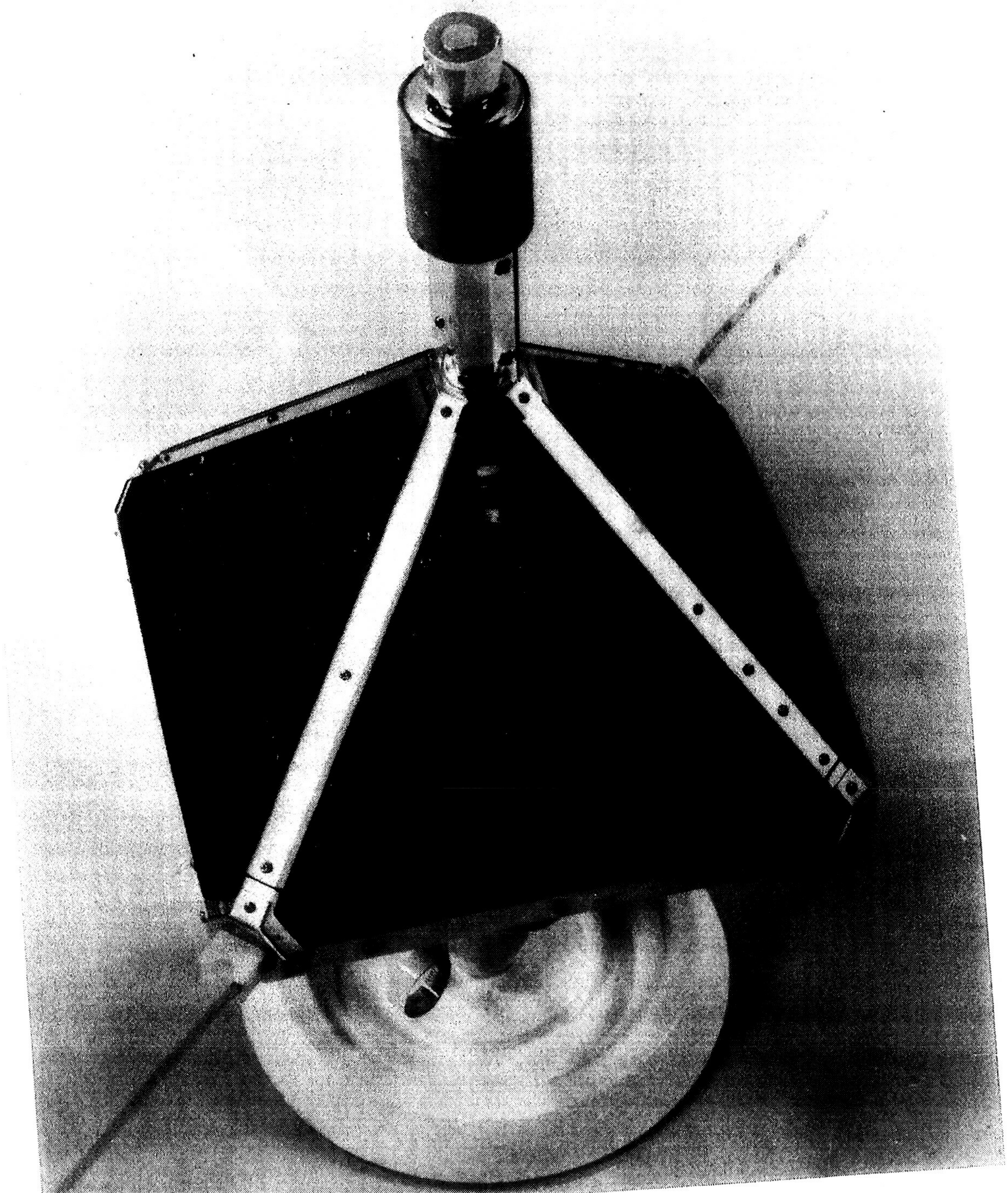

Figure 5-9. A TETR satellite. The edges of the octahedron are 28-cm long.

points of tracking and data acquisition. During the spring of 1965, during a meeting at JPL, Lorne Robinson (OTDA) and Eberhardt Rechtin (JPL) discussed the possibility of using the unmanned Lunar Orbiters as MSFN targets.[52] This was a particularly attractive possibility because Lunar Orbiter circled the Moon much like Apollo spacecraft would and also carried equipment that would permit both passive and active tracking by USB-equipped MSFN stations with minor modifications. During the last half of 1965 and the first half of 1966, meetings were held between engineers from Houston, Goddard, Langley (the NASA center with Lunar Orbiter Project responsibility), JPL, and NASA Headquarters to work out the details of the proposed program.[53] Basically, Houston wished the network to track the Lunar Orbiters passively during the first 30 days, while the spacecraft were completing their photographic missions, and actively thereafter. Active tracking would entail two-way coherent Doppler tracking and ranging and could not be used until the primary photographic objectives of the Lunar Orbiters had been met. The two main objectives of this tracking were to qualify Houston's Apollo navigation system and qualify the MSFN remote sites. JPL's Deep Space Network was the primary tracking and data acquisition network and MSFN data could be compared directly with data acquired by JPL during the regular mission.

During 1966 and 1967, five Lunar Orbiters were launched successfully. These were tracked with the MSFN 26-m and 9-m USB antennas at three sets of four stations each:

Canberra	Madrid	Goldstone
Carnarvon	Ascension	Hawaii
Guam	Canary Island	Guam
Hawaii	Bermuda	Bermuda

The Lunar Orbiters proved to be excellent targets for the MSFN, permitting Goddard to compare its lunar tracking techniques directly with those of JPL.[54] The personnel at the MSFN stations had the invaluable experience of working real lunar spacecraft. In summary, the Lunar Orbiters were extremely useful in preparing the network for Apollo operations.

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[52]Interview with Lorne Robinson, September 9, 1971

[53]M.S. Johnson, "Minutes, Meeting to Discuss the Relationship Between the Apollo Project, Manned Space Flight Network and Lunar Orbiter Tracking and Data System," April 7, 1966.

[54]Goddard and JPL navigational calculations did not always agree for lunar spacecraft. See the later discussion of the Apollo-8 navigation "crisis."

Apollo Flight Operations

MSFN Apollo operations began with unmanned test flights of the launch vehicle and spacecraft from Cape Kennedy. (Table 5-7) Although the suborbital flights down the range toward Ascension did not require the full array of network stations, telemetry and tracking during these flights were of utmost importance to the engineers at Houston and Huntsville who were building the spacecraft and Saturns. On the unmanned Apollo-5 flight, for example, the network's capability for real-time command helped turn near-failure into success when an engine was prematurely shut down by onboard equipment. Using network-supplied data, Mission Control, at Houston, was able to diagnose the problem and shift to an alternate (and successful) mission plan. The mettle of the network was tested again during the Apollo-13 abort in 1970. Generally, one can say that whether the mission was an unmanned suborbital test, a "routine" lunar landing, or an emergency abort the network was effective and flexible.

Before going into actual network operations, let us review briefly the Apollo mission structures, particularly those involving the lunar flight. Each Apollo mission is laid out as a series of decision points at which critical events occur. For example, should the spacecraft be injected from its parking orbit into a translunar trajectory, etc.? It is one of the purposes of the Apollo Network to supply sufficient information to Houston to permit such decisions to be made correctly. With this decision-point structure in mind, the MSFN should perform as described in the following paragraphs.

After CADFISS and other network tests, the first interface between the network and the Apollo launch vehicle/spacecraft combination occurred before launch, when the Merritt Island USB station linked the Saturn launch vehicle and spacecraft to the Mission Control Center (MCC) at Houston. The MSFN's 9-m USB antennas provided continuous contact with the spacecraft and astronauts during launch and insertion into Earth orbit. Merritt Island, Bermuda, Antigua, Grand Bahama, and an Atlantic Apollo ship were required during this phase of the flight. A go-no-go orbit decision was made here. During the Earth-parking-orbit phase, flight parameters provided by the MSFN are evaluated at the MCC and a go-no-go decision for a translunar trajectory insertion was made. As the spacecraft left the vicinity of the Earth, the injection burn was monitored by land- and ship-based equipment with ARIA communication relays where necessary. Approximately 16,000 km above the Earth, the 26-m MSFN dishes acquired the spacecraft and remained the primary source of contact until the return to Earth. The lunar orbit, lunar

Table 5-7. Summary of Apollo Flights

Designation[a]	Launch Date/ Launch Vehicle	General Description of Flight
SA-201/Apollo 1	February 26, 1966 Saturn IB	Unmanned, suborbital, launch-vehicle-development flight. Demonstrated the compatibility and structural integrity of the spacecraft/launch/vehicle configuration. Tested heat shield at high heating rate.
SA-203/Apollo 2	July 5, 1966 Saturn IB	Unmanned, orbital, launch-vehicle-development flight. Liquid-hydrogen tests of S-IVB stage vent and engine restart capability. Also tested S-IVB separation and cryogenic storage at zero-g. Flight terminated during liquid hydrogen pressure and structural test.
SA-202/Apollo 3	August 25, 1966 Saturn IB	Unmanned, suborbital, launch-vehicle and spacecraft development flight. Tested spacecraft subsystems structural integrity and compatibility. Also included heat shield test at high heat loads.
AS-501/Apollo 4	November 9, 1967 Saturn V	Unmanned, orbital, launch-vehicle and spacecraft development flight. First launch of Saturn V. Tested heat shield and simulation of new hatch at lunar reentry velocity.
AS-204/Apollo 5	January 22, 1968 Saturn IB	Unmanned, orbital Lunar Module development flight. First flight test of Lunar Module. Verified ascent and descent propulsion systems, including restart and throttle operations. Tested Lunar Module staging and S-IVB/IU orbital performance.
AS-502/Apollo 6	April 4, 1968 Saturn V	Unmanned, orbital, launch-vehicle development flight. Anomalous operation of J-2 engine igniters on second and third stages. S-IVB restart not accomplished. Spacecraft performance satisfactory.
AS-205/Apollo 7	October 11, 1968 Saturn IB	Manned, orbital flight to test spacecraft operations. Eight successful Service Module engine firings. Seven live TV transmissions. Rendezvous to within 21m with S-IVB stage. Duration: 10.8 days. Astronauts: Walter M. Schirra, Donn F. Eisele, and Walter Cunningham.

[a]The so-called "Little Joe" tests took place at White Sands and did not involve the MSFN.

Table 5-7 (cont.

Designation	Launch Date/ Launch Vehicle	General Description of Flight
AS-503/Apollo 8	December 21, 1968 Saturn V	Manned circumlunar flight and first manned flight of Saturn 5. Tested capabilities of crew, spacecraft, and mission support. Ten lunar orbits with good photographic coverage. Duration: 147 hours. Astronauts: Frank Borman, James A. Lovell, Jr., and William A. Anders.
AS-504/Apollo 9	March 3, 1969 Saturn V	Manned, orbital flight. First manned flight of all Apollo hardware. First manned space flight of Lunar Module. Successful rendezvous of Lunar Module. Extra-vehicular activity (EVA) of 37 minutes duration. Atlantic recovery postponed one orbit due to weather. Duration: 241 hours. Astronauts: James McDivitt, David Scott, and Russel Schweickart.
AS-505/Apollo 10	May 18, 1969 Saturn V	Manned lunar development flight. Evaluated Lunar Module performance in cislunar and lunar environment. Lunar Module descended to within 15,000 m of lunar surface. Nineteen color-TV transmissions. Duration: 192 hours. Astronauts: Eugene A. Cernan, John W. Young, and Thomas P. Stafford.
AS-506/Apollo 11	July 16, 1969 Saturn V	Manned lunar landing mission. Assessed the capabilities of astronauts and their equipment in the lunar environment. Limited surveys, photography, lunar sampling, and inspection of the Moon. Deployed EASEP. Duration: 195 hours. Astronauts: Neil A. Armstrong, Michael Collins, and Edwin E. Aldrin, Jr.
AS-507/Apollo 12	November 14, 1969 Saturn V	Manned lunar landing mission. Demonstrated point landing capability, sampled mare area, deployed ALSEP, investigated Surveyor-3 spacecraft, and photographed candidate exploration sites. Duration: 10 days, 4 hours, 36 minutes. Astronauts: Charles Conrad, Jr., Richard F. Gordon, Jr., and Alan L. Bean.
AS-508/Apollo 13	April 11, 1970 Saturn V	Manned lunar landing attempt. Flight aborted after 56 hours due to loss of liquid oxygen pressure in Service Module and the failure of two fuel cells. Duration: 143 hours. Astronauts: James A. Lovell, Jr., Fred W. Haise, Jr., and John L. Swigert, Jr.

Table 5-7 (cont.)

Designation	Launch Date/ Launch Vehicle	General Description of Flight
AS-509/Apollo 14	January 31, 1971 Saturn V	Manned lunar landing mission. Inspected and sampled lunar terrain in Fra Mauro region. Deployed ALSEP. Photographed candidate sites for future exploration. Duration: 216 hours, 42 minutes. Astronauts: Alan B. Shepard, Stuart A. Roosa, and Edgar D. Mitchell.
AS-510/Apollo 15	July 26, 1971 Saturn V	Manned lunar landing mission. Conducted extensive lunar exploration and sampling with lunar roving vehicle. Deployed ALSEP. Conducted scientific experiments in lunar orbit and released a lunar satellite. Duration: 295 hours. Astronauts: David R. Scott, James B. Irwin, and Alfred M. Worden.

descent, lunar ascent, lunar-orbit rendezvous, and return to Earth were all monitored by the 26-m USB dishes and/or their DSN "backups." As the spacecraft returned to Earth, mid-course corrections were based on MSFN data, so that the 55-km-square reentry corridor would be hit. During reentry black-out, the radar on the nearest Apollo ship tracked the plasma sheath. ARIA were employed as highly mobile voice and telemetry relay stations before and after blackout.

All of the Apollo flights were different, but it is not necessary here to describe network operations in detail for each one. It is more significant to concentrate on those missions which bring out the evolutionary processes that went on within the MSFN. With this goal in mind the following flights will be covered more thoroughly than the others:

Apollo 3	A typical suborbital flight. Only part of network in support.
Apollo 8	Manned lunar flights, no landing. Network built up to near maximum.
Apollo 11	First lunar landing. Full network deployed.
Apollo 13	Aborted flight. Network flexibility in emergency displayed.
Apollo 15	Lunar landing, including use of rover, ALSEP, and lunar scientific satellite. Network consolidating.

Apollo 3. Apollo 3 was a suborbital development flight using the Saturn IB as the launch vehicle. The major objectives of the network were:[55]

1. Evaluate the USB under actual mission conditions. (This was the first opportunity to exercise fully the USB system with an actual Apollo spacecraft.)
2. Provide C-band radar tracking
3. Receive and record telemetry
4. Receive and record the 400-Hz tone on VHF from the spacecraft
5. Provide real-time computing support for range safety, data acquisition prediction, and reentry prediction.

Because this flight terminated near Wake Island, the network configuration (Table 5-8) by necessity included many MSFN sites as well as DOD supporting stations. The network was far from the "standard" Apollo Network shown previously in Table 5-2. The only Apollo USB stations "on-the-line" during Apollo 3 were Merritt Island, Bermuda, and Carnarvon.

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[55]Goddard Space Flight Center, "Network Performance Analysis of the AS-202 Mission (Greenbelt: X-552-66-531, November 17, 1966).

Table 5-8. Network configuration for Apollo 3.

Systems / Stations	Metric Tracking			USB					TLM			CMD		A/G			Data Processing			COMM				Other		
	C-band	Glotrac	ODOP	Ranging	Updata	Telemetry	Voice	Antenna	No. of VHF Links	No. of Decoms	Display	Updata Digital	CMD Destruct	HF A/G	VHF A/G	A/G Record	Data Proc'r	Data Remote	ALDS	HS Data	WB Data	TTY	Voice	Acq Aid	FC Manned	Acq Bus
TEL II									16												X		X	X		
CIF									16	7							X	X	X		X		X	X		
MIL				X	X	X	X	X														X	X			
CNV	X	X	X									X	X		X	X						X	X	X		X
MLA	X																					X	X	X		X
PAT	X																			X		X	X	X		X
GBI	X								16	3		X	X		X	X	X	X	X	X	X	X	X	X		X
GTK	X	X							5	2		X	X		X	X	X	X	X	X	X	X	X	X		X
BDA	X	X		X	X	X	X	X	12	1		X	X		X	X	X	X		X		X	X	X		X*
ANT	X	X							12	3		X	X		X	X	X	X	X	X	X	X	X	X		
ASC	X								3						X							X	X			
CRO	X			X	X	X	X	X	3	1	X	X			X	X	X			X		X	X		X	X*
PRE	X								3						X	X						X	X	X		
MLB									13																	
NSB									13																	
ATF		X																								
ELU		X																								
RKV									4	2	X	X		X			X					X	X	X	X	
CSQ												X		X			X					X	X	X	X	
RTK	X								3					X										X		
WHE	X								2					X	X	X						X	X	X		
TLM Ship									9														X	X		
2 A/C									2						X	X								X		

*BDA and CRO can slave the USB antenna to the Acquisition Bus.

Ship Positions:

RKV: 40.2°W, 12.7°N
CSQ: 130.5°E, 9°.5° S

WHE: 140°E, 1°S
TLM Ship: 38° W, 10°N

Most other support came from DOD stations, the well-remembered Mercury Gemini ships (*Rose Knot* and *Coastal Sentry*), and communication facilities at selected NASA stations.

The MSFN was placed on mission status August 8, 1966, 12 days before launch. Premission activities included tests and simulations. At liftoff, all systems were GREEN except the Carnarvon radar, the Merritt Island tape recorder, the RF command equipment at Antigua, and several other equipments of a noncritical nature. The flight proceeded down the Eastern Test Range, over Africa, and terminated with the heat shield tests during reentry 83 minutes later near Wake Island.

All network equipment performed well with the following exceptions: (1) the White Sands FPS-16 radar did not actively track the spacecraft during reentry because the spacecraft signal strength was lower than expected and the acquisition aid could not bring the radar close enough for active tracking; and (2) a shorted cable shield in the sweep acquisition circuitry at Carnarvon precluded two-way lock with the USB systems. These problems did not compromise the mission.

Apollo 4. This Apollo test flight introduced the Saturn V and also provided the first extended flight test of the network USB equipment. The spacecraft was separated from the S-IVB stage just after the second burn on the second orbit which took the two targets to an 18,000 km apogee prior to the high speed reentry and recovery near Hawaii. (Fig. 5-10) During the apogee pass over Ascension, the spacecraft and S-IVB stage were separated sufficiently so that both the MSFN and DSN 9-m antennas at Ascension could track the objects separately. This was the first time that collocated MSFN and DSN facilities had to operate as a unit. Apollo aircraft (ARIA) were also first tested during this mission.

Apollo 5. During this orbital flight, the complete (but unmanned) Lunar Module was tested under conditions similar to those in lunar orbit. From the network standpoint, prime objectives were to check the compatability of the Lunar Module with the MSFN and to evaluate the network's USB stations both individually and as they were integrated into the network. USB stations at Ascension, Antigua, Bermuda, Canberra, Carnarvon, Grand Canary, Grand Bahama, Guam, Guaymas, Hawaii, Merritt Island, and Texas supported the mission. In addition, the *Redstone* and the *Watertown* (Apollo ships) and the *Rose Knot* and *Coastal Sentry* (Gemini ships) were on station. ARIA tests were also made. In summary, the Earth-orbital portion of the Apollo Network was well exercised during

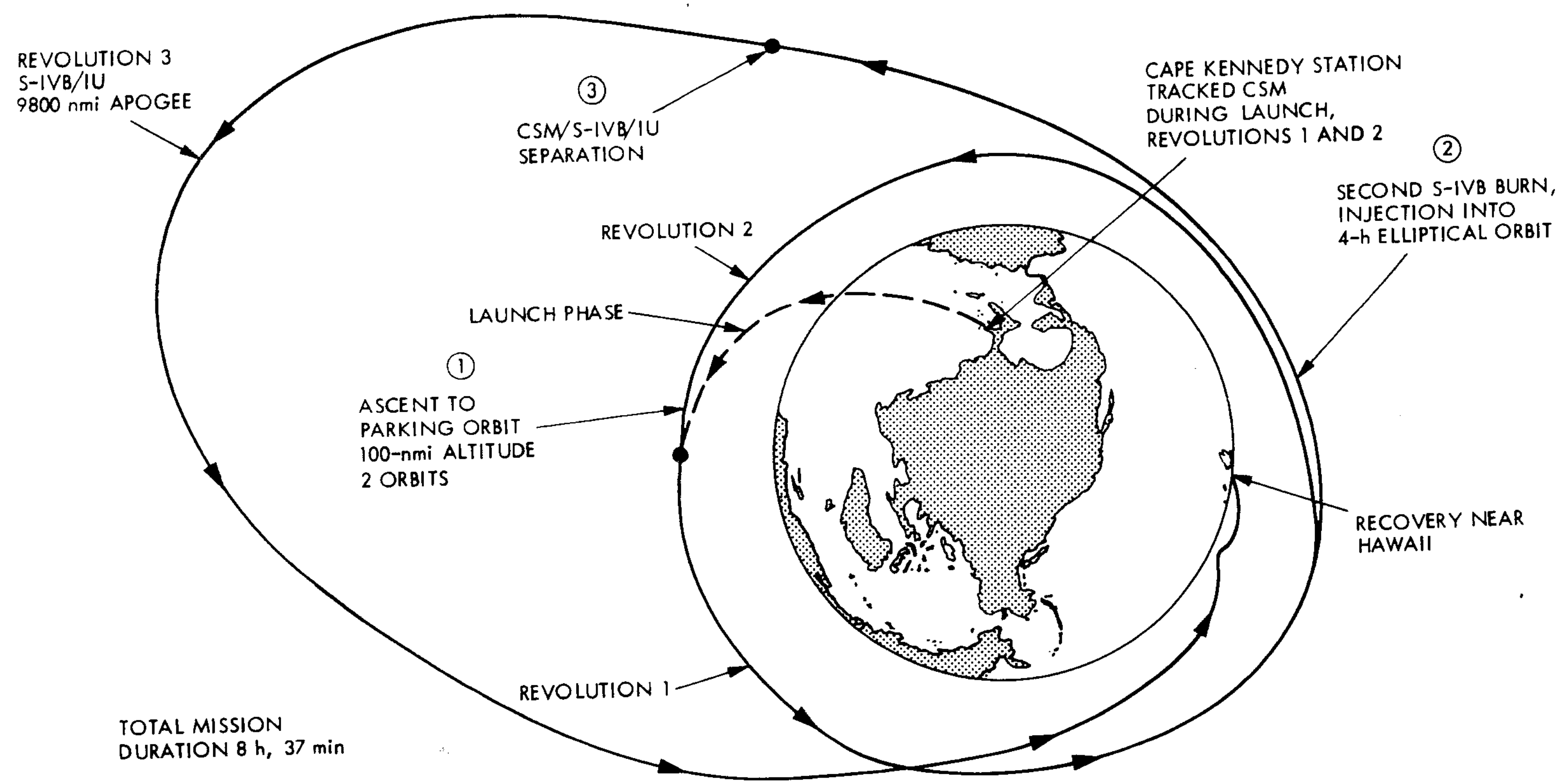

Figure 5-10. The Apollo-4 mission profile.

Apollo 5.[56]

Apollo 6. The Apollo-6 flight was supposed to resemble the successful Apollo-4 test of the Saturn V and spacecraft except that it was planned the S-IVB stage would propel the spacecraft down into the atmosphere at full lunar injection velocity. However, the S-II second stage shut down prematurely during launch and the S-IVB did not restart for the lunar injection burn. The network supported this mission well despite the anomalies. It had been hoped that the MSFN 26-m antennas and the DSN 26-m collocated antennas could be exercised together, but the S-IVB failure precluded this.

Apollo 7. Lasting almost 11 days, the Apollo-7 manned orbital flight checked out the spacecraft in its entirety and provided rendezvous training for the crew with the S-IVB target. For the network, the flight was a complete orbital testing of the communication system, including real-time TV while over the United States. By October 11, 1968, the launch date for Apollo 7, the Apollo Network was essentially ready for manned flights to the Moon.

Apollo 8. The first comprehensive test of the Apollo Network came just before Christmas 1968, when Apollo 8 carried the first men to the vicinity of the Moon, where the spacecraft was inserted into lunar orbit. There was no attempt to land, nor were there attempts at lunar-orbit rendezvous. Launch took place on December 21, 1968, with splashdown in the Pacific on December 27, 1968, for a total flight time of 6 days, 2 hours, and 59 minutes. The major phases of flight are indicated in Fig. 5-11 and the network configuration in Table 5-9. All stations in the "standard" Apollo Network operated together for the first time. Four of the five Apollo ships and six of the eight ARIA were part of the network configuration.

Before describing network performance during the flight, two premission developments must be interjected. These are the so-called Apollo-8 "navigational error" and the diversion of JPL's 64-m antenna to Apollo use.

During the Fall of 1968, Houston engineers became concerned that navigational errors based on terrestrial tracking errors might be sufficient to cause a mission abort. Very bluntly, Houston was afraid that small errors might be magnified causing the spacecraft to plunge into the Moon

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[56]For details on this and subsequent Apollo flights, the "post-mission" reports should be consulted; viz, "MSFN Postmission Report on the As-204 LM Mission," (Greenbelt: May 1968).

Table 5-9. Network configuration for Apollo 8

Station	Code	Tracking					USB			Telemetry					Data Processing			Communications					
Systems:		C-band (High Speed)	C-band (Low Speed)	ODOP	Optical	USB	Voice (A/G)	Command	Telemetry	VHF Links	FM Remoting	Mag. Tape Recording	Decommutators	Displays	642B Telemetry	642B Command	1218	High Speed Data	Wideband Data	Teletype	Voice (SCAMA)	VHF A/G Voice	Video
DOD	CIF											x	x					x	x		x		x
Florida	TEL-4									x	x	x											
facilities	CNV	x		x	x																	x	
	PAT	x	x																				
	MLA	x	x																				
Merritt I.	MIL					x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
Grand Bahama (DOD)	GBI	x	x							x		x											
Grand Bahama	GBM					x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Grand Turk	GTK	x	x			x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Antigua	ANG																						
Antigua (DOD)	ANT	x	x							x		x											
Bermuda	BDA	x	x			x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Ascension (DOD)	ACN					x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Ascension	ASC		x																				
Madrid	MAD					x	x	x	x		x	x	x		x	x	x	x		x	x		x
	MADX					x	x	x	x								x			x	x		
Grand Canary	CYI		x			x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Pretoria	PRE		x																				
Tananarive	TAN		x							x		x								x	x	x	
Carnarvon	CRO	x	x			x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Honeysuckle	HSK					x	x	x	x		x	x	x		x	x	x	x		x	x		x
Creek	HSKX					x	x	x	x								x			x	x		
Guam	GWM					x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Hawaii	HAW		x			x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Vandenburg	CAL	x	x																	x	x	x	
White Sands	WHS	x	x																	x	x		
Goldstone	GDS					x	x	x	x		x	x	x		x	x	x	x		x	x		x
	GDSX					x	x	x	x								x			x	x		
Guaymas	GYM					x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Corpus Christi	TEX					x	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Huntsville	HTV		x			x	x		x			x	x							x	x	x	
Redstone	RED	x	x			x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x
Vanguard	VAN	x	x			x	x	x	x	x	x	x	x		x	x		x		x	x	x	x
Mercury	MER	x	x			x	x	x	x	x	x	x	x		x	x		x		x	x	x	x
	ARIA (6)					x	x		x	x		x									x	x	

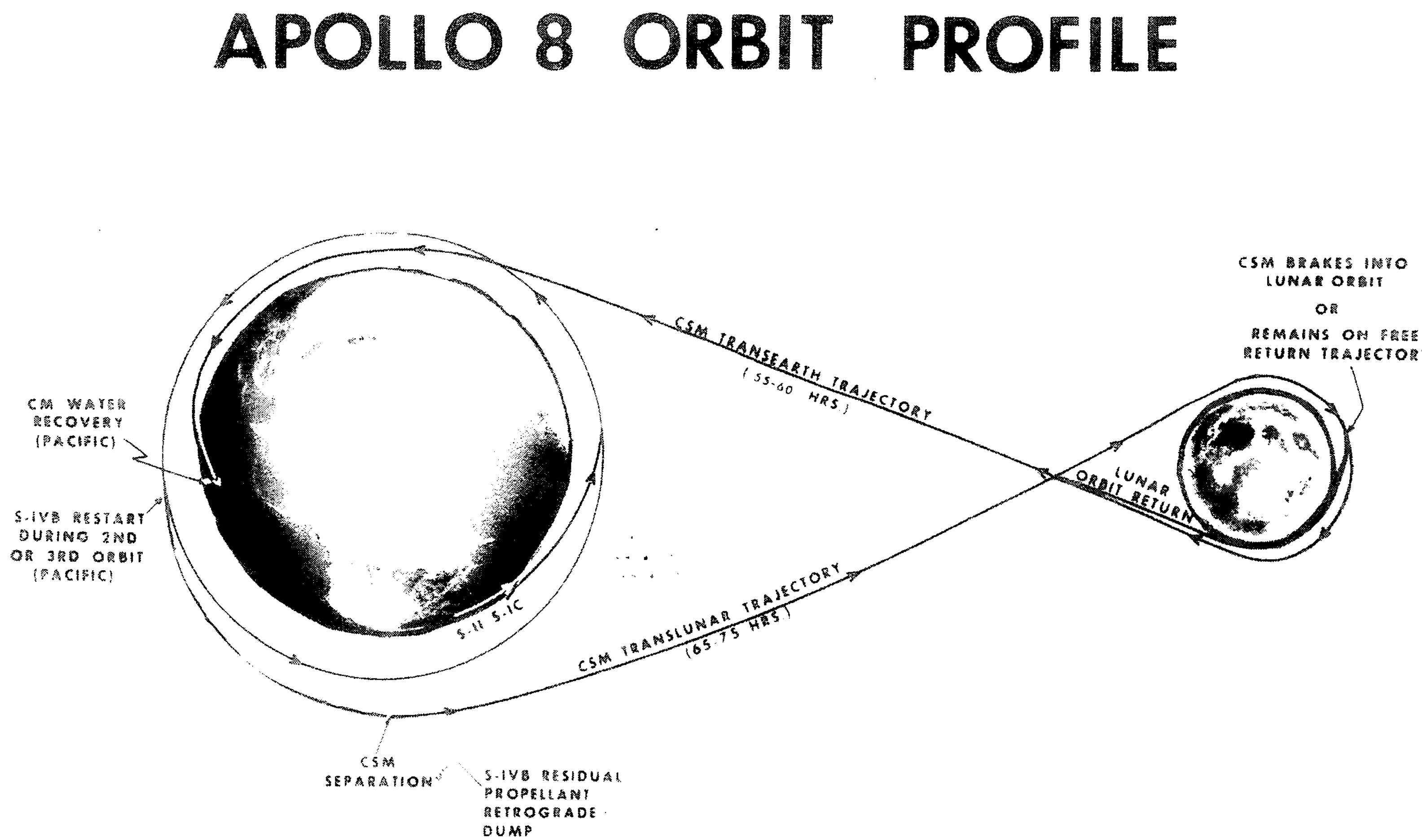

Figure 5-11. The Apollo-8 mission profile.

rather than orbit it. If there was the least doubt in the Mission Director's mind about the accuracy of the navigational data as the spacecraft approached the Moon, he would direct the astronauts to swing around the Moon and return rather than settle down for the planned ten orbits. To increase their confidence in their navigational techniques, Houston asked for help from JPL, an organization with more experience than anyone else in lunar navigation.[57]

During the last half of November and the first half of December 1968, JPL checked out the Houston navigational techniques. JPL concluded that Houston software introduced some errors but that the errors introduced by incorrect tracking station locations could be amplified at the Moon. For example, an error of 100 meters in tracking station coordinates could lead to a 10-kilometer error in lunar orbit altitude.[58] It appeared that MSFN station location data in the Houston computer programs needed to be improved if an abort at the Moon were to be avoided due to a potential near miss or just loss of confidence in navigation techniques. JPL recommended that Goddard and Houston use geographical corrections based on their collocated DSN stations and their tracking of Lunar Orbiters. Goddard and Houston agreed and, less than two days before the launch of Apollo 8, the new coordinates were introduced into the computers at Houston. During the actual flight, the navigational equipment onboard the spacecraft agreed with the terrestrial tracking system (400,000 kilometers away) to within one kilometer.

While the search for the highest possible confidence in lunar navigation led to a last-minute change in MSFN station reference coordinates, the concern over lunar communications brought the Goldstone 64-m antenna into the network during Apollo 8. The successful Apollo-7 flight had created confidence that Apollo 8 could be upgraded from an Earth-orbital mission to the lunar-orbital flight, but there remained one piece of spacecraft equipment that had not yet been checked out in space--the high-gain antenna.[59] If this antenna system failed near the Moon, the MSFN and DSN 26-m antennas would not be able to receive the spacecraft's high-

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[57]JPL Interoffice memorandum from T.W. Hamilton to W.H. Bayley entitled, "JPL Contribution to Apollo 8 Navigation," dated January 1, 1969.

[58]Interview with Thomas W. Hamilton, March 23, 1971.

[59]F.M. Flanagan, P.S. Goodwin, and N.A. Renzetti, "Deep Space Network Support of the Manned Space Flight Network for Apollo, 1962-1968." (Pasadena: JPL TM 33-452, July 15, 1970), p. 133.

bit-rate signal. Houston considered this an unnecessary risk and, in a meeting in October 1968, JPL was told that the 64-m antenna was an absolute requirement for Apollo 8, for only it would be sensitive enough to pick up the spacecraft signal should the high-gain antenna fail.[60] With only two months remaining before the Apollo-8 launch, the 64-m Mars facility at Goldstone had to be reconfigured so that it could feed signals to the MSFN prime 26-m site at Goldstone, which then could relay them through NASCOM to Houston. The Space Flight Operations Facility (SFOF) at Pasadena also had to be called in to generate predictions for the 64-m antenna, which did not possess autotrack capabilities. These problems were solved by December 20, and the 64-m antenna was available for Apollo flights when needed. On later flights, the 64-m dish proved essential for receiving color TV pictures from the Moon.

Apollo 8 was also the first mission during which all three collocated DSN stations (Goldstone, Tidbinbilla, and Robledo) were called upon to support the MSFN. DSN support was excellent and assumed more importance than originally planned in the years preceding the lunar missions. For example, when the spacecraft was in view of Goldstone during the flight to the Moon three Goldstone antennas were receiving signals simultaneously: the MSFN 26-m antenna, the DSN 26-m Pioneer dish, and the DSN 64-m Mars dish. Generally, the best data stream was selected automatically by computers at the MSFN prime station and relayed to Houston via NASCOM. As the spacecraft neared the Moon, the superior data-receiving capabilities of the 64-m antenna were used more and more. Instead of switching spacecraft transmissions to low-data-rate modes receivable by the 26-m dishes, the high data rates were used with the 64-m antenna when Goldstone could see the spacecraft.

Support by MSFN stations was also excellent. Two classes of problems did arise, although none of these affected the mission:

1. Voice remoting via the six ARIA assigned to the Pacific[61] sector was successful on less than half the attempts to VHF frequencies. S-band relay proved far superior.

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[60] Interview with Paul S. Goodwin, March 23, 1971.

[61] Two Pacific ARIA assigned to monitor the translunar injection were moved to the Atlantic following this phase so that they would be in position to cover a mission abort should it occur.

2. Although most USB tracking data met mission requirements, many minor discrepancies cropped up, particularly during the lunar orbits. The lunar orbit problem was different from the "navigation error" situation described earlier. The MSFN USB systems had experienced some difficulty in determining lunar orbits from tracking exercises using Lunar Orbiter. Similar difficulties arose during Apollo 8. It soon became clear that the source of the problem lay in the mathematical model of the lunar gravitational field.[62] Scientists at JPL later hypothesized that mass concentrations, the well-known "mascons," near the lunar surface perturbed lunar satellites.

Apollo 9. Because Apollo 9 was an Earth-orbital flight only, network requirements were less severe than they had been for Apollo 8. For example, the DSN wings were not required except for the wing at Canberra (Tidbinbilla), which was needed because the Lunar Module and Command Service Module were too far apart during orbital tests for the MSFN Honeysuckle Creek station to work both spacecraft.

Although there were the usual minor equipment failures and operator errors, the network followed the launch, the maneuvering, the rendezvous, Lunar Module tests, docking, and reentry phases with high reliability. One important mission change was handled by the network very easily: the reentry was delayed one orbit by rough seas, and the recovery area consequently moved 480 km north and east.

Apollo 10. With all spacecraft hardware proven in Earth orbit, the focal point of Apollo moved again to the Moon for Apollo 10. Everything was done except actually land on the Moon. Many of the "firsts" accomplished during this mission involved the network:

1. First real-time color TV from the Moon
2. First mission with two manned spacecraft in lunar orbit
3. First lunar rendezvous

The network configuration for Apollo 10 was essentially the same as it was for Apollo 8. Again, the DSN 64-m antenna was pressed into service, this time because of the additional communication capacity required by the addition of color TV. OTDA informed JPL of the possibility of color TV on April 9, 1969, about 6 weeks before the planned launch. JPL planning proceeded on the basis that color TV would definitely be a feature of the mission. The confirming teletype message arrived May 12, 1969--six days before launch.

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[62]Goddard Space Flight Center, "MSFN Metric Tracking Performance Report AS-503," (Greenbelt: X-832-69-69, February 1969). p. 23.

Once again the evolving mission requirements demanded closer and closer involvement of DSN in Apollo operations. The presence of two separated spacecraft in lunar orbit also necessitated the promotion of backup DSN 26-m antennas to "prime" elements of the network as the collocated MSFN and DSN antennas tracked the two spacecraft separately.

Throughout the 192-hour mission, the network performed well, with only the usual minor equipment failures and operator errors. Software limitations (computer programs) interfered with command capabilities at some stations when command histories were being processed. This was not serious and is mentioned only to illustrate that, in a machine as large and as complex as the Apollo Network, all interactions cannot be predicted in advance.

Apollo 11. The landmark Apollo-11 flight placed men on the Moon and returned them safely to Earth. All of the preceding Apollo flights constituted a step-by-step progression toward this goal. All phases of manned lunar flight were involved (Fig. 5-12), and the Apollo Network was at its greatest extent, as indicated in Table 5-10).

Apollo 11 was similar to Apollo 10 except that the Lunar Module made the final descent to the surface on this flight and the astronauts explored the surface. The astronauts made sample-collecting tours and set up EASEP, the Early Apollo Scientific Experiments Payload. Hundreds of millions of people around the world saw the astronauts step onto the lunar surface and followed their activities on the bleak terrain. The whole event seemed so near that one might have thought the program came from New York or Los Angeles studios instead of a lifeless spot where man had never been before. The impact of this great technological achievement was multiplied greatly by the ability of the Apollo Network to pick up the TV signals from the Moon, collect them via cables and communication satellites from stations around the world, and route them to conventional TV circuits.

During the preparations for the Apollo-11 flight, it became apparent that the Goldstone 64-m dish would not be able to see the Lunar Module during the critical walk on the Moon--and the extra gain of the 64-m antenna was needed for good television coverage of this historic event. The schedule called for the Moon walk to begin when the spacecraft was in view from Australia, but the MSFN had only 26-m paraboloids in Australia. However, west of Sydney, at Parkes, the Australians operated a 64-m antenna as part of their research program in radio astronomy. By tapping this antenna through an existing microwave link, the Moon walk

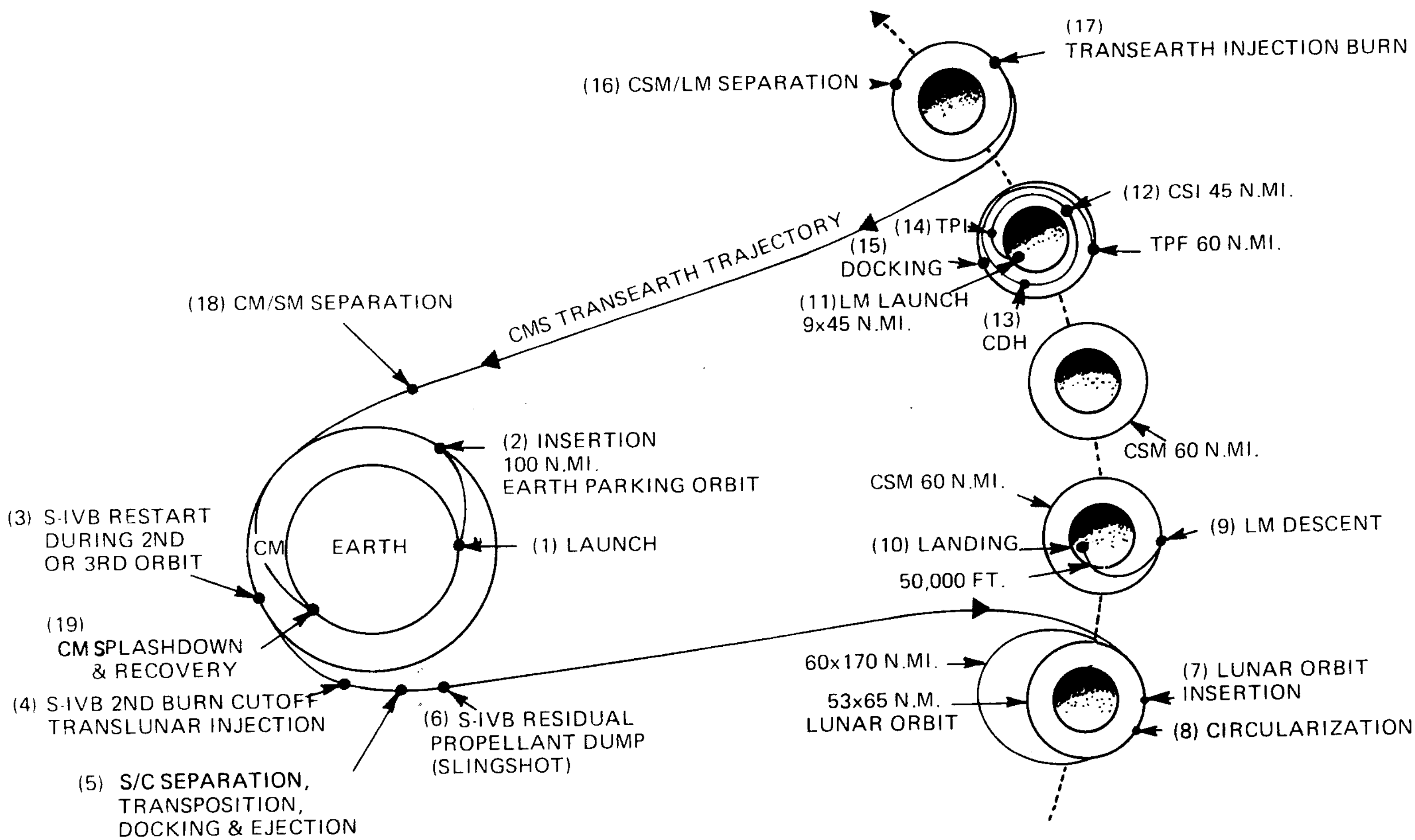

Figure 5-12. The Apollo-11 mission profile.

Facilities \ Systems	C-band (High Speed)	C-band (Low Speed)	ODOP	USB	Optical	TV to MCC	Voice	TLM	Command	VHF Links	FM Remoting	MAG Tape Recording	Decoma	Displays	CMD Destruct	642B TLM	642B CMD	CDP	1218	High Speed Data	TTY	Voice (SCAMA)	Voice VHF A/G	Riometer	SPAN	
PAT	x	x													x											Note 1
CMV	x	x																								
MLA	x	x																								
MIL				x			x	x	x	x	x	x	x			x	x		x	x	x	x	x			
GBI	x	x													x											Note 2
GBM				x			x	x	x	x	x	x	x			x	x		x	x	x	x	x			
ANT	x	x													x											
ANG				x			x	x	x	x	x	x	x			x	x		x	x	x	x	x			
BDA	x	x		x			x	x	x	x	x	x	x		x	x	x		x	x	x	x	x			
CYI				x			x	x	x	x	x	x	x			x	x		x	x	x	x	x	x	x	
ASC	x	x																		x						
ACS				x			x	x	x	x	x	x	x			x	x		x	x	x	x	x			
PRE		x																								
TAN		x								x		x									x	x	x			
GRO	x	x		x			x	x	x	x	x	x	x			x	x		x	x	x	x	x	x	x	
GWM				x			x	x	x	x	x	x	x			x	x		x	x	x	x	x			
HAW	x	x		x			x	x	x	x	x	x	x			x	x		x	x	x	x	x			
CAL		x																			x	x	x			
GDS				x		x	x	x	x		x	x	x			x	x		x	x	x	x				
GYM				x			x	x	x	x	x	x	x			x	x		x	x	x	x	x			
TEX				x			x	x	x	x	x	x	x			x	x		x	x	x	x	x			
HSK				x		x	x	x	x		x	x	x			x	x		x	x	x	x				
MAD				x		x	x	x	x		x	x	x			x	x		x	x	x	x				Note 2
ARIA (8)				x			x	x		x		x									x	x	x			
RED		x		x			x	x	x	x	x	x	x			x	x	x	x	x	x	x	x			
VAN	x	x		x			x	x	x	x	x	x	x			x	x	x	x	x	x	x	x			
MER RTV		x		x			x	x	x	x	x	x	x			x	x	x	x	x	x	x	x			
RTV		x		x			x	x	x	x		x	x					x	x		x	x	x			
MARS (64-m)						x					x															Note 4
PARKES (64-m)						x					x															Note 4
GTX	x	x													x						x		x			
ADCC																										
GDSX				x			x	x	x										x							Note 3
HSBX				x			x	x	x										x							Note 3
XADC				x			x	x	x										x							

Note
1. launch phase
2. launch & earth orbit phase
3. post TLI coverage
4. lunar surface operations only

could be televised. NASA negotiated an agreement with the Australian Government whereby the Parkes antenna could be used to augment the MSFN for the television portion of the Moon walk. As it turned out, the Moon walk began early and considerable television coverage was possible with the Goldstone 64-m dish. Later, when the Lunar Module came into view of the Parkes antenna, it was brought into the MSFN.

The DSN 210-ft antenna at the Goldstone Mars site was added to the network during lunar operations for two reasons: (1) the reception of color TV signals; and (2) the reception of high-bit-rate telemetry during the critical descent of the Lunar Module should the spacecraft's steerable S-band antenna falter. These are the same reasons the 64-m dish was requested on earlier missions. Diversion of the antenna to Apollo required interruption of tests in preparation for the encounter of Mariner 6 with Mars, which occurred only ten days after Apollo lunar surface operations.

Besides adding the Parkes 64-m antenna to the network, the fleet of ARIA was increased from the six aircraft employed during Apollo 11 to the full eight. At launch, three ARIA were positioned at both Darwin and Guam, one at Cocos, and one at Mauritius. This deployment provided maximum translunar injection (TLT) coverage for all possible launch azimuths. Only three ARIA were used during reentry. All were based at Hickam Field, Hawaii, and flew into positions southwest of Hawaii to receive voice and telemetry signals from the reentering spacecraft.

The deployment of the eight ARIA and the four remaining Apollo ships represented the maximum use made of mobile stations during the Apollo program. Apollo 11 was a difficult and critical mission; for it the network was at its peak in geographical extent and flexibility.

Apollo 11 carried the first of the active scientific "packages" to be left behind on the Moon. EASEP was a short-lived, battery-powered group of scientific experiments which had to be monitored and commanded by the Apollo Network. Communication between the Apollo stations and EASEP consisted of a direct command uplink at 2119 MHz and a downlink for telemetry at 2276.5 MHz. The telemetry bit rate was normally 1060 bits/sec. A helical antenna for EASEP was set up by the astronauts and pointed at Earth before their departure.

During lunar operations, there were four sources of communication signals: the two astronauts, the Lunar Module, and the Command Module in orbit, as shown in Fig. 5-13. From the network standpoint, its collocated 26-m antennas saw only two sources: the antennas on the Lunar Module and those on the Command Module. Of course, EASEP constituted a third

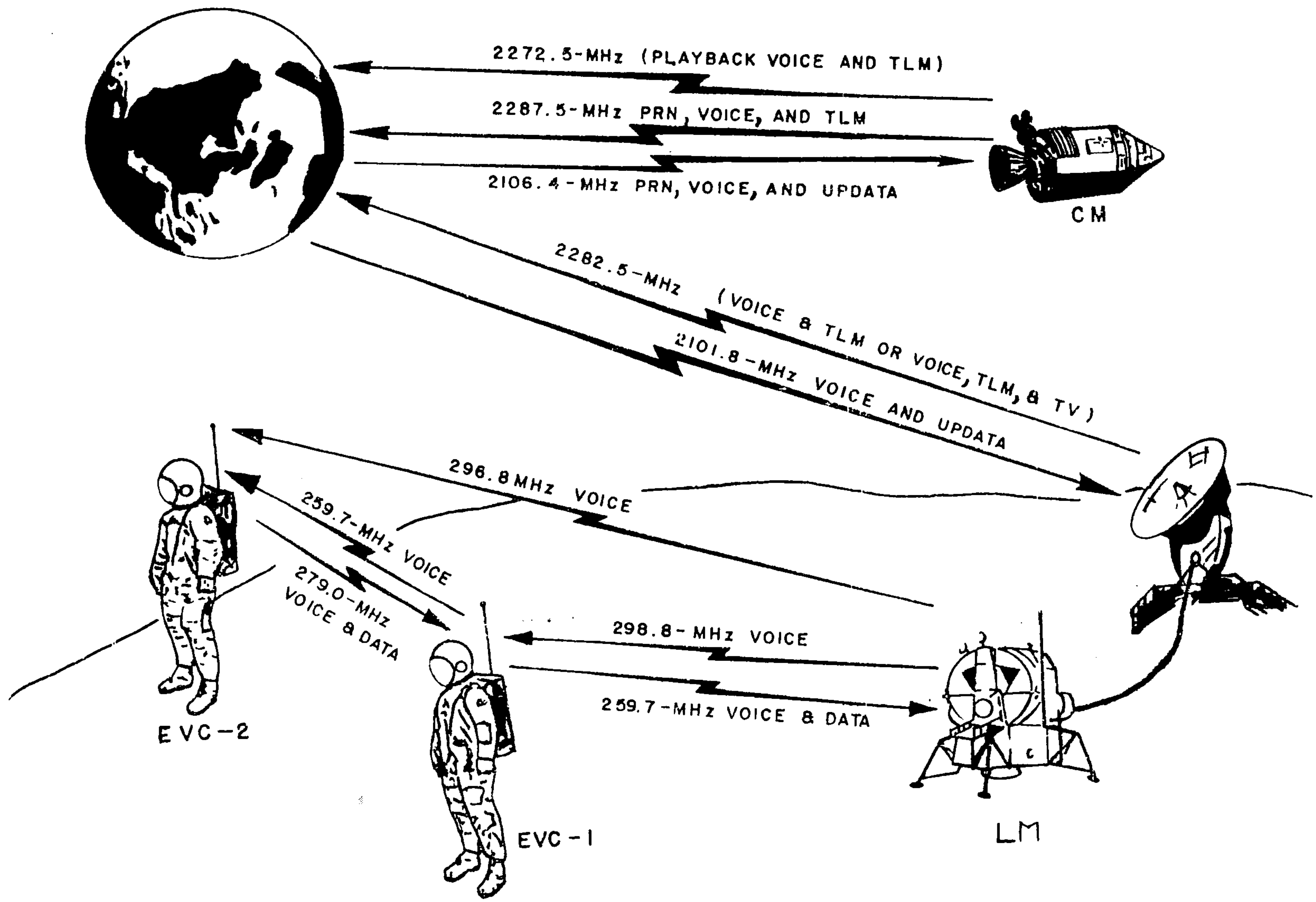

Figure 5-13. Communications during lunar surface operations on the Apollo-11 flight.

signal source after the astronauts had adjusted it for maximum reception. However, to receive EASEP transmissions an Apollo Network station had to be reconfigured as indicated in Fig. 5-14. This operation required about 70 minutes, while 115 minutes were needed to return the station to Apollo-11 support.

Tracking and data acquisitions during the entire Apollo-11 mission were outstanding. The difficulties that did crop up were minor--the inevitable equipment failures and operator errors that occur with any very large machine. Typical during Apollo 11 were minor data losses due to recorder failures, problems with the USB public address system, and insignificant loss of tracking information when the 1218 computers at five stations faltered. Most of the Apollo-11 problems were procedural rather than outright equipment failures. For example, the handovers from one station to another were not flawless. Important tracking data were lost on one occasion when a station terminated the uplink carrier 30 seconds early. In no way, however, was the mission compromised by any of these errors and failures. Indeed, one cannot completely avoid such problems, and the network performed successfully despite them because sufficient redundancy and flexibility were originally built into it.

An excellent example of redundancy, human ingenuity, and hard work occurred at the DSN wing at the Tidbinbilla station, in Australia, while the Apollo-11 astronauts were on their way to the Moon. A fire caused by a short in the power supply for transmitter #2 caused extensive damage to internal parts and some melting of metalwork. "Fortunately," spares for long-leadtime items were available at the station. Wiring and other needed components were removed from obsolete gear. Working around the clock with the assistance of the crew at the nearby MSFN prime station at Honeysuckle Creek, the transmitter was again available to the Apollo Network in a little over a day. It is important to note that transmitter #1 was tracking the spacecraft when the fire broke out and that by virtue of intentional redundancy mission support was unaffected.

Apollo 12. The launch of Apollo 12 was marked by two events which modified network support slightly but did not materially affect the success of the mission. During the countdown, weather conditions and the need to replace a spacecraft fuel cell necessitated changing the launch azimuth to 106°. In response, an extra ARIA was placed on alert, the *Vanguard* was moved to a new station, and the MSFN station at Antigua was reactivated.

Approximately 36 seconds after liftoff and again at

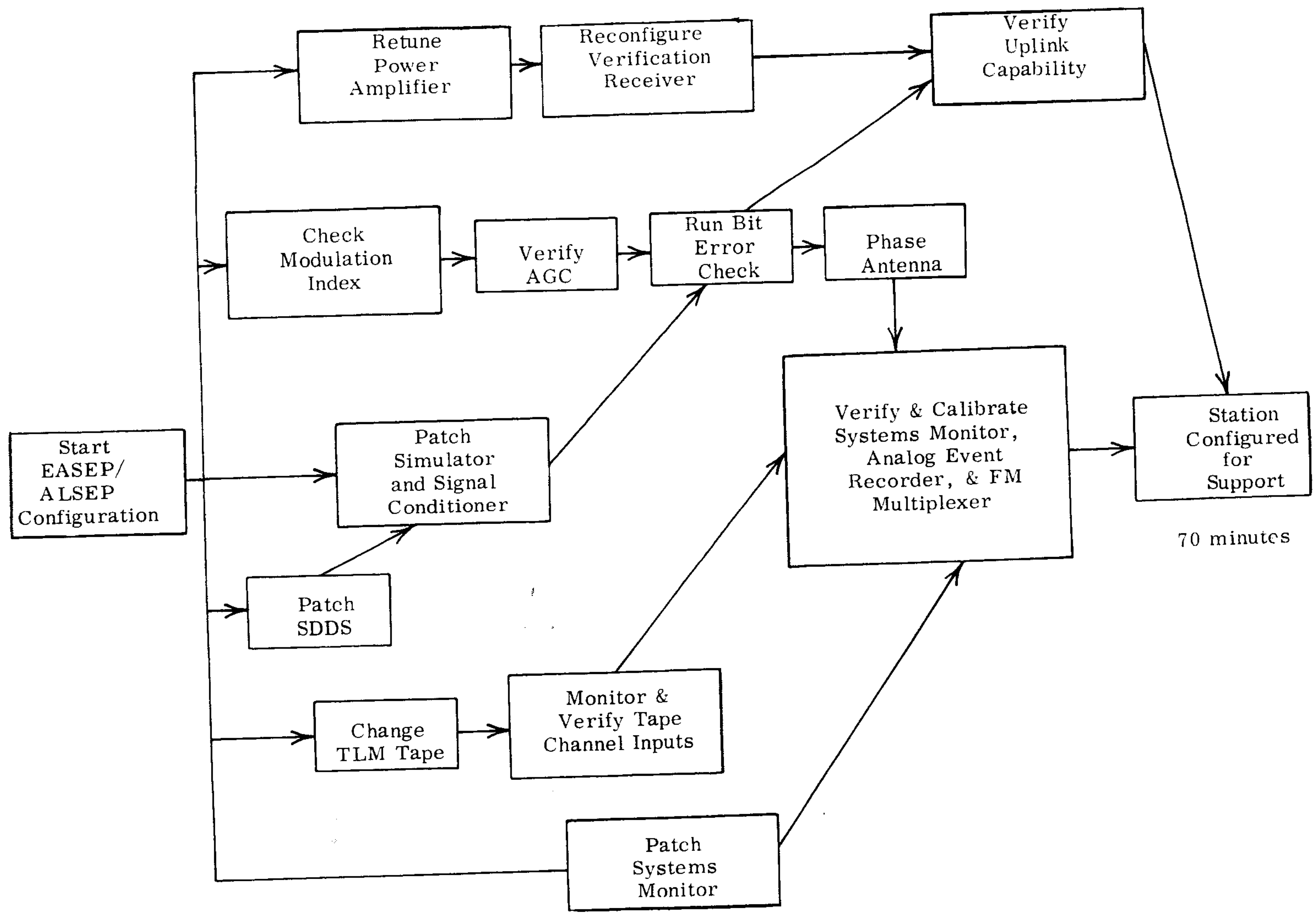

Figure 5-14. Configuration changes necessary to convert an MSFN station from mission support to EASEP/ALSEP support.

52 seconds, an electrical discharge tripped numerous spacecraft circuit breakers. The guidance system on the S-IVB and prompt action by the crew prevented an abort of the mission. However, during orbital flight and the translunar flight, the crew had to realign the spacecraft guidance platform and make many additional checks to ascertain that all was ready for the lunar landing mission. For the first time, the spacecraft was placed in a non-free-return lunar trajectory, meaning that the spacecraft propulsion system had to work properly when they reached the Moon. The remainder of the mission was executed flawlessly through the successful reentry and splashdown ten days later, about 3300 km southwest of Hawaii.

With the experience of 11 previous Apollo flights, it had become apparent that the network did not require as many ships and aircraft as originally planned. The ARIA history is one of repeated reduction in number until only four are now needed for Apollo flights. The number was reduced from twelve to eight when ARIA were permitted a 24-hour turnaround time so that the same planes could cover both the Atlantic and Pacific. Then, it was discovered that by shaping the Earth orbit properly the two-ocean problem could be made a one-ocean problem, eliminating the need for ARIA in the Atlantic. In addition, experience with Saturn-V launches showed that the azimuth window (which strongly affected the amount of territory the ARIA had to monitor) could be cut from 70-108° down to 72-96° for nominal launches. As a consequence, four ARIA are now sufficient.

The original network plan had called for five Apollo ships to cover orbital insertion, translunar injection, and reentry. In 1968, the number was reduced to four, one in the Atlantic and three in the Pacific, when the *Watertown* was turned back to DOD for WTR use on October 7, 1968. Flight experience showed again that the network was designed conservatively. The narrowing of the Saturn-V launch-azimuth window and other changes in flight requirements made it possible to cover the critical injection and post-injection events over the Pacific from land stations, thereby eliminating the need for the two injection ships. NASA thus released the *Redstone* and *Mercury* over to DOD, which assigned the *Redstone* to the ETR and turned the *Mercury* over to the Maritime Administration in San Francisco. In the Pacific, the reentry corridor was narrowed, and adequate coverage could be provided by land stations and aircraft. Consequently, the remaining reentry ship, the *Huntsville*, was released for DOD use on the WTR.

The deactivation of the MSFN Antigua station prior to Apollo 12 was also part of the network-wide consolidation trend. The consolidation of the network through the deactivation of stations does not infer a reduction of overall network capabilities. In fact, during the later Apollo flights the network had more to do than ever before.

During the important checkout of the Lunar Module following the electrical discharge that occurred right after liftoff, the network 26-m antennas had to call upon the DSN Mars 210-ft antenna for unscheduled support. The Lunar Module and the S-IVB transmit on the same frequency and, because the two spacecraft had not separated far enough, the 26-m antennas received both signals and could not resolve them. The 64-m antenna, which was following the flight for training purposes, was able to point at the Lunar Module with its much narrower beam and keep the S-IVB out of the main beam. The only usable Lunar Module telemetry was received by the 64-m antenna during this early, unplanned checkout of this spacecraft. The 64-m antenna came in handy again when the Command Module signal level dropped sporadically by 10-12 db; the big antenna was the only one in the network able to receive the data without any degradation.

The introduction of the first ALSEP (Apollo Lunar Surface Experiment Package) during Apollo 12 required that MSFN stations remain active in a data acquisition role long after the astronauts have returned to Earth. Whereas the Apollo-11 EASEP was powered by short-lived batteries, the ALSEPs received electricity from a Radioisotope Thermoelectric Generator (RTG) and may return scientific data from the Moon for years (two years nominal). (Fig. 5-15) The ALSEPs include such scientific instruments as ion detectors, seismometers, magnetometers, and heat flow detectors. Those ALSEPs with passive seismic experiments (no artificially induced seismic waves) can be worked by the 9-m MSFN dishes. The active seismic experiments on later ALSEPs required the 26-m dishes to handle the larger data stream. The network configuration for ALSEP operations is shown in Table 5-11. The steps taken at each station to convert to ALSEP operations were the same as those presented for EASEP in Fig. 5-14.

The normal ALSEP downlink transmits PCM telemetry at 1060 bits/sec with a contingency rate of 530 bits/sec (the same as EASEP). Each supporting network site incorporates a special Remote Site ALSEP Processor (RSAP) which processes the data stream for transmission to Goddard where more processing is done. Goddard then transmits the data to Houston for analysis. Commands from Houston flow in the opposite direction.

The only other phenomenon worth mentioning in this brief summary involves the 642B remote site computer, which

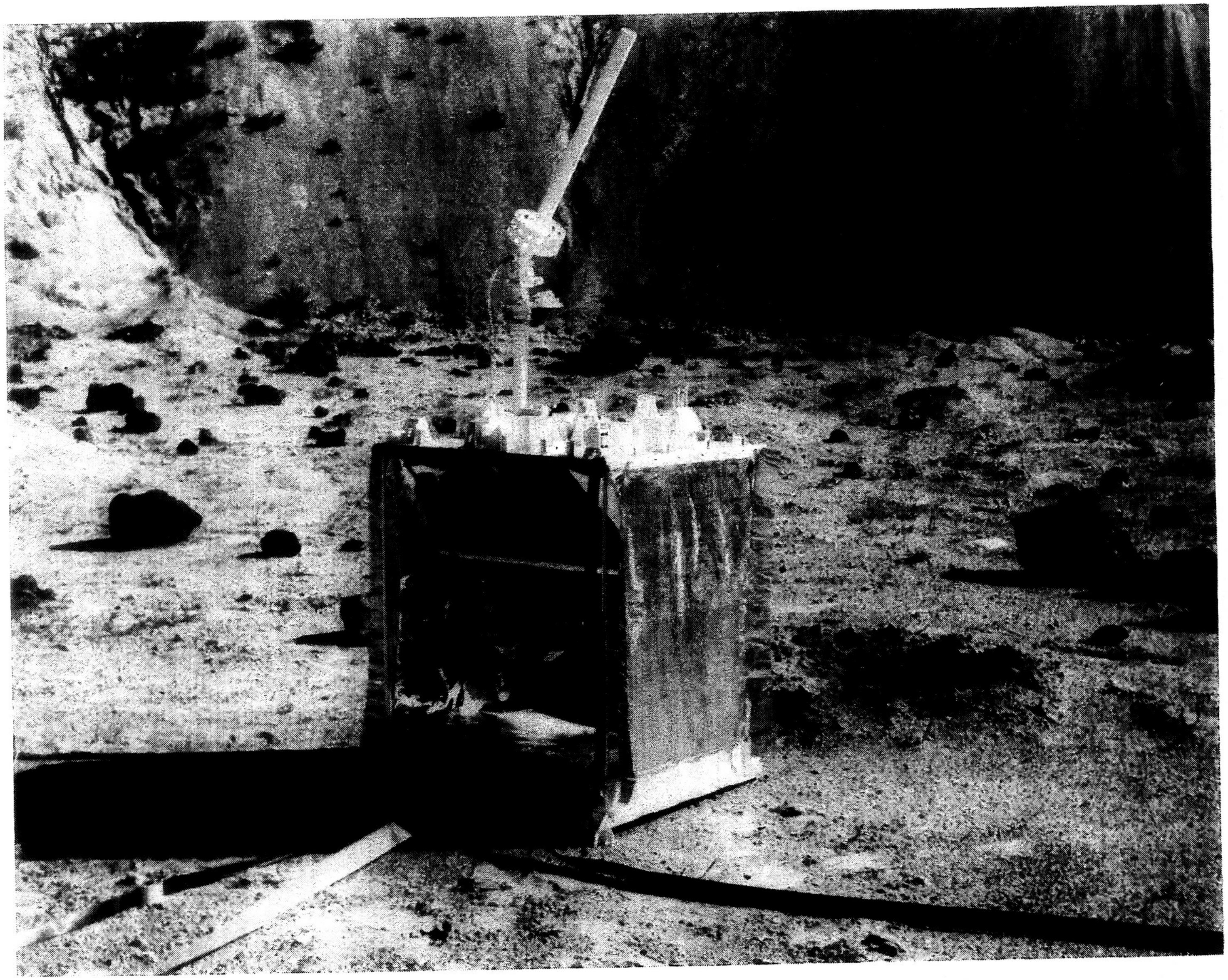

Figure 5-15. The ALSEP unit deployed on the lunar surface on Apollo 12.

Table 5-11. ALSEP Configuration of the Apollo Network

MSFN SITE	Code	USB 26-m Dual	USB 9-m Single	USB 9-m Dual	Voice	Teletype	RSAP[b]
Ascension	ACN			x	x	x	x
Bermuda	BDA		x		x	x	x
Carnarvon	CRO			x	x	x	x
Canary Island	CYI		x		x	x	x
Guaymas	GYM			x	x	x	x
Goldstone[a]	GDS	x			x	x	x
Goldstone Wing[a]	GDSX	x					
Guam	GWM			x	x	x	x
Hawaii	HAW			x	x	x	x
Honeysuckle Creek[a]	HSK	x			x	x	x
Honeysuckle Wing[a]	HSKX	x					
Merritt Island	MIL			x	x	x	x
Madrid[a]	MAD	x			x	x	x
Madrid Wing[a]	MADX	x					
Texas	TEX		x		x	x	x

[a]Required for active seismic experiment

[b]Remote Site ALSEP Processor

experienced numerous faults during this mission. There were 15 unexplained computer faults at Goldstone. Seventeen telemetry and six command computer faults at Hawaii reduced confidence in the station computers and the station was removed from backup status.

Despite the computer faults and other minor problems, overall support of the mission was excellent.

Apollo 13. The disposition of Apollo Network resources was basically the same for Apollo 13 as it was for Apollo 12 five months earlier. The network configuration, Table 5-12, was essentially unchanged. For the first 56 hours of flight, all went well, except that one of the Saturn-V second-stage engines shut down 2 minutes and 10 seconds early. The other engines compensated by burning longer. Then, the unexpected happened; one of the 66-cm oxygen tanks ruptured, causing the first flight mission abort in the Apollo program.

With a full-scale emergency, the most important test of the network was at hand. The response of the network was described by Gerald Truszynski in his statement before Congress in the spring during the NASA appropriation hearings of 1971:

> From the time of the initial warning by Astronaut John Swigert--"Houston, we've had a problem"--until splashdown some three and one-half days later, the network continuously received and transmitted data between the Apollo-13 crew and the Mission Control Center located in Houston, Texas. The problem, a ruptured oxygen tank, had produced the worst crisis in the nine years of American manned space flight. The steady stream of data carried by the network from Apollo 13 to the Control Center during this emergency period permitted project personnel to evaluate the spacecraft system and the condition of the astronauts.
>
> Using telemetry data received by the network stations, personnel were able to simulate on the ground the conditions existing within the spacecraft, even though Apollo 13 was almost a quarter of a million miles from Earth. The earthbound scientific and engineering personnel were then able to explore alternate flight procedures for the astronauts and, after verifying the feasibility of the alternates, send the necessary commands to the spacecraft via the network.

Table 5-12. Network Configuration for Apollo 13

Systems	TRACKING		USB					TLM				DATA PRO-CESSING				COMM				OTHER		REMARKS
	C-band (High-Speed)	C-band (Low Speed)	USB	TV to MCC	Voice	TLM	Command	VHF Links	FM Remoting	Mag Tape Recording	Decoms	642B TLM	642B CMD	CDP	1218	High-Speed Data	TTY	Voice (SCAMA)	Voice VHF A/G	Range Safety	SPAN	
ACN			X		X	X	X	X	X	X	X	X	X		X	X	X	X	X			
ANT																				X		
ARIA(4)			X		X	X		X		X							X	X	X			Note 1
ASC																						
AOCC																	X		X			
BDA	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		
CNV																				X		
CRO	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	
CYI			X		X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	
GBI																				X		
GDS			X	X	X	X	X		X	X	X	X	X		X	X	X	X	X			
GDS-X			X		X	X	X								X							Note 2
GTK																				X		
GWM			X		X	X	X	X	X	X	X	X	X		X	X	X	X	X			
GYM			X		X	X	X	X	X	X	X	X	X		X	X	X	X	X			
HAW		X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X			
HSK			X	X	X	X	X		X	X	X	X	X		X	X	X	X				
HSK-X			X		X	X	X								X							Note 2
MAD			X	X	X	X	X		X	X	X	X	X		X	X	X	X				
MAD-X			X		X	X	X								X							Note 2
MARS				X	X	X			X													Note 2
MIL			X		X	X	X	X	X	X	X	X	X		X	X	X	X	X			
MLA		X																		X		
PAT																				X		
TEX			X		X	X	X	X	X	X	X	X	X		X	X	X	X	X			
VAN	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			

Note

1. TLI and reentry
2. Post TLI coverage

Typical of the "fixes" contrived by engineers on the ground was an apparatus for purifying the air in the Lunar Module which became the astronauts' "lifeboat." After checking out the apparatus on the ground, flight controllers at Houston instructed the Apollo-13 crew how to build a fresh-air circulation system from spacesuit hoses, plastic bags, and tape. Drawing air from the Command Module purifiers, the Lunar Module then became a safe refuge. Good network communications with the spacecraft were vital during this trying time. Even though the spacecraft transmitter power levels had to be cut back drastically to conserve power, the network was able to maintain continuous real-time voice communications with Apollo 13.

Because of the low spacecraft transmitter power levels, the DSN 64-m antenna at the Goldstone Mars site again became an important feature of the network. In addition, NASA requested that the Australian 64-m radio astronomy antenna at Parkes be reconfigured quickly to help cope with the emergency.

When the oxygen tank rupture occurred, the spacecraft was already well into its translunar flight. There was nothing that could be done to shorten the mission except cancel the lunar orbit and landing phases of the flight and let the spacecraft swing around the Moon and be pulled back to Earth by gravity. (Fig. 5-16) This is what happened and, with careful husbanding of electrical power and consumables, the astronauts splashed down safely in the Pacific approximately 143 hours after launch.

During the mission, the usual minor operator and equipment errors cropped up. Generally, mission support was outstanding, and the network was truly the astronauts' "lifeline" to Earth.

After the safe recovery of the astronauts, attention shifted to the analysis of the accident. The great bulk of information transmitted back to Earth from an Apollo spaceship is in the form of telemetry rather than the voice messages one hears on TV and radio. This heavy flow of engineering data, consisting of instrument readings from all over the spacecraft and launch vehicle, is recorded at the network stations for later analysis. Valuable clues about the origin of the oxygen tank rupture were found when the magnetic tapes were studied by engineers. With these data, the Apollo-13 Review Board was able to pinpoint the events that led up to the explosion and recommend changes in spacecraft design.

Apollo 14 and Apollo 15. After the crisis of Apollo 13, NASA's next two lunar landing missions, Apollo 14 and Apollo 15, were near-perfect from the standpoints of results and network performance. The network was roughly the same configuration in both instances. The configuration, shown in Table 5-13 and Figs. 5-17 and 5-18, resembles that of Apollo 13, except that the Guaymas station, in Mexico, has been eliminated. With 13 Apollo flights behind it, NASA felt that mission coverage from Hawaii, Goldstone, and Corpus Christi was adequate. Consequently, Guaymas was dropped from the network.

The major new piece of Apollo equipment, the Lunar Roving Vehicle (LRV), was used with great success on Apollo 15. (Fig. 5-19) The range over which the astronauts can operate from the Lunar Module is limited normally by the short lunar horizon. To extend this range, NASA developed the Lunar Communications Relay Unit (LCRU), which acts as a portable relay station for voice, TV, and telemetry between 15, the LCRU was carried directly on the Lunar Roving Vehicle and, when the vehicle's dish antenna was pointed at Earth, transmitted signals directly to waiting 26-m or 64-m antennas. (Fig. 5-20).

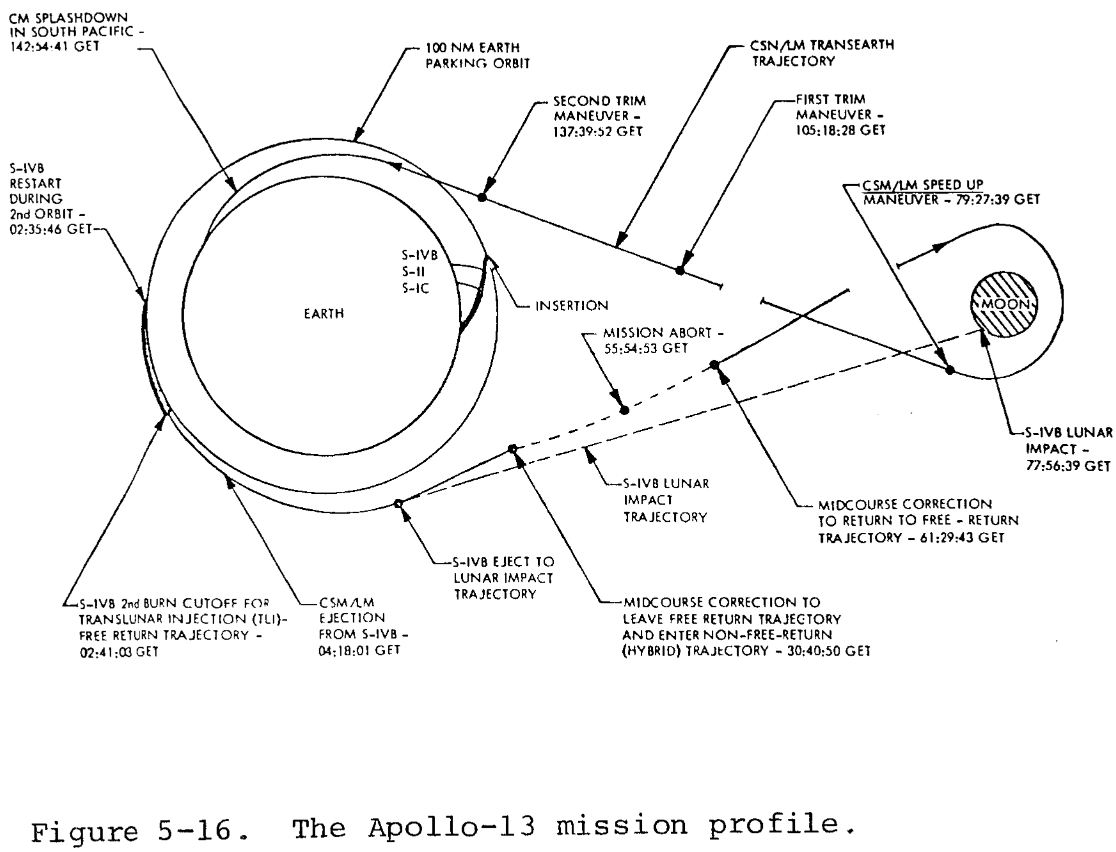

Figure 5-16. The Apollo-13 mission profile.

Table 5-13. Network Configuration for Apollo 15.

Systems	TRACKING			USB				TLM				DATA PROCESSING				COMM				OTHER		REMARKS
	C-band (High-Speed)	C-band (Low Speed)	USB	TV to MCC	Voice	TLM	Command	VHF Links		Mag Tape Recording	Decoms	642B TLM	642B CMD	CDP	1218	High-Speed Data	TTY	Voice (SCAMA)	Voice VHF A/G	Range Safety	SPAN	
ACN			X		X	X	X	X		X	X	X	X		X	X	X	X	X			
ANT	X	X						X											X	X		
ARIA(4)					X	X		X		X							X	X	X			Note 1
AOCC																	X	X				
BDA	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X	X	X		
CNV	X	X																		X		Note 4
CRO	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X	X		X	
CYI			X		X	X	X	X		X	X	X	X		X	X	X	X	X		X	
GBI	X	X																		X		Note 4
GDS			X	X	X	X	X			X	X	X	X		X	X	X	X	X			
GDS-X			X		X	X	X								X							Note 2
GTK	X	X																		X		Note 4
GWM			X		X	X	X	X		X	X	X	X		X	X	X	X	X			
HAW			X		X	X	X	X		X	X	X	X		X	X	X	X	X			
HSK			X	X	X	X	X			X	X	X	X		X	X	X	X				
HSK-X			X		X	X	X								X							Note 2
MAD			X	X	X	X	X			X	X	X	X		X	X	X	X				
MAD-X			X		X	X	X								X							Note 2
MARS				X	X	X																Note 2 & 3
MIL			X		X	X	X	X		X	X	X	X		X	X	X	X	X			
MLA	X	X																		X		Note 4
PARKES				X	X	X																Note 2
TEX			X		X	X	X	X		X	X	X	X		X	X	X	X	X			
VAN	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X	X			

Note

1. TLI and reentry
2. Post TLI coverage
3. Bi-static radar experiment
4. High-speed C-band tracking data (launch phase only)

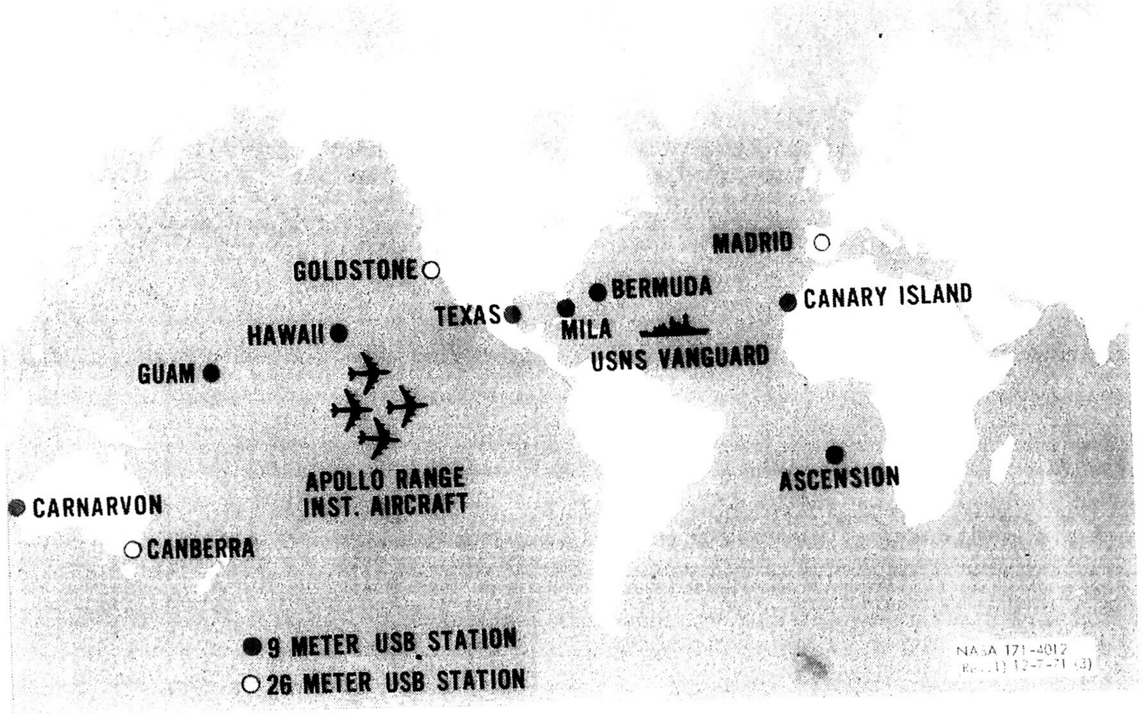

Figure 5-17. The MSFN as of December 1971.

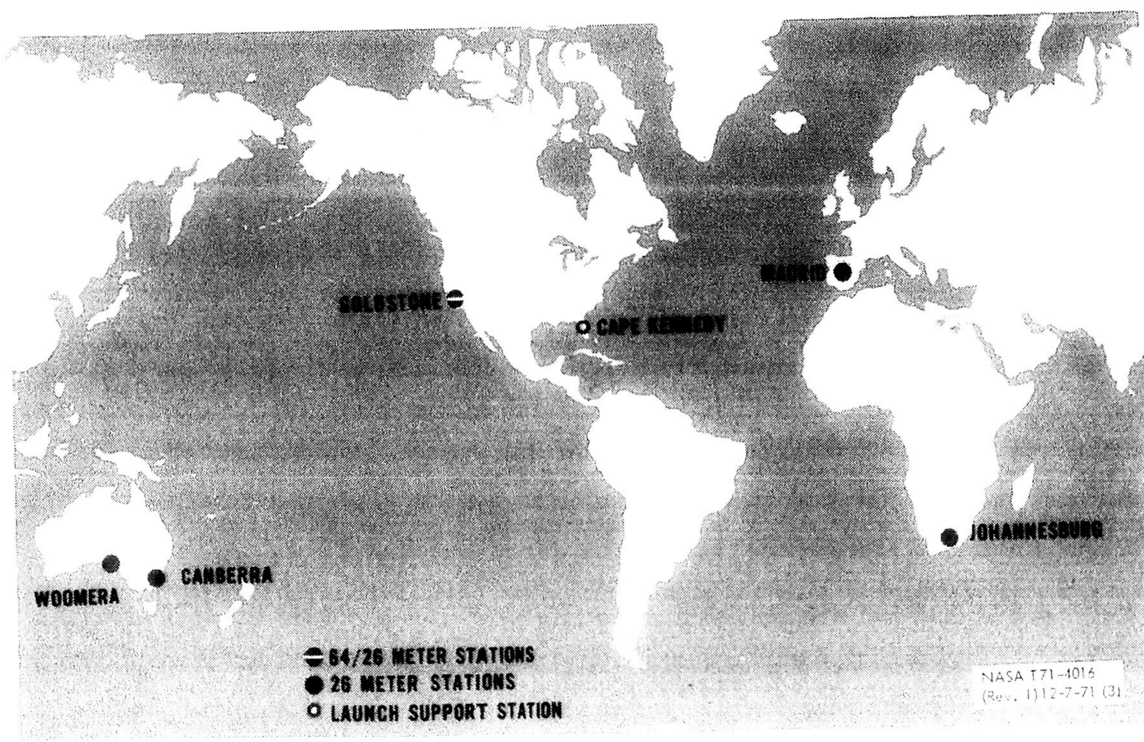

Figure 5-18. The DSN as of December 1971.

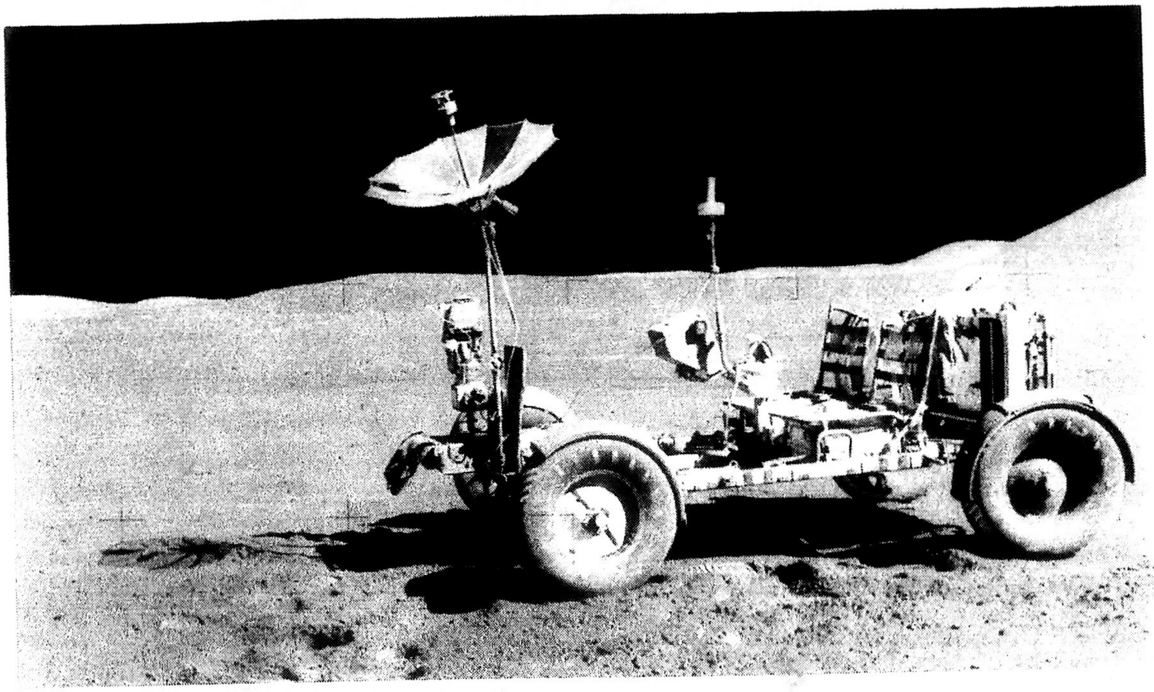

Figure 5-19. The Lunar Roving Vehicle.

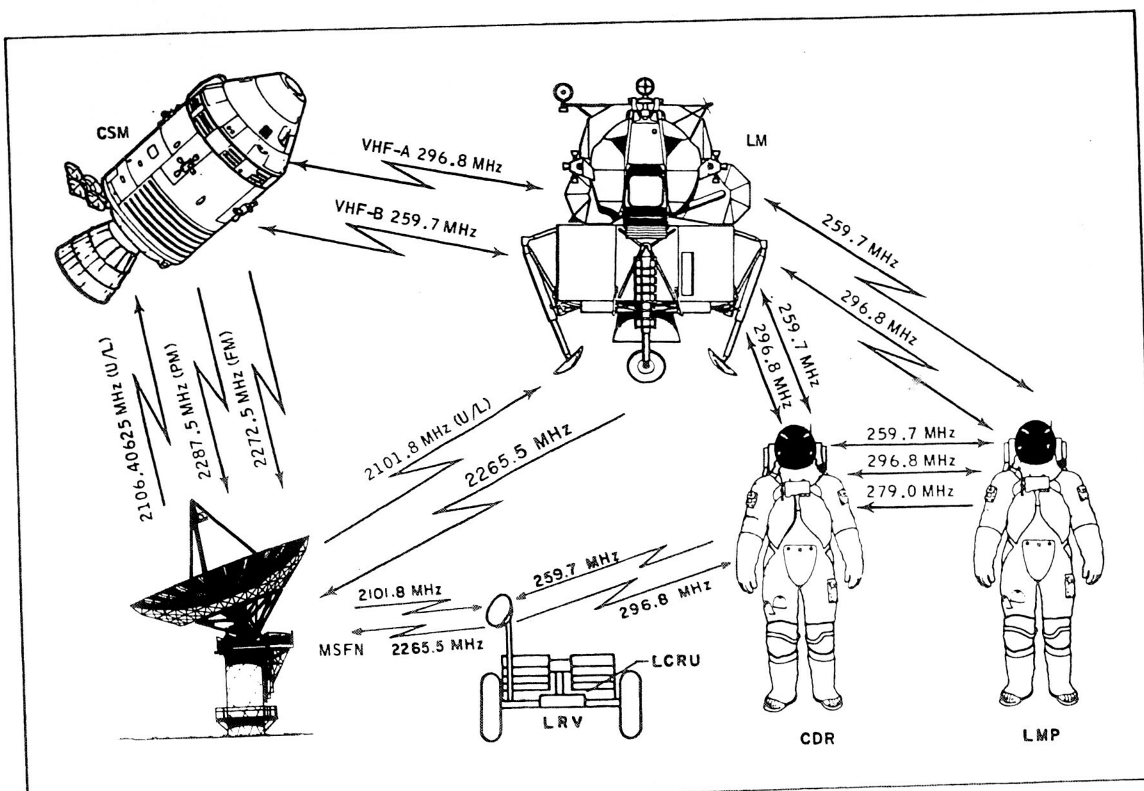

Figure 5-20. Communication links on the Moon during Apollo 15.

Network support on both missions was excellent. On the Apollo-14 flight, the total number or errors, both operator and procedural, was less than in any previous Apollo mission. Communications with Apollo-15's roving vehicle were also good, giving everyone back on Earth a ringside seat of man's first automobile ride on another astronomical body.

Apollo 16. From the launch of Apollo 16 on April 16, 1972 until splashdown some eleven days later, the MSFN served as the vital communications link between the in-flight astronauts and the ground controllers in the Mission Control Center (MCC) at Houston, Texas. Throughout this period, the network in addition to transmitting data critical to the success of the mission and the safety of the crew provided the means for millions of Americans to visually share the experiences of Astronauts Young, Duke, and Mattingly.

The Apollo-16 mission proceeded in an almost letter perfect manner through the docking of the command craft Casper with the lunar landing vehicle Orion. However, shortly thereafter, insulating paint began peeling from Orion and initially it was feared that the craft was perhaps damaged and that the lunar landing would have to be cancelled. After extensive inspection of the craft by the astronauts and the analysis of similar insulation material by ground personnel, it was determined that the peeling was not serious and the mission could continue. The message to proceed with the lunar landing was delivered via the network shortly before the astronauts reached the halfway point in their trip to the moon.

As Apollo 16 approached its lunar orbit another problem appeared, this time in the spacecraft guidance and navigation system. An electrical irregularity had wiped out Apollo-16's space reference system, creating a situation analogous to a compass failing on a ship at sea. However, engineers on the ground, in constant communications with the Apollo crew, were able to work around the problem and reduce it to nothing more than a nuisance.

The most serious problem during the mission occurred after the two vehicles separated in lunar orbit, preparatory to the landing of Orion on the Moon's surface. The problem was not with the lunar module, but with the command ship Casper. Astronaut Mattingly reported to the Mission Control Center that as he prepared to fire the spacecraft's engine a gauge on the control panel indicated that the engine would not lock into firing position.

The network again provided the vital link between the spacecraft and the project personnel on Earth, relaying information and instructions between them. After hours of analysis, including three hours of simulations in a mockup command ship, the problem was traced to a faulty electrical circuit. Detailed instructions were transmitted to Commander Mattingly on how to work around the problem. The lunar landing, although six hours late, proceeded successfully.

The operational situations described above underscore the need for mission information to be available in "real time" at the Mission Control Center as well as the spacecraft.

The landing craft Orion touched down on a plateau high in the Moon's rugged Descartes Mountains. Using Orion as a base of operations, Astronauts Young and Duke began their three-day scientific exploration of the moon. During this period, the tracking network returned to Earth remarkable television views of the lunar highlands and permitted millions of viewers to "ride along" with the astronauts as they guided the Lunar Rover vehicle through large rocks and up to the rims of various craters.

While the MSFN stations were supporting the astronauts on the lunar surface, the same facilities were tracking the command ship Casper as it orbited the moon. Also, the stations were simultaneously receiving and recording data from the Apollo Lunar Surface Experiment Packages (ALSEPs) deployed by the crews of Apollo 12, 14, 15, and 16, as well as a subsatellite ejected into lunar orbit by the Apollo-15 crew on the preceding mission. Added to this workload was another subsatellite that was later placed in orbit by the Apollo-16 astronauts.

One of the most impressive sights transmitted by the network during the mission was the liftoff of the lunar module Orion. The launching was televised by a camera left at the landing site and marked the second televised lunar takeoff. Remotely controlled from the Houston Control Center via signals sent by the network stations, the camera tracked the vehicle for at least two minutes after lift-off.

Apollo 17. On December 7, 1972, the MSFN began its support of the Apollo-17 flight to the Moon. Although the launch was delayed a few hours due to a last-minute malfunction, the Apollo-17 flight was in all other respects nearly letter perfect. All systems, including the ground networks, performed well, and the time lost at launch was recovered early in the flight.

Four days later, on December 11, the network relayed information between the astronauts and the Mission Control Center as the lunar module Challenger descended safely to the lunar surface. This marked the sixth time that the network had acted as the vital real-time communications link for astronauts landing on the moon. The Challenger landed only a few hundred feet short of its target, making it the most accurate of all the Apollo landings.

Throughout the mission the MSFN maintained excellent communications with the astronauts and received what were perhaps the best television pictures from the Moon. The network also provided the communications necessary for the astronauts, working on instructions from Mission Control at Houston, to repair a broken fender on the Lunar Rover, using stiff, plastic-coated traverse maps.

With Apollo-17, the Apollo Program came to an end, and the MSFN turned its primary attention to imminent manned orbital missions, such as Skylab. With the tracking and communications capabilities supplied by the MSFN, the Apollo Program had accomplished far more than the first planners had proposed back in the late 1950's.

Managing the Apollo Network

Building and operating the Apollo Network was a much larger task than the Mercury and Gemini Networks had been--not only in terms of physical size and complexity but also management. To be sure the same interfaces that existed between Goddard, Houston, NASA Headquarters, and DOD during Mercury and Gemini remained, but now JPL, Marshall Space Flight Center, and the Kennedy Space Center had entered the picture. There were also new organizational groupings, many new personnel, and new technical concepts and equipment (such as the USB gear, the aircraft, and the DSN Wings). It is fair to say that the most critical task in designing, implementing and operating the Apollo Network was organizing and coordinating the thousands of people in NASA, its contractors, and the supporting elements of DOD.

In early 1964, as the Apollo configuration of the MSFN began to take firm shape, NASA's overall management plan included the following assignment of responsibilities:[63]

NASA Element	Responsibilities
Office of Tracking and Data Acquisition (OTDA), NASA Headquarters	1. Generation, direction, and execution of the network implementation plan 2. Implementation of this plan 3. Technical operation of the network 4. Assessment and evaluation of network performance and reliability
Office of Manned Space Flight (OMSF), NASA Headquarters	1. Generation of network requirements in conjunction with MSC and MSFC
Goddard Space Flight Center (GSFC)	1. Generation of the <u>detailed</u> network implementation plan 2. Management, direction, and execution of the network implementation plan after plan approval by OTDA with the concurrence of OMSF 3. Technical operation of the network, including network communications and the computations necessary for good network performance 4. Network research and development
Manned Spacecraft	1. Planning, implementation, and operation of the mission, launch, and recovery centers, including computations for mission control and simulations

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[63] The basic authority for these responsibilities came from the landmark letter from Robert C. Seamans to top NASA management dated March 11, 1963, which had as an enclosure the "Management Plan for the Manned Space Flight Network," dated February 5, 1963, and which is reproduced in Appendix D. Additional detail can be found in: NASA, "Tracking and Data Acquisition," Program Review Document, (Washington: February 29, 1964), p. 25; and Goddard Space Flight Center, "Data System Development Plan, Apollo Ground Stations Network," (Greenbelt: July 28, 1966), Part V and Appendices A and B.

Jet Propulsion Laboratory (JPL)	1. Supply receiver subsystems (RER) and other specific USB hardware 2. Backup Apollo flights with the collocated 26-m antennas
Marshall Space Flight Center (MSFC)	1. Provision of requirements for the Saturn launch vehicle

The Role of Goddard. For Goddard, the key responsibilities were technical design and operation; that is, conceiving, building, and running the huge MSFN machine, even though Houston possessed "operational control" during an actual mission. It was this assignment of "technical operation" to Goddard that Seamans reiterated for all parties concerned in his letter of March 11, 1963. Network design and implementation and network operation were the biggest tasks in terms of men and money. Obviously, they were "service" roles in the sense of the previous discussions.

The Goddard position as network "technical operator" should be explained more fully. When Houston, in its role as mission controller, is finished with an MSFN site for a few hours, as the spacecraft orbits below the horizon, it returns the site to Goddard's Network Operations Director. Goddard personnel then check out the station equipment and ensure that it will be ready for further tracking when Houston calls for it again.[64]

The responsibility of checking out the network and directing network simulations led to Goddard retaining considerable computing capability, even after the mission computation task was transferred to Houston early in the Gemini Program. In memoranda and memos circa 1962, Goddard frequently made the point that it had to have computing facilities to assure the readiness of the network.

The major organizational changes that have taken place within Goddard have already been chronicled in the Mercury and Gemini chapters. In general, it is accurate to say that Goddard's tracking and data acquisition organization has remained stable for almost a decade. The most important change came in 1961 when the previously acquired tracking expertise of Langley and NRL was augmented by the real-time radar network capabilities represented by Ozro Covintgon and his White Sands group. A second important change came on July

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[64]Interview with Dale W. Call, October 17, 1969.

25, 1967, when the Tracking and Data Systems Directorate was split into two groups of about 500 people each. (Fig. 5-21)

During the design, implementation, and operation of the Apollo Network, Goddard applied these four elements of management philosophy:[65]

1. Establish and maintain the capability to engineer, install, and operate the MSFN.
2. Have direct access to all sites and stations to take action necessary to maintain configuration control over all MSFN equipment and systems.
3. Have direct access to the lowest command echelon having responsibility for DOD-owned equipment that supports NASA, for the purpose of directing configuration control that is consistent with program/mission requirements.
4. Have direct access to the management of all projects being served by the MSFN.

Intrinsic in these four policies is the philosophy of abundant exchange of information at all levels. In other words, Goddard management believed that success in such a complex, far-flung activity required heavy coordination.[66] Philosophy #1, above, is essentially a statement of Goddard's basic approach of retaining an inhouse competence in all facets of a project through doing some part of every technical task. The bulk of the MSFN work was, of course, accomplished by private industry, with Goddard engineers working alongside. As Eugene W. Wasielewski put it, Goddard needed the mobility of industry as well as the new blood and ideas that would not be present in a totally inhouse effort.

It is apparent from the foregoing delineations of responsibilities and philosophies that NASA management for the Apollo Network was more deliberate and precise than it was in the hectic days of Mercury. Of course, it had to be, because Apollo was a much larger program and needed a more rigorous management approach. But it was also true that NASA had more time to develop management techniques for Apollo. The Mercury job was "informal" by comparison.

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[65] NASA, Goddard Space Flight Center, "Report to the Associate Administrator, Tracking and Data Acquisition, on Management for Mission Support Reliability in the Manned Space Flight Network," NASA GSFC X-800-68-269, 1968, p. 3.

[66] Personal interview with Eugene W. Wasielewski, April 10, 1969.

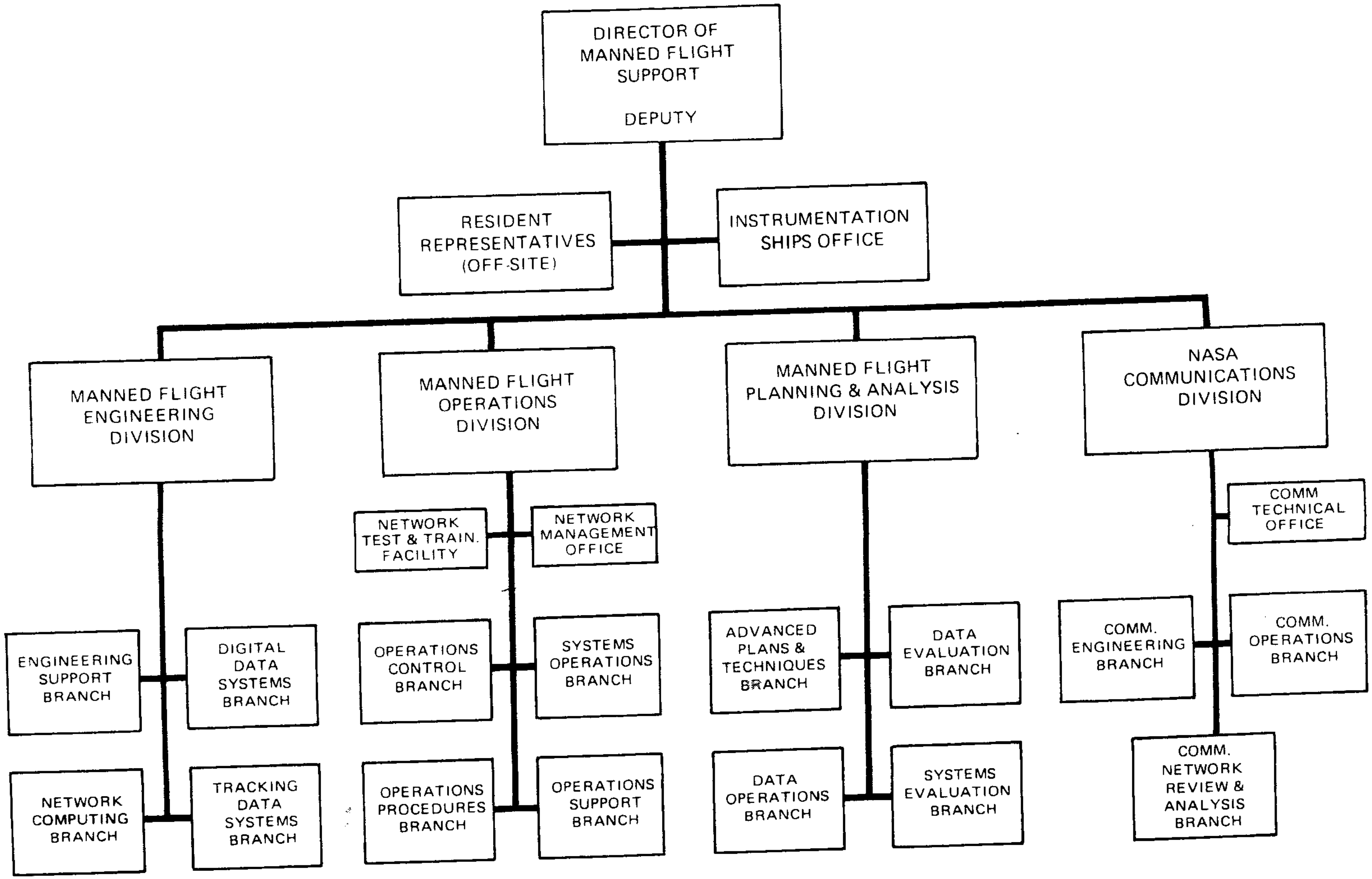

Figure 5-21. The Goddard Apollo Network organization.

JPL's Role. As discussed earlier in this chapter, JPL's entry into the Apollo Program began as a consultant to Houston. The depth of the involvement increased, against some JPL resistance, until three DSN stations were assigned as MSFN backups and JPL was overseeing the design and procurement of considerable USB gear.[67] The JPL involvement became even deeper in 1965 when it became apparent that DSN stations would do more than just back up the colocated MSFN 26-m antennas. Two 26-m antennas were needed to track and communicate with the Lunar Module and the Command Module when they were at the Moon. This change in DSN position was stated in a memo by Rechtin in July 1965[68] and later formalized in 1966.[69]

Originally, the JPL Space Flight Operations Facility in Pasadena was not slated for primary status in Apollo--it would only back up Goddard. However, the utility of "backup" status for the SFOF and the DSN 26-m antennas became suspect in the mid-1960s. If a Goddard 26-m antenna dropped out of the network or the MSFN Operations Center at Goddard failed, could JPL's antenna or the SFOF be brought into the network quickly enough to save the mission? The answer was NO, and three DSN stations and the SFOF necessarily assumed more active operational roles.

One of JPL's strong points has always been interplanetary trajectory computation and navigation. The potential Apollo-8 "error" mentioned earlier is an example of how JPL applied its interplanetary expertise. The JPL contributions in orbit and trajectory computation were great during Apollo. In fact, the capabilities of the DSN were employed as a criterion to help establish the performance of the MSFN.[70]

The Roles of the Other NASA Centers. Both Marshall and Houston were, in effect, customers of Goddard and JPL network services. Houston was, of course, the focal point of

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[67]Jet Propulsion Laboratory, "Memorandum of Understanding" dated April 30, 1963, between E.C. Buckley (OTDA) and W.H. Pickering (JPL).

[68]Letter from E. Rechtin to the DSN Executive Committee, dated July 28, 1965, and entitled "New Definition of the JPL/DSN Role for Project Apollo."

[69]Jet Propulsion Laboratory, "The Deep Space Net (DSN) Engineering and Operations Role for Project Apollo." (Pasadena: June 1, 1966).

[70]Interviews with John Thatcher and Thomas Hamilton, March 23, 1971.

the entire Apollo program. Most network requirements applied to the spacecraft and originated at MSC. The prime Houston input to the network was thus in the form of the multitudinous requirements discussed earlier. Houston and Goddard engineers always worked together directly, although they reported through OMSF and OTDA, respectively, at Headquarters. The Goddard-Houston interface was essentially that defined by the Seamans letter of March 11, 1963.

Houston and its progenitor, the Langley Space Task Group (STG), had worked with network problems since 1958, but Marshall Space Flight Center was a new element in the management picture. Marshall's Saturn series of launch vehicles was an integral part of the Apollo effort. Like the spacecraft, the Saturns were in the development stage during much of the Apollo program, making precision tracking and data acquisition of prime importance. Saturn tracking and telemetry requirements, for example, helped establish the network configuration in the Cape area and downrange toward Ascension.[71] In addition, the Saturns required an FPQ-6 radar at Bermuda for precision tracking. Thus, Marshall became an additional source of network requirements, which were formulated in EIRDs (Engineering Instrumentation Requirements Documents) directed to OTDA and Goddard. Marshall representatives, such as Otto Hoberg and Harvey Golden, sat on many network panels, working groups, and other coordinating committees.

The only other NASA center with an important network interface was the Kennedy Space Center. During Mercury and Gemini, GSFC network people had dealt directly with DOD at the Cape; that is, the AFETR, the Air Force Eastern Test Range. By 1965, NASA facilities at the Cape and downrange had built up to the point where the Kennedy Space Center naturally became the primary NASA point of contact at the Cape with the Air Force Eastern Test Range on range matters. Because NASA had to avoid presenting "several faces" to DOD at the Cape, policies regulating the DOD interface had to be worked out. To coordinate network matters, Kennedy and Goddard drew up a Memorandum of Understanding which dealt at length with DOD contacts.[72] In this document, it was agreed that KSC should be the focal point for general NASA relations with the Commander of the AFETR. Goddard would work directly with AFETR (keeping KSC informed) on station implementation at joint NASA-DOD sites, prelaunch testing, and during the

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[71] Interview with Harvey Golden, June 7, 1971.

[72] "Memorandum of Understanding Between KSC and GSFC," circa December 1966.

orbital phase. During the launch phase, however, KSC had primary cognizance with AFETR on all matters, including all NASA support requirements.

The NASA-DOD Interface. Prior to each series of manned space flights, NASA and DOD have negotiated a basic agreement at the Administrator level. For Apollo the pertinent document was the "DOD-NASA Agreement Regarding Land-Based Tracking, Data Acquisition, and Communications Facilities," signed jointly in May 1965. Within NASA, the consequences of this agreement were promulgated by a memorandum from Robert C. Seamans, Jr., to the Associate and Assistant Administrators at Headquarters, dated November 21, 1966.[73]

There were also several highly important NASA-DOD agreements specifically associated with Apollo. (Fig. 5-22) These are summarized in Table 5-14.[74]

Panels and Other Coordinating Groups. During the Apollo effort, there were literally thousands of intracenter meetings of engineering and management personnel. The above paragraphs attest to the complexity of the coordination problem. NASA management at all levels sought to bridge the many, many interfaces by forcing everyone to "talk to each other" at meetings of various interlocking panels, working groups, committees, steering groups, etc. A few of the more important of these coordinating groups are listed below.

Coordinating Group	Comments
Ground Instrumentation Support Panel (GISP)	Cochaired by Ozro Covington and Barry Graves. Helped make major network decisions, such as the selection of JPL USB system.
Apollo Navigation Working Group (ANWP)	A Goddard-centered group that helped rough out the network with trajectory studies.

73Memo title: "Relationships with NASA and between NASA and DOD elements in the planning, establishment, and use of launch, launch support, tracking, data acquisition and processing, and communications facilities."

74For details, see: Committee on Government Operations," Missile and Space Ground Support Operations," (Washington: GPO, 1966). This document exemplifies the continuing concern in Congress over possible NASA-DOD duplication of effort and facilities.

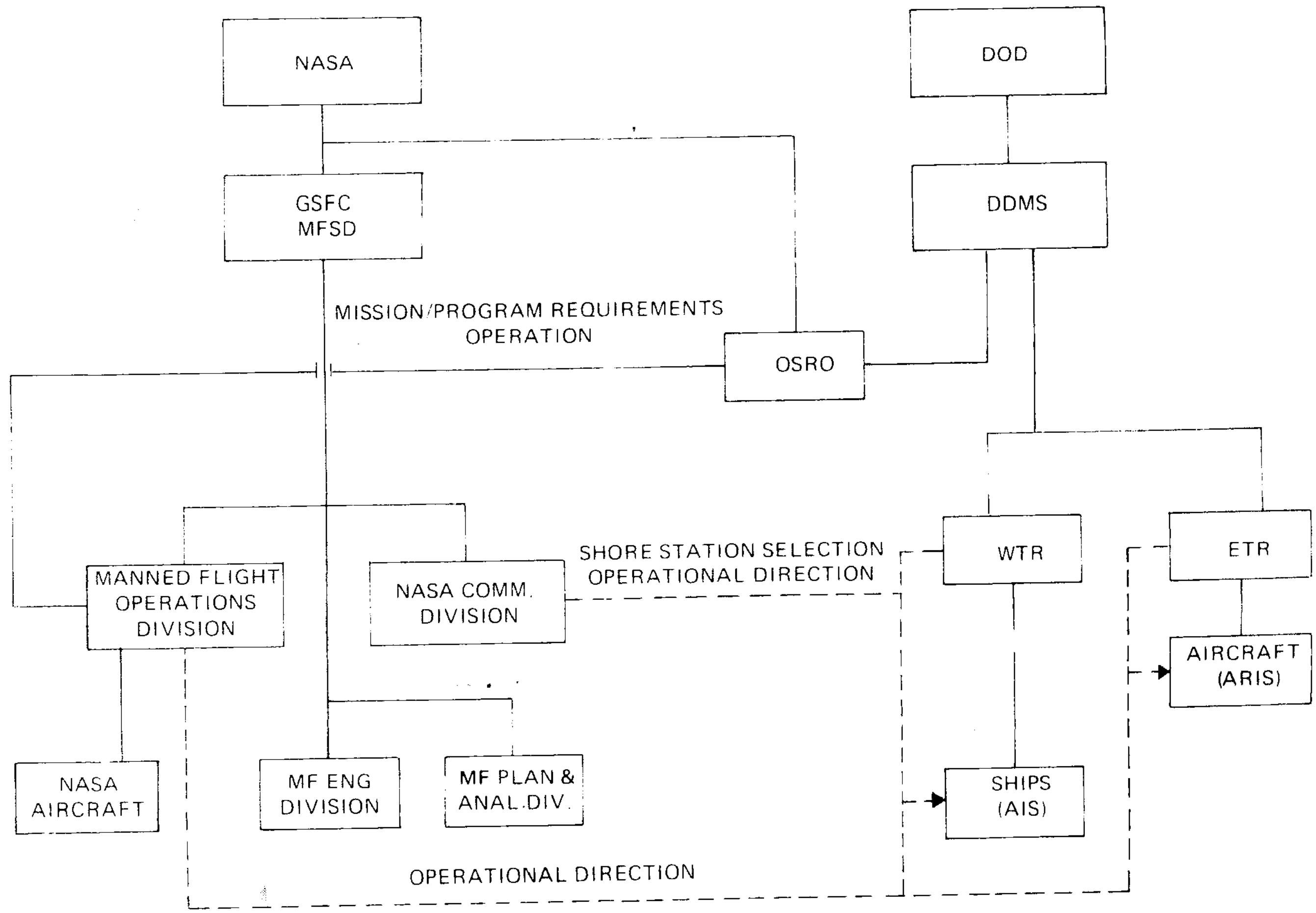

Figure 5-22. NASA-DOD management channels used for ship and aircraft support during Apollo.

Table 5-14. Specific NASA-DOD Agreements During the Apollo Program

Item of Contention	Background and Resolution
Responsibility for launch operations	The Air Force originally launched all spacecraft from ETR and WTR, including Gemini vehicles. NASA "involvement" increased as its own launched vehicles were introduced. The Apollo program necessitated acquisition of new land and facilities. Under Webb-Gilpatric agreement of Aug. 24, 1961, NASA began to procure land at Cape. Under Webb-McNamara DOD-NASA agreement of Jan. 17, 1963, NASA was recognized as owner and manager of the Merritt Island Launch Area (MILA), although DOD retained responsibility for overall scheduling, safety, and downrange tracking at the Cape.
Responsibility for Apollo ships and aircraft	DOD operated all instrumentation ships during Mercury and Apollo. In NASA's 1963 request for funds to convert ships from the maritime reserve into Apollo support ships, NASA implied that it would manage the ships rather than DOD: This marine incursion of NASA bothered Congress. Under the terms of the NASA-DOD agreement of Jan. 14, 1964, a ship pool was established and the Air Force was given the responsibility for centralized planning, scheduling, and management of all Apollo instrumentation ships. (The Apollo ships were jointly financed and also contain non-Apollo Air Force equipment.) A similar agreement was signed in Dec. 1964 giving the Air Force management responsibility for the ARIA.
Management of collocated ground stations	In March 1965, Congress asked NASA and DOD why their tracking activities, particularly at Antigua, Ascension, and Hawaii could not be merged. The NASA-DOD agreement of May 22, 1965, provided that a single agency *would* manage collocated facilities, including the instrumentation, utilities, logistics, etc. Ultimately the Hawaiian station at Kokee Park was transferred from DOD to NASA (as were the MSFN stations at Canton I. and Corpus Christi, where collocation was not an issue). In a supplementary agreement signed on Aug. 3, 1965, Ascension and Antigua were recognized as "exceptions," where DOD provided so-called "base-support" but NASA was responsible for operating its own USB installation.
Equipment standardization	See earlier discussion on the USB and SGLS.

Network Control Group	Chaired by William Wood (GSFC). Included DOD, MSC, KSC, MSFC. Wrote NOD and signed off on it.
Instrumentation and Communication Panel	Chaired by Otto Hoberg (MSFC). One of the most important intracenter groups. Assured that the spacecraft, launch vehicle, and network were all mutually compatible. Began meeting in late 1961. "Pulled everything together."
Apollo Operations Steering Group	Chaired by General Phillips. Included Covington, Truszynski, Robinson, Varson, Kraft. Provided a framework for discussion of general network problems.
Communications and Tracking Steering Group	Chaired by Edmond Buckley. A management group aimed at understanding the broader issues.
Communication and Tracking Working Group	Worked under the above Steering Group. Cochaired by Ozro Covington and Barry Graves. Made detailed network studies and decisions.
Flight Operations Panel	Chaired by Fridtjof Speer (MSFC). Developed operations concepts.

The MSFN: A summary of Trends

The MSFN--in its Mercury, Gemini, and Apollo configurations--has been an indispensable cornerstone for the successes of American manned ventures into space. It has been in effect the information lifeline between the astronauts and the Earthbound flight controllers and computers. The MSFN has not remained static during the past dozen years. It began during Mercury days as a world-circling chain of radars and control sites; it has become a highly automated, integrated complex of electronic sensors and computers at the very forefront of technology. The following points summarize the trends that have characterized the evolution of the MSFN:

1. The Mercury Network was built largely with proven equipment but both the Gemini and Apollo Networks pressed the state of the art in data handling, displays, real-time operation, high-bit-rate communication and computerization. The major technological contribution of the MSFN has been the reliable performance of a man-machine system that is immense in geographical area and in the number of people and machines committed.
2. The desire to make and keep this country's man-in-space program civilian in character has been instrumental in helping NASA gain and retain management of the MSFN.
3. NASA network management at OTDA and Goddard has remained remarkably stable through Apollo 17.
4. The assumption of a service role by Goddard in MSFN operations has been important in depoliticizing the MSFN.
5. There has been a strong trend within NASA toward consolidating network management and keeping it separate from mission management.
6. The network is tending strongly toward site consolidation, wherein fewer, better-instrumented primary sites handle complete mission support.
7. The policy, adopted during Mercury, of providing high redundancy and frequent network exercises with simulations and non-Apollo targets has been a prime reason for the operational success of the MSFN.
8. The Gemini Network was essentially an extension of the Mercury Network. In contrast, the Apollo Network required more radical changes, such as the introduction of Unified S-Band (USB) equipment and the 9-m, 26-m, and 64-m antennas.
9. The Jet Propulsion Laboratory has been brought more and more closely into the Apollo Network by virtue of its DSN and unparalleled background in tracking and data acquisition at lunar distances.
10. The following technical trends are also manifest:
    a. Analog techniques have been supplanted by digital techniques.
    b. The MSFN has been computerized at the remote sites and the control center.
    c. Mission control has been centralized, with the MSFN stations acting primarily as data collection points.
    d. The multiplicity of tracking and communication systems has been replaced by a unified-frequency system.
11. The 26-m MSFN sites have been located near DSN sites and wings have been added at these DSN stations, permitting joint use of the antennas.

12. The MSFN (with NASCOM as a vital part) has emerged as an important national resource capable of supporting a broad range of programs.
13. The overall performance of the MSFN during the Mercury, Gemini, and Apollo programs has been excellent.
14. Apollo mission support has become more complex with the introduction of ALSEP and the Lunar Roving Vehicle, but the Apollo Network has been able to support these missions successfully while still consolidating the Network.

Chapter 6. THE EVOLUTION OF NASCOM

The Purpose of NASCOM

NASA's ground communication system, NASCOM, is the central nervous system of all three of its major tracking and data acquisition systems -- the MSFN, STADAN, and the DSN. It links all spacecraft with their assigned control centers. If NASCOM communication lines are likened to nerve fibers, then the control centers are brains and the spacecraft are sensors. The analogy ends here because nature has packed its nervous systems into containers with dimensions of a few feet; but NASCOM spans the globe.

NASCOM communication traffic, which includes voice, television (video), commands, and data, moves via microwave links (including satellite relays), undersea cables, and land lines. By 1969, some 3,200,000 km of circuits had been established. In addition to the communication lines, NASCOM's switching centers at Goddard and various overseas locations are essential technical features that are critical to effective, economic, and reliable communication between network stations and their control centers.

It would be inefficient to have three separate communication systems for the NASA networks. Technically, economically, and administratively, a single system makes sense. Established formally in 1964, NASCOM was the first and most obvious example of ground environment commonality in NASA.

Other large communication systems exist; viz., the commercial telephone system and several military systems. The first is not broad band; systems in the second class are not real-time on a global basis. In terms of superlatives, NASCOM is the world's largest, real-time, broad-band communication system. The NASA networks could not function without it. Furthermore:

> Again and again, the state of the art in communications dictated the shape of the network.[1]

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[1]Personal interview with Ozro M. Covington, April 10, 1969. Covington was referring specifically to the MSFN.

Military Precursors

The small telephone systems set up during the 1880s were the first real-time communication systems of any real complexity.[2] These, of course, grew and were ultimately interconnected until one could converse fairly well with anyone, anywhere, in narrow-band real time. Teletype networks, such as that of Western Union, also connected many points throughout the world. In the Far East and South America, the military pioneered communication networks development. These teletype lines -- so narrow-band by modern standards -- were essential to Minitrack communications, as we shall see.

But telephone and teletype circuits cannot handle the data traffic that flows between the computers on manned spacecraft, at the MCC, and at MSFN sites. Recall the adage from Chapter 5: "Real-time wide-band is the name of the game." Consequently, the real progenitors of NASCOM technology are found elsewhere; namely, in the military surveillance networks and fledgling missile ranges.

The first electronic surveillance networks of any size appeared in England early in World War II. Communication here, however, was largely via narrow-band voice and teletype channels. Communication circuits within NORAD (North American Air Defense) were more akin to those in NASCOM. In particular, the SAGE (Semi-Automatic Ground Environment) system deployed during the 1950s used voice-band circuits and computers extensively. These developments are mainly in the classified domain and cannot be covered here, but they did contribute technology to NASCOM.

In the open literature, communication systems on the U.S. missile ranges are described very briefly. Generally, the voice-band circuits were simply UHF and VHF microwave links supplemented by cables and leased telephone lines. Sharpe and Lowther, for example, mention the AN/GRC-27 UHF system at the Edwards High Range, the early 12-channel (4 kHz per channel) submarine co-axial cable at the AMR, and many other types of communication equipment introduced at the ranges.[3] Here, the DAICOM sys-

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[2]The first telephone *exchange* was built in London in 1879.

[3]Mitchell R. Sharpe, Jr., and John M. Lowther, "Progress in Rocket, Missile, and Space Carrier Vehicle Testing, Launching, and Tracking Technology," in *Advances in Space Science and Technology*, Vol. 7, F. I. Ordway, III, ed. (New York, 1964).

tem at White Sands is singled out as representative.[4]

When the Army Signal Corps assumed responsibility for the White Sands communications in 1952, one of its first acts was to let a contract to Bell Laboratories to recommend: (1) What should be done right away to replace the "ancient" open-wire system, and (2) What the "ultimate range communication system" would look like? DAICOM (Data and Instrumentation Communications) grew out of Phase 2 of the Bell study.

The DAICOM plan divided the range up into nine areas to be served from primary distribution centers located within them (the "exchange" principle). Also pertinent to NASCOM (still more than a decade away) were the types of communication links that were eventually installed:

1. A 23-channel microwave system (1700-1900 MHz) Audio response: 300-3300 Hz (Figure 6-1)
2. Multichannel VHF circuits.
3. A VHF data circuit to broadcast acquisition data
4. An acquisition station voice net.

One can see in DAICOM precursors of the voice and data circuits ultimately installed in NASCOM -- on a vastly different scale, of course. Nevertheless, the real-time wide-band pattern essential to modern tracking and data acquisition was beginning to emerge.

The MINSTREL ground environment system (mentioned in Chap. 3) would have carried White Sands a long step ahead in the state of the art. Intrinsic in MINSTREL were such features as digitization, a central real-time control center, and solid-state computers. Such thoughts were rather advanced for White Sands, or any other range, in 1958; and MINSTREL was never built as proposed.

As NASA began recruiting personnel from the Edwards High Range, White Sands, Langley, and various military and industrial organizations, its pool of communications know-how grew. Specifically, it inherited the real-time wide-band, computer-based network concept along with knowledgeable personnel from the military ranges and surveillance networks.

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[4]David K. Barton, "History, Signal Corps Instrumentation, White Sands Proving Ground, 1945 through 1953," (Belmar, New Jersey: Signal Corps Engineering Laboratories, 1955).

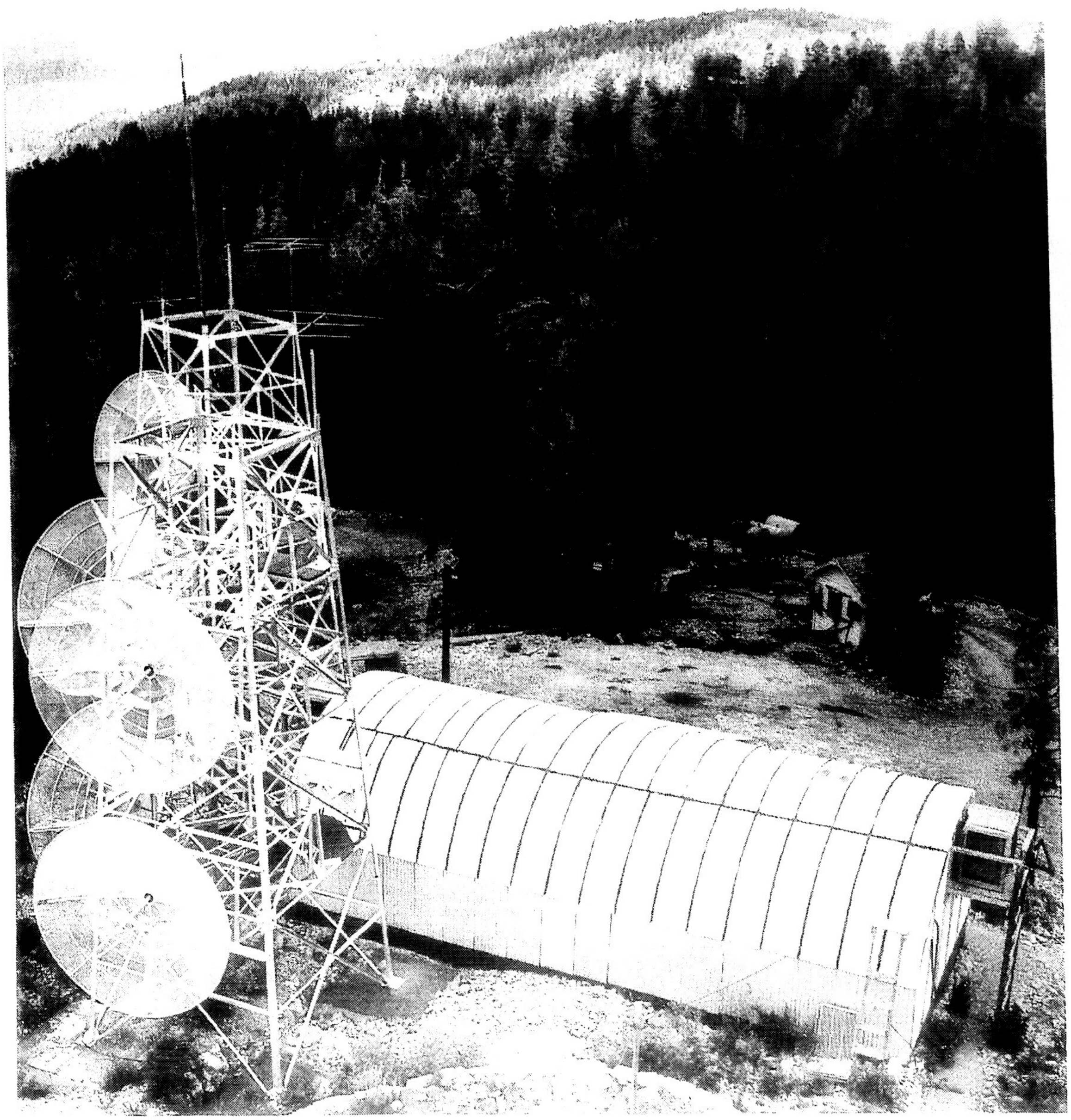

Figure 6-1. Antennas for data relay station at White Sands circa 1954.

Minitrack Communications

While the Army and Navy were pushing communication technology in its ranges and networks -- both geographically limited -- the Naval Research Laboratory, in 1955, was faced with the job of getting tracking data and scientific information back from a worldwide network. Many of the proposed Minitrack stations were either in undeveloped parts of the world (South America) or at great distances (Australia). At first, the problem in Minitrack was just getting any data back--forget about real-time and wide-band idealizations. Minitrack was a far cry from a cozy "little" range in a technologically advanced country.

Real-time communication was not essential in Minitrack. The early scientific satellites possessed little capability for control from the ground anyway. And, of course, they were unmanned so that quick go-no go decisions did not need to be made. There was only moderate urgency in getting tracking data back to the Vanguard Control Center at NRL, located in southeast Washington, D.C., where they would be relayed to the Vanguard Computing Center, 615 Pennsylvania Avenue, in downtown Washington, where a computer would grind out orbital parameters. Speed was not too important because the Minitrack station interferometers possessed wide acceptance angles and needed no acquisition data.[5] As for scientific data, that was recorded on magnetic tape and airmailed back to NRL. It was a rather slow, very-narrow-band communication system that evolved, but with it many of the major scientific discoveries in space were made.

Within the continental United States, teletype lines were easily found to service such Minitrack stations as San Diego, Blossom Point, and Fort Stewart. The real communication problems arose in South America and Australia. Fortunately, the Army, by virtue of its Inter-American Geodetic Survey (IAGS) work, was able to come to the rescue and supply teletype links with the stations in the South American extension of the Minitrack fence. (See Chap. 2.) By October 1, 1957, the linkup of the teletype lines shown in Figure 6-2 had been completed, save for the checkout of a few segments. This date was important because just a few days later, the first bona fide tracking data began to converge on the Vanguard Control Center from those Minitrack stations

[5]However, Minitrack-generated acquisition data were used by the SAO Baker-Nunn cameras.

which had been hurriedly converted to the 40-MHz beacon frequency of Sputnik 1.

Figure 6-3 provides more details on the communication equipment employed at the Minitrack stations. The stations shown (South African and Australian stations are omitted) are all essentially offshoots of U.S. military activities in the Western Hemisphere. The teletype lines and associated equipment are also military. Teletype service from the Woomera station was brought in a few months later than the South American stations via Air Force and Navy radio teletype links. (Figure 6-3) The South African station near Johannesburg was served by commercial links. Note that Minitrack communications were primarily "point-to-point" and that the switching centers featured in today's NASCOM are almost absent. The overwhelming military presence in Minitrack communications was vital to Minitrack's success on one hand but detracted somewhat from the purely scientific atmosphere that the Navy (and later NASA) wished to promulgate.

The military teletype circuits were part of the Army ACAN system, which was served by so-called "torn-tape" equipment.[6] Data rates were limited to the standard teletype speed of 60 words per minute, which corresponds to about 30 bits per second -- very, very slow by modern standards, but fast enough to transmit sufficient interferometer data back to Washington.

Minitrack communication served the space program well for the first two or three years of NASA's existence, but it was too slow for the advanced Explorer-class and Observatory-class satellites on NASA's drawing boards in the early 1960s. And the Minitrack lines were totally unsuited for Project Mercury, which posed the first real-time data/voice communications requirements.

Mercury Ground Communications

When man occupies a spacecraft, the complexion of the ground communication system changes radically. Most obvious is the fact that the ground-based flight controllers want to talk directly with the astronauts. Thus, voice circuits must be added to the data circuits that suffice for unmanned sat-

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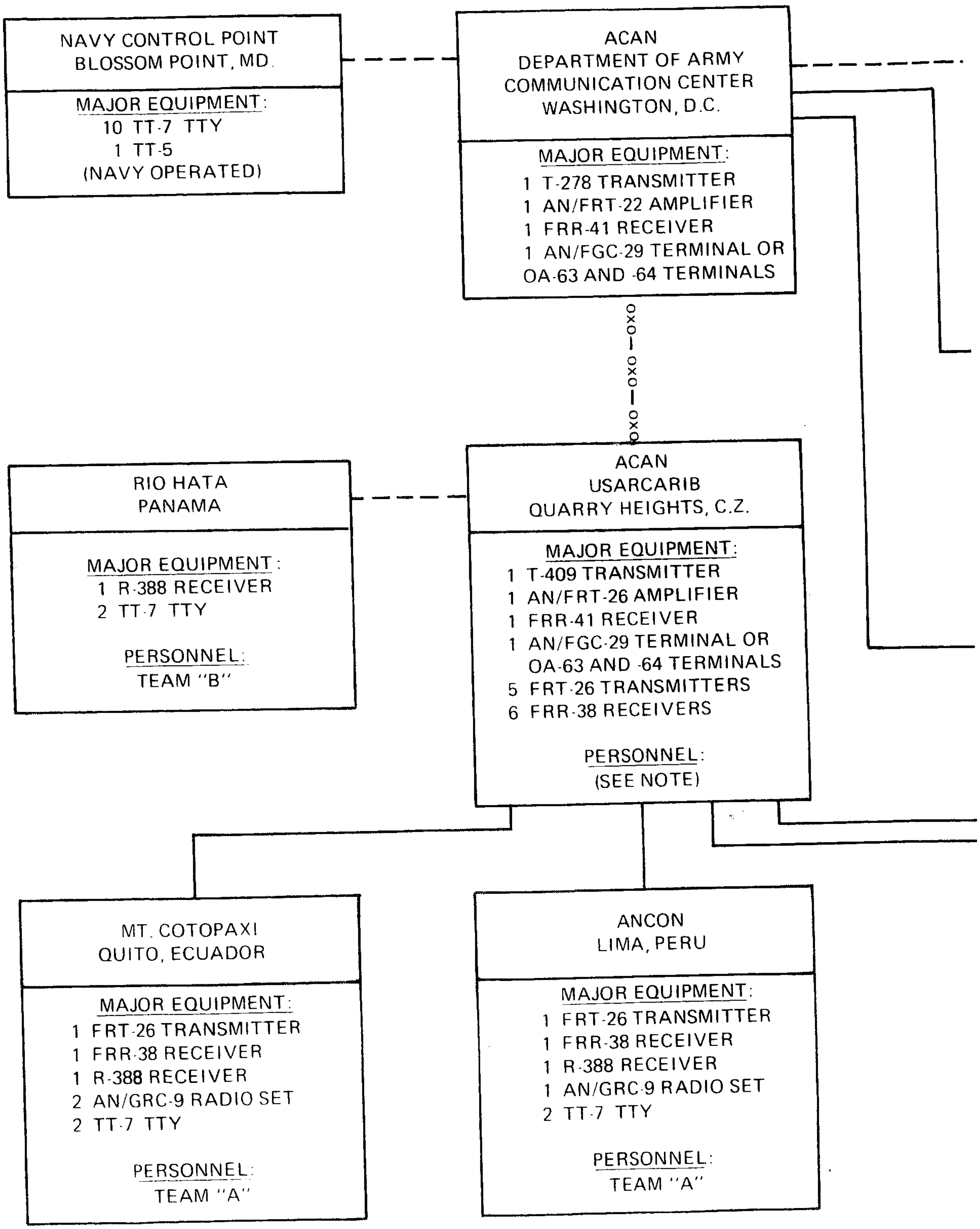
[6] "Torn tape" refers to the message-carrying punched paper tape used by the teletype equipment.

Figure 6-2. Army communications plan for prime Minitrack stations.



LEGEND

———	SIMPLEX RATT
oxo— oxo—	16 CHAN. SSB
— — — — —	LEASED TTY CIRCUIT

FORT STEWART GEORGIA

MAJOR EQUIPMENT:
1 R-388 RECEIVER
2 TT-7 TTY

PERSONNEL:
TEAM "B"

PERSONNEL TEAM "A"

No	Title	MOS
1	Officer	0502
1	Fixed Sta. Supv.	272.6
1	Fixed Sta. Rec. Repairman	271.1
1	Fixed Sta. Trans. Repairman	272.1
1	Powerman	351.1
1	Army Tech. Rep.	- - - - -
2	Fixed Sta.Attendants	270.0
2	Fixed Sta.Elec.Eqpt.Repairman	294.2
10	Total	

BATISTA FIELD HAVANA, CUBA

MAJOR EQUIPMENT:
1 R-388 RECEIVER
2 TT-7 TTY

PERSONNEL:
TEAM "B"

PERSONNEL TEAM "B"

No	Title	MOS
1	Officer	0502
1	Army Tech.Rep.	- - - - -
2	Fixed Sta.Attendants	270.0
2	Fixed Sta.Elec.Eqpt.Repairman	294.2
6	Total	

COOLIDGE FIELD ANTIGUA ISLAND

(NAVY OPERATED)

NOTE: ADDITIONAL PERSONNEL REQUIRED AT USARCARIB STA.

No	Title	MOS
2	Fixed Sta. Attendants	270.0
3	Fixed Elec.Eqpt.Repairman	294.2
3	Total	

ANTOFAGASTA CHILE

MAJOR EQUIPMENT:
1 FRT-26 TRANSMITTER
1 FRR-38 RECEIVER
1 R-388 RECEIVER
2 AN/GRC-9 RADIO SET
2 TT-7 TTY

PERSONNEL:
TEAM "A"

PELDEHUE MILITARY RESERVATION SANTIAGO, CHILE

MAJOR EQUIPMENT:
1 FRT-26 TRANSMITTER
1 FRR-38 RECEIVER
1 R-388 RECEIVER
1 AN/GRC-9 RADIO SET
2 TT-7 TTY

PERSONNEL:
TEAM "A"

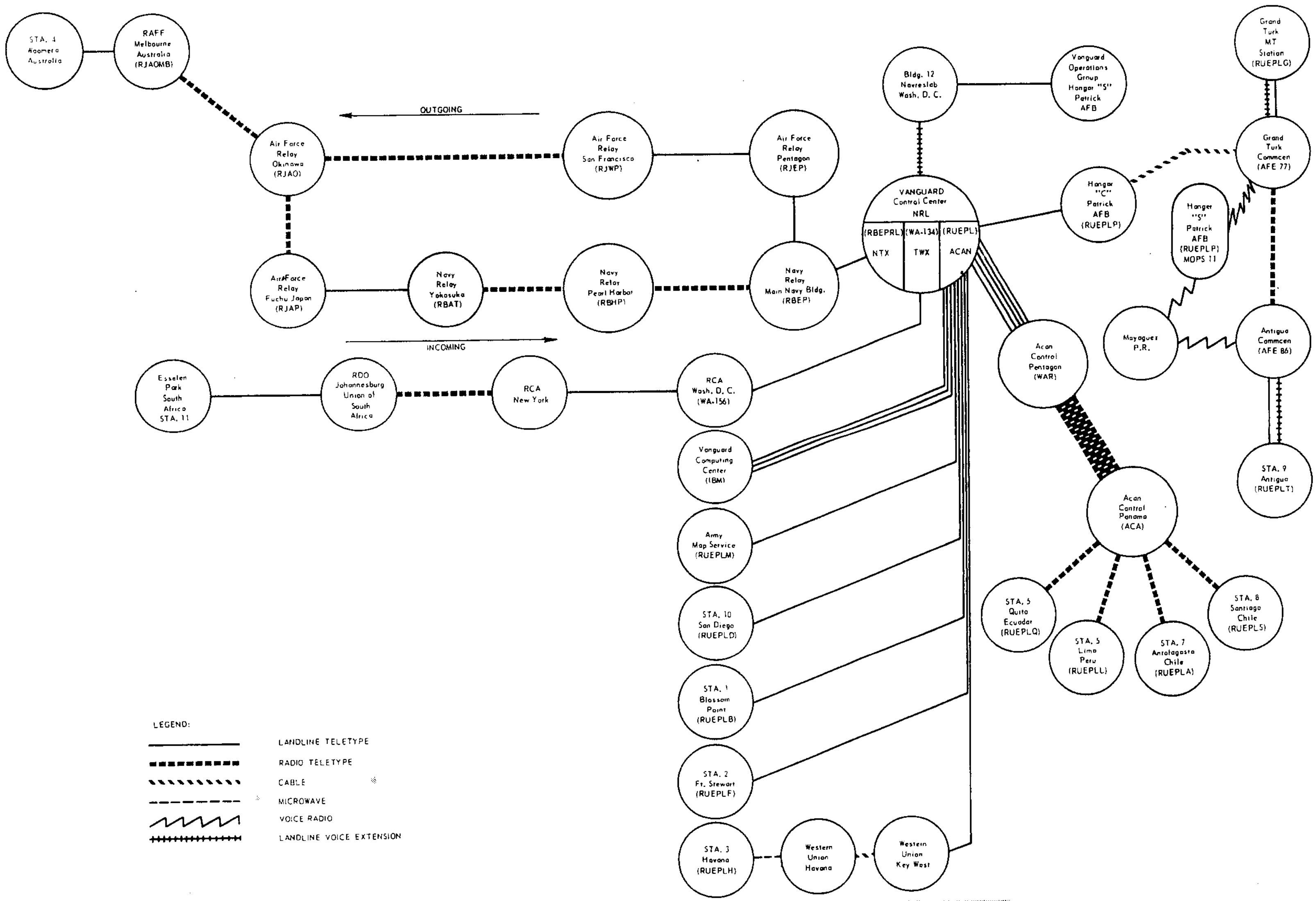


Figure 6-3. The Minitrack communication network, showing the great variety of links pieced together for this program.

ellites. Television coverage inside the Mercury capsule was proposed, but TV capability was not added until the Apollo series of spacecraft. As mentioned earlier, Project Mercury needed real-time, wide-band communications; the first for quick trajectory computations and mission decisions, the second for the heavier data traffic required to monitor and converse with a man in orbit. A final and highly important difference between Minitrack and Mercury communications concerned reliability. If ground communications failed during preparations for re-entry, the mission and life of the astronaut might be compromised. So, high reliability was more critical to Mercury than to any unmanned satellite ventures.

These basic facts of life for Mercury became apparent to Langley TAIGU engineers in late 1958 as they struggled to define the Mercury Network. As mentioned in Chapter 3, they were soon startled to discover they could not readily piece together a worldwide real-time communication system from existing commercial or military circuits. Some of the technical pioneering work that was necessary has already been described in Chapter 3.

In fact, it was difficult in 1958 and 1959 to consider the communication problem as separate from the overall Mercury Network task. Mercury communications were being designed specifically for the Mercury Network -- and it was a rush job. Commonality and integration with the extant Minitrack circuits was a remote consideration. The two networks were too different in the types of service they provided and in station location.

It is easy to look back and ask why three different networks existed. In 1959, the networks were so different that their communication systems were even different. Yet, the transmission of radar data can be put on the same basis as interferometer data -- information is information, even though the data-generating sensors are different. For this reason, the integration of Minitrack, Mercury, and JPL network communication lines was a logical place to begin pulling the NASA ground environment together into a single package. But even this synthesis came about slowly.

TAGIU designed the Mercury communications network with the help of Goddard engineers.[7] When Goddard absorbed

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[7]Actually, STG was administratively attached to Goddard and TAGIU to Langley.

some of the TAGIU communications engineers between July 1 and October 1, 1961, they were assigned the newly created communications Branch within the Manned Space Flight Support Division, under Niles R. Heller. At this point in time, NASCOM did not exist and the Minitrack and Mercury Network communications organizations were in separate divisions within J. T. Mengel's Tracking and Data Systems Directorate. During 1961 and 1962, however, the growing Goddard involvement in ground communications came under scrutiny. Studies were made of possible economies achievable through circuit sharing and common communication equipment. These studies were convincing, because in July, 1963, an integrated dommunications Division was formed at Goddard under Laverne H. Stelter to coordinate all NASA ground communications.

In Chapter 3, Goddard's designation as NASA's center for communication and computers expertise was discussed. The Mercury Network specifications, in fact, also assigned this responsibility to Goddard for Project Mercury. Of course, by the time these specifications were issued on May 21, 1959, the major decisions affecting communication philosophy had already been made by TAGIU and STG. These basic 1959 decisions still shape NASCOM today. These were:

1. There would be a Mission Control Center at Cape Canaveral (but moved to Houston for Gemini).
2. The Mercury computers would be located at Goddard, necessitating a high volume "data pipe" between Goddard and the Cape; and, further, all station data must converge on Goddard. Goddard thus retained the computer/communication center role it had assumed with Vanguard.
3. Overseas switching subcenters and relay points would be established to funnel data from overseas stations into a limited number of transoceanic cables. Economy helped dictate this decision for "trunk sharing" because transoceanic cables service is much more expensive than continental land line service.[8] Reliability also played an important role in the decision to build overseas switching centers, because they provided flexibility, that is, the opportunity to bypass a cable break with another link should that kind of emergency arise.

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[8]Personal interview with Laverne H. Stelter on March 11, 1969.

The Mercury communications network, as it finally emerged, bore a much stronger resemblance to modern NASCOM than did the data links serving Minitrack. The Mercury communication links are illustrated in Figure 6-4. There are really two congruent networks; one for voice, (Figure 6-5) the other for teletype, each with its own channel and backup channel. The Mercury teletype circuits were based on the Western Union 111 Torn-Tape Relay System, which (unfortunately) could not better the Minitrack speed of 60 words per minute due to the limitations of already installed terminal equipment. In contrast to Minitrack communications, many Mercury links were commercial, although DOD provided some circuits and helped build the redundancy necessary for high reliability. The overseas switching subcenters were at Adelaide, Honolulu, and London. In Figure 6-4, Goddard was obviously the hub and main switching center. A more detailed view of the Grand Canary-to-Goddard communication route is illustrated in Figure 6-6 as typical.

Two additional features of the Mercury Network were significant. First, the "data pipe" between Goddard and the Cape represented a substantial advance in wide-band long lines. In mid-1961, four two-way, voice-bandwidth (about 4 kHz), data-grade circuits, each capable of carrying 1000 bits per second were installed between the Cape and Goddard. One of these channels, therefore, transmitted thirty times the data volume of the teletype lines connecting the remote sites to Goddard. The function of Goddard was to process the thin trickles of data and generate data to drive the real-time displays at Mission Control at the Cape.

Later, other wide-band data lines were installed by NASA, notably between its new STADAN Data Acquisition Facilities, such as Rosman and Alaska, and Goddard. Another important voice-band link was established between Bermuda and the mainland in early 1963, when a submarine cable went into operation. This Bermuda link could carry 2000 bits per second and permitted NASA to remove the Bermuda computer, upon which NASA had depended for the go-no go decision in the event radio communication with the continental U. S. failed during a Mercury launch.[9] The Goddard-to-Cape high-speed data link may thus be considered a precursor of those now so common in NASCOM.

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[9]William G. Dickinson, Donald D. Wilson, and Vaughn E. Turner, "Implementation of a Worldwide High-Speed Data-Transmission System for NASA Mission Support," NASA GSFC X-500-66-402, 1966.

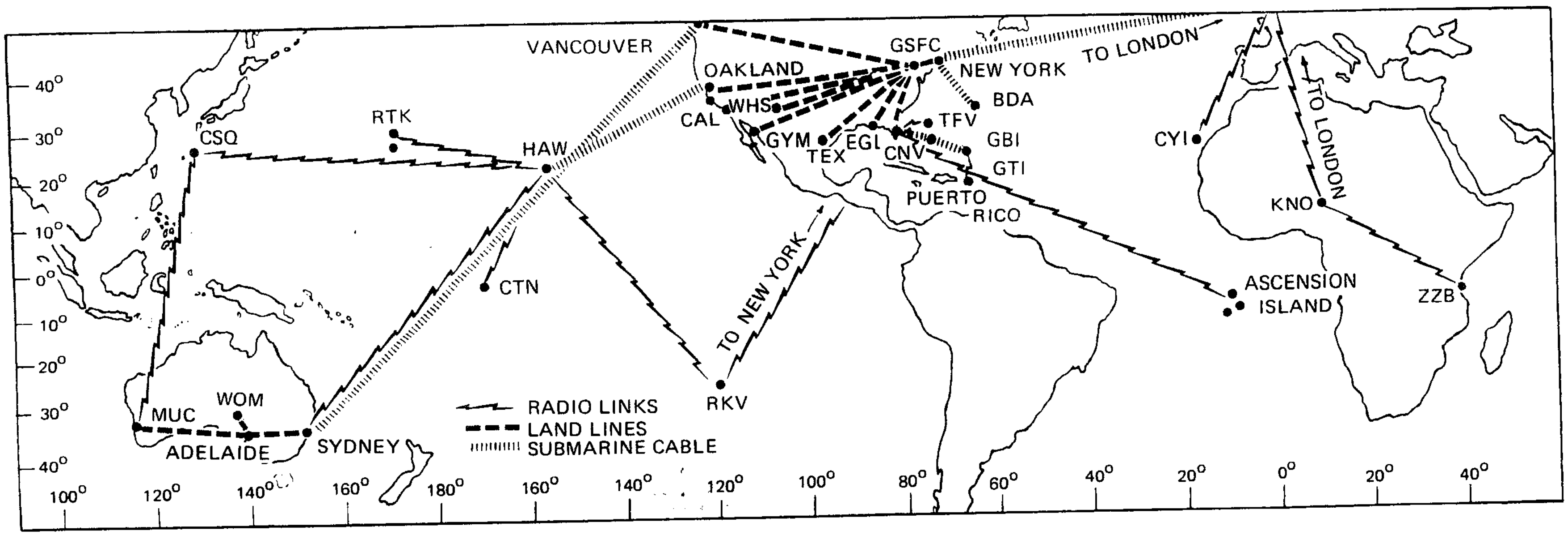

Figure 6-4. Simplified diagram of the Mercury communications network configured for MA-9. The configuration varied somewhat from flight to flight.

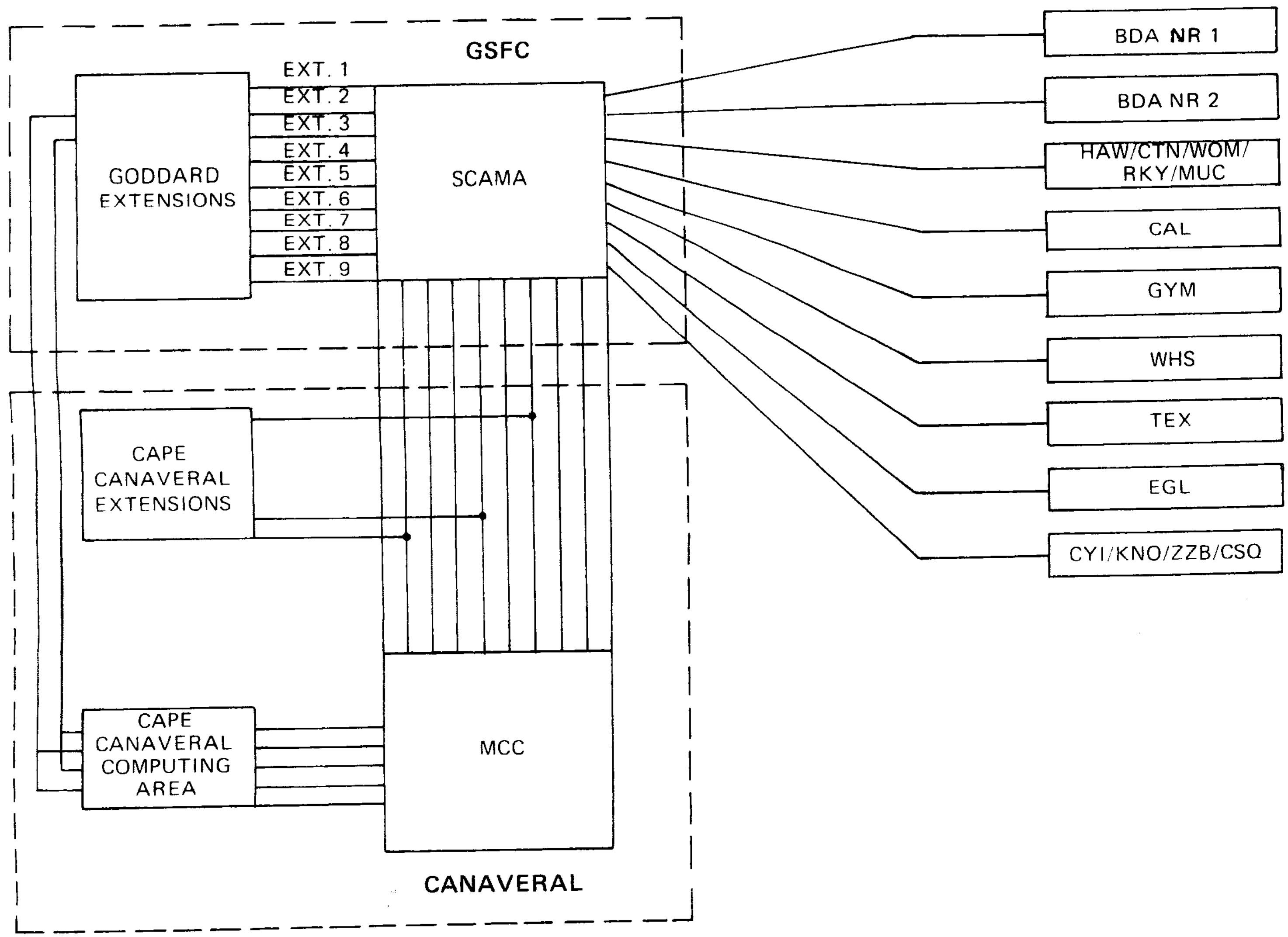

Figure 6-5. The Mercury voice network, illustrating the switching capabilities of SCAMA.

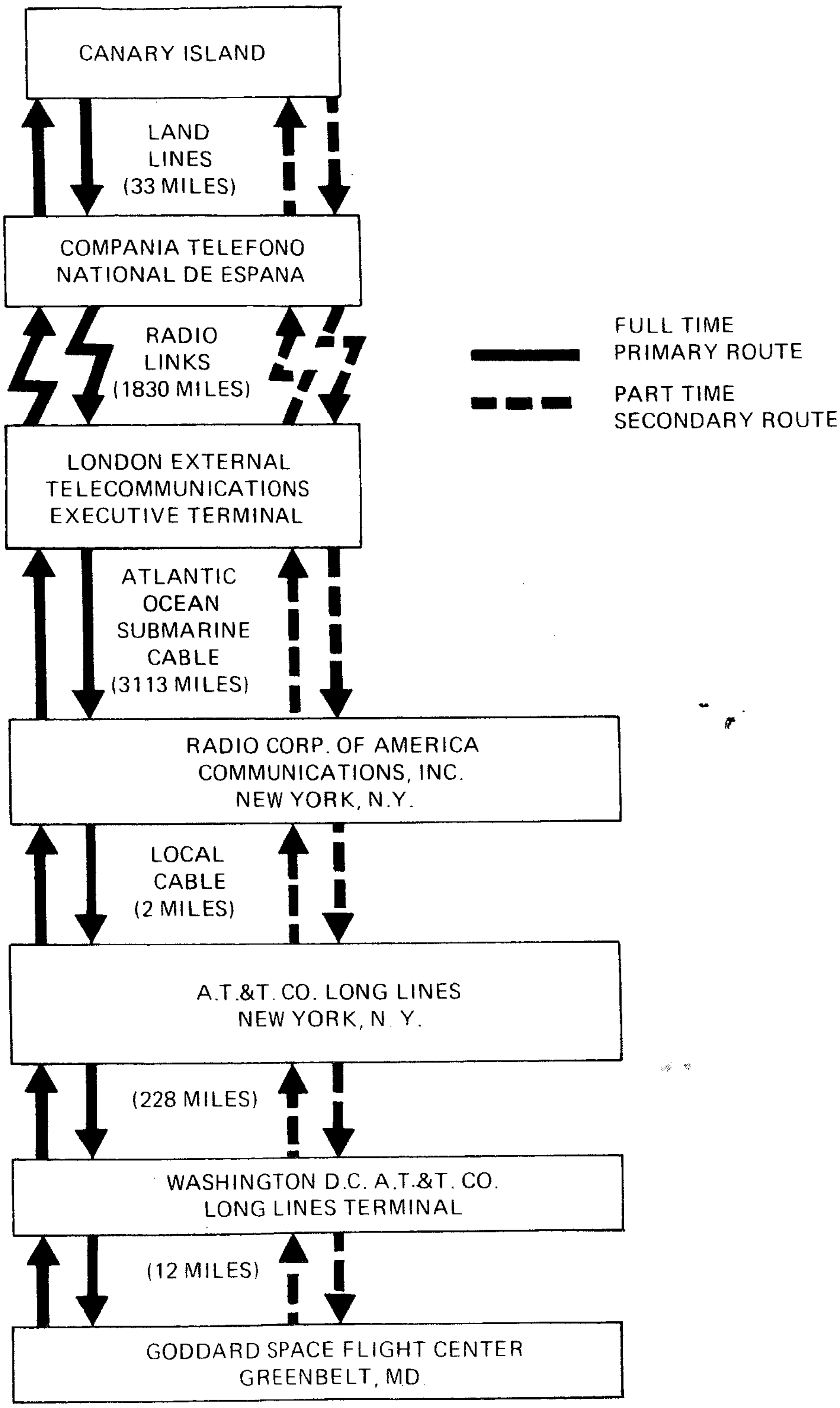

Figure 6-6. Details of routes available from Grand Canary, illustrating NASCOM redundancy.

The second element of the Mercury communication system to be singled out is the Communications Center at Goddard. Actually, the teletype and voice switching equipments were separate, just as the communication lines themselves were separate. Teletype messages were switched automatically by circuits that recognized coded addresses. With this equipment, the following modes of relay operation were possible.[10]

1. From any site to the Mercury Control Center and/or the Goddard Communications Center.
2. Any site can broadcast to all sites.
3. From radar sites to the Goddard computers.
4. From the Mercury Control Center, the Goddard Communications Center and the Goddard computers to any site.
5. From the Mercury Control Center, the Goddard Communications Center to all sites simultaneously.

Voice traffic in the Mercury Network was switched manually through SCAMA (Switching, Conferencing and Monitoring Systems) as illustrated in Figure 6-7.[11] SCAMA enabled the following functions to be performed:

1. The Mercury Control Center could be supplied rapidly with real-time capsule status information enabling mission controllers to deal quickly with any unusual circumstances.
2. Voice directives from the Mercury Control Center could be given to the command sites in case rapid changes in capsule retrofire settings were required for expedited re-entry of the vehicle.
3. All sites having voice capabilities could be fully informed at all times of mission status by monitoring the voice traffic on the conference hookup.
4. The conversation between the astronaut and any voice-equipped site could be monitored by all the voice sites on the network.
5. Where an area of overlap occurred between sites in radar or command transmitter coverage, the voice circuits could be used to establish the exact time at which one site ceases transmitting and the next site starts in order to avoid any possible conflict with radar beacon responses or confused command signals.

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[10]NASA Communications Branch "Project Mercury, Ground Communications Network Description," NASA GSFC X-531-62-202, 1962.

[11]R.H. Bidlack, "The 304 Conference Switching System," *Bell Laboratories Record*, Vol. XLIII, Jan. 1965, p. 9.

Figure 6-7. Part of the SCAMA switchboard and ancilliary equipment.

With the completion of the Mercury Network, on June 1, 1961, many features of modern NASCOM had been deployed. NASCOM was not officially named as yet, but further evolution would primarily be more of the same; i.e., wider band, more nearly real time, more computer control.

NASCOM Expansion During the Gemini Program

The titles of this and the preceding section infer that NASA's manned space flight programs predominated in the shaping of NASCOM. This is certainly true. STADAN and the DSN had no need for voice communication, except for administrative matters, and real-time spacecraft control was desirable but not an absolute necessity. Yet, scientific and applications satellites and JPL's lunar and planetary probes were becoming more sophisticated and more susceptible to operational control from the ground.[12] The OGO and Surveyor spacecraft, for example, boasted command repertories enabling a ground-based controller to "drive" them by remote control -- in real-time if suitable communication links could be set up. In other words, the ground communication requirements of manned and unmanned spacecraft were beginning to converge in the 1962-1964 era.

Convergence was a two-way street. Digital communication had appeared as early as 1959 on such scientific spacecraft as Explorer 6. While the Mercury Program employed analog signals for ground/spacecraft communication, the Gemini Program switched to digital coding. Thus, the MSFN, STADAN, and DSN stations began to look the same to NASA ground communication circuits.

Commonality, economy, and centralization of flight control were all factors that led Goddard to establish its Communications Division in July 1963. These same kinds of forces plus communications difficulties that had arisen during the Cuban missile crisis led the Federal Government to pool its ground communications with the formation of the National Communications System (NCS) at about the same time.[13] NASA, DOD, the FAA, the State Department;and the General Services Administration (GSA) were among the original members.

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[12]See Chapter 2 for discussion of the STADAN satellites control centers, which are analogous to the centralized MSFN Mission Control Center located first at the Cape and now at Houston.

[13]Personal interview with Laverne H. Stelter, May 7, 1969.

At this time NASA Headquarters defined all NASA long-line communications as "NASCOM," a term that was already in general use with respect to NASA's ground communications complex. NASCOM was NASA's contribution to NCS. OTDA, at Headquarters, was charged with the responsibility of managing NASCOM -- a task it delegated to Goddard.[14] Except for a few local links, such as the wide-band link between the Goldstone DSN site and JPL's Space Flight Operations Facility (SFOF), in Pasadena, all NASA long lines were integrated into NASCOM. In theory, the local links are part of NASCOM, but management responsibility has been delegated to JPL.

As of mid-1964, the NASCOM mission stood well-defined and Goddard's communications Division had been charged with meeting the new requirements of Gemini and Apollo as well as the ever-more complex unmanned spacecraft. In addition, a truly *integrated* network had to be built from some combination of existing circuits and the various plans in being for automating and computerizing the switching centers and expanding data conduits in terms of capacity and geographical coverage. With all this, NASA expected more efficient, reliable, economical ground communications.

A step-by-step description of the expansion and augmentation of NASCOM from FY 1964 through FY 1966 follows:[15]

FY 1964-1965

- All teletype switching functions were integrated into a solid-state automated message switching system at Goddard, and the torn-tape and electromechanical switching systems were retired. SCAMA I was replaced with SCAMA II. Long-haul voice circuits of all three networks were integrated into a common trunking, switching, and conferencing system.
- In addition, the entire switching center at Goddard was redesigned to provide increased capacity and reliability.
- The MSFN portion of NASCOM was modified to accommodate the new Gemini Network configuration (See Chap. 3.) (Figure 6-8) The MSFN voice capability was extended to all MSFN, DSN, and other sites.

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[14]NASA General Management Instruction 2520.1, June 25, 1964. Management of NASCOM included planning, designing, operating, etc.

[15]NASA GSFC, "Data System Development Plan (DSDP), NASCOM Network," Revision 4, Section I, System Description and Capabilities, Sept. 11, 1968.

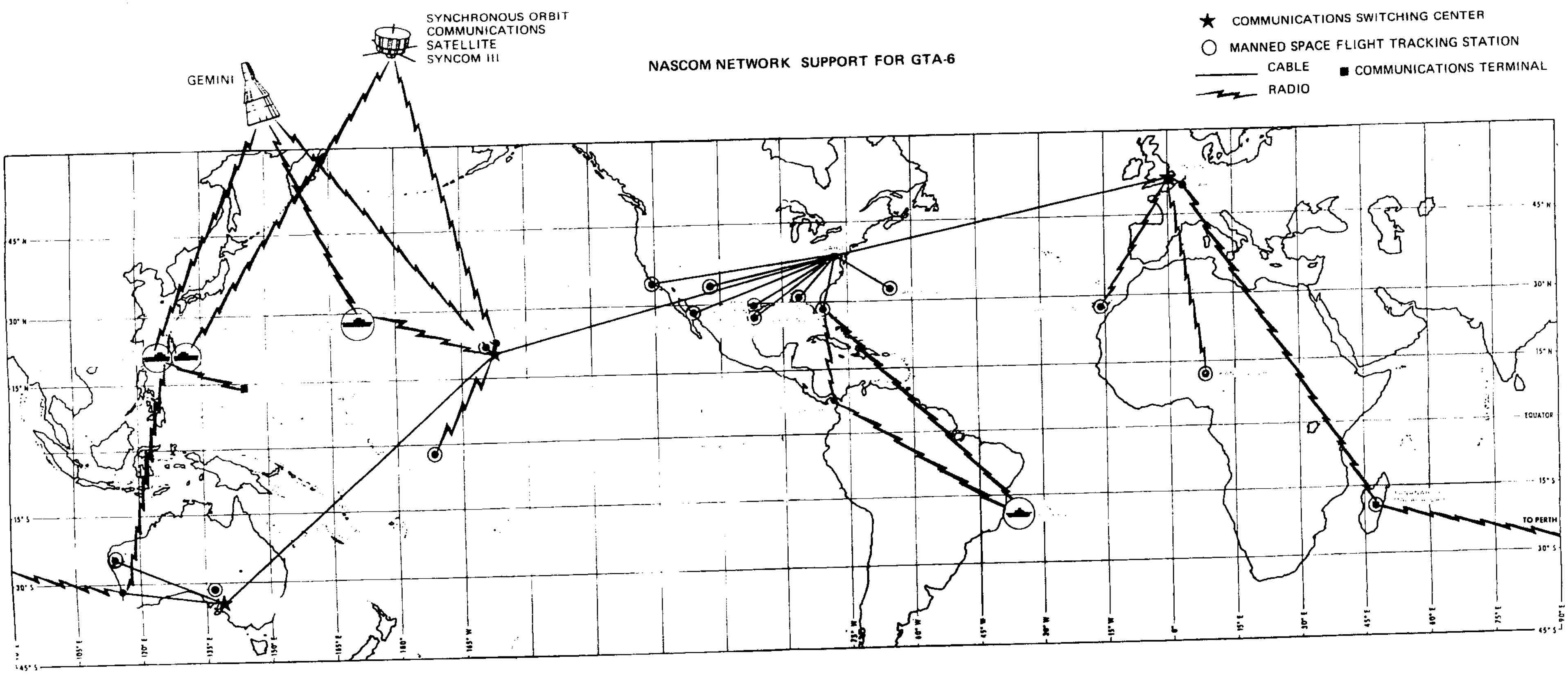

Figure 6-8. NASCOM Network Support for GTA-6.

- Long-haul, wide-band data systems were installed and implemented between Goddard and the Data Acquisition Facilities at Rosman and Alaska.

FY 1966

- Completed modifications to the MSFN portion of NASCOM to accommodate the communications requirements of the Gemini Program and engaged in major engineering effort to modify and augment the network to accommodate the Apollo Program.

- Completed modifications and additions to the wideband data system between GSFC and Fairbanks and Rosman, North Carolina.

- Established initial elements of a worldwide high-speed data network as part of the NASCOM system.

- Established automated teletype message multiplexing at the London and Canberra switching centers with high-speed transfer to Goddard systems. (Figure 6-9)

- Completed system design of automated high-speed and wideband data message switching system and implemented initial elements at GSFC with switching to Goddard IBM 7094s and via a wideband channel to Houston (MCC) Univan 494s. (Figure 6-10)

It is apparent from the above list of accomplishments that NASCOM was influenced most strongly by the manned flight programs and that the Gemini and Apollo implementation phases overlapped one another. The incremental nature of NASCOM evolution -- an improvement here, upgrading there -- is also obvious. Like Mother Bell, NASCOM's goal is satisfied "customers." The customers of NASCOM, as mentioned before, are NASA's various project control centers. (Figure 6-11)

NASCOM During the Apollo Period

The Apollo Program meant further expansion of NASCOM, not only geographically but also in terms of circuit capacity.

Figure 6-9. The NASCOM Teletype Center at Goddard.

Figure 6-10. NASCOM's Univac 490 real-time automatic switching computer for handling high-speed data circuits.

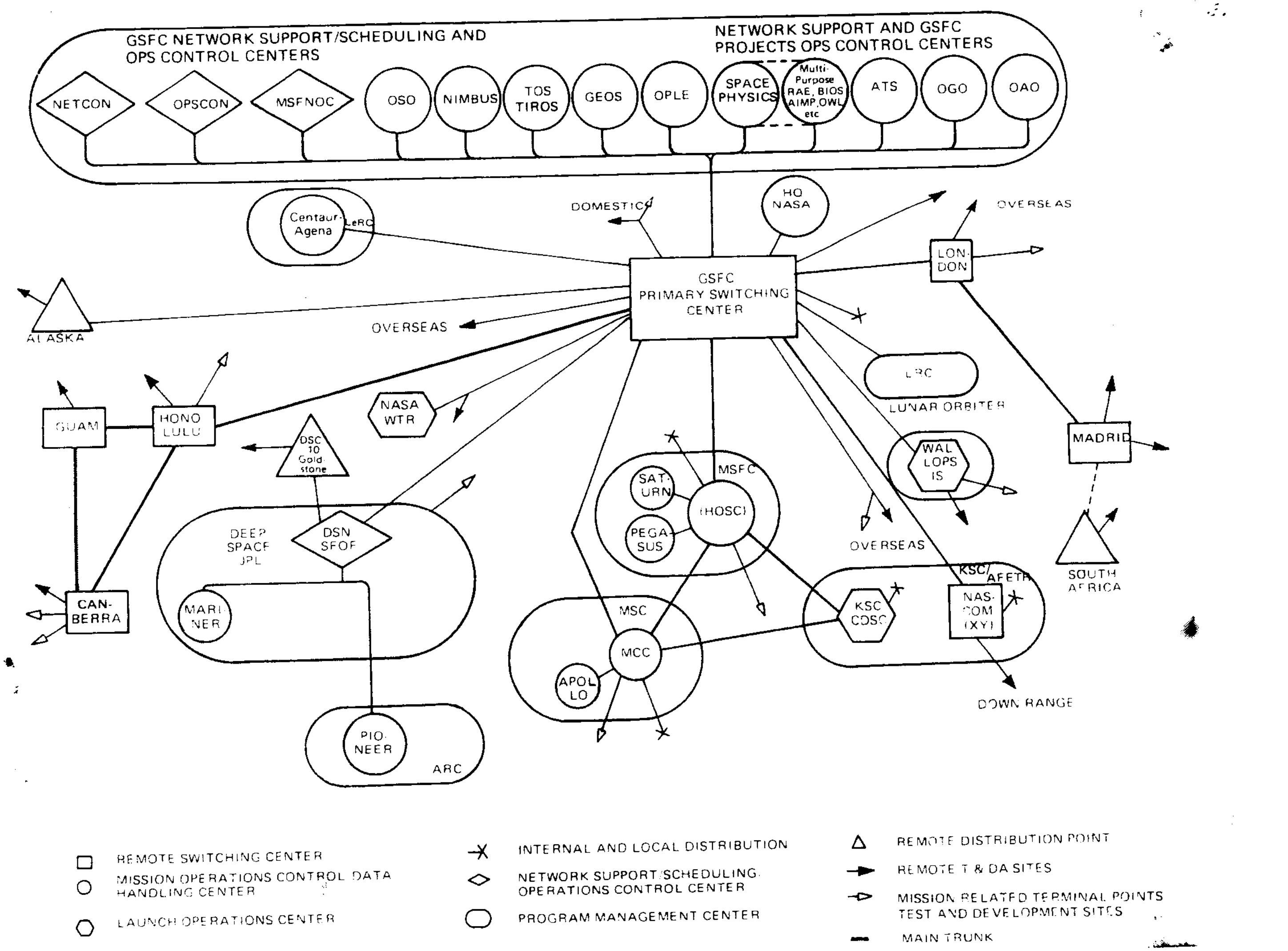

Figure 6-11. The basic NASCOM configuration, showing the various control centers served.

The most important addition to NASCOM during Apollo was the communication satellite. NASA's demanding requirements for Apollo forced the early introduction of commercial communication satellites in a dramatic way.

NASA had already experimented with communication satellites on some of the Gemini flights, using *Syncom 2* and *Syncom 3* to prove out the operational use of communication satellites on real-time missions. The Syncoms were prototype synchronous communication satellites which NASA employed as alternate means of communication with the Gemini tracking ships. The success of these Gemini experiments led NASA to consider synchronous communication satellites as permanent parts of NASCOM. As it turned out, the Apollo remote site requirements could be satisfied only by satellite. There was no other way to insure reliable communications between the ships, Ascension, Grand Canary, Carnarvon, and the rest of the MSFN.

NASA could have launched its own communication satellites for Apollo, or it could have requested satellite channels on some of the military communication satellites. A third source of satellite services was the Communications Satellite Corporation, which as yet had not orbited any spacecraft. In June 1965, reflecting a political decision to give the new Corporation a "shot in the arm," NASA asked the Manager of the National Communications System (NCS) to initiate discussions with the Communications Satellite Corporation about the provision of satellite services during Apollo.[16] This NASA initiative led to the signing of an agreement between Comsat Corp. and NASA, which called for the launch of three satellites to support Apollo but which would also have additional commercial capacity.[17] The first satellite in this series, Intelsat 2A, did not attain a synchronous orbit. The next two, however, were successful; Pacific 1 was launched in January 1967, and Atlantic 2, in March 1967. These met the Apollo requirements and soon began handling commercial traffic.

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[16]NASA had to have communication satellites; the aid to Comsat Corp. was only a secondary consideration.

[17]The letter of intent was entitled "Agreement Between the NASA and Communications Satellite Corporation for Communications Services." It was dated July 5, 1966. Originally, NASA agreed to assume a liability of $6 million to compensate Comsat Corp. should this new technology not be as well-developed as NASA maintained.

The addition of communication satellites to the NASCOM equipment inventory provided a step-increase in reliable service to several difficult MSFN stations. However, more gradual improvements occurred along all NASCOM technological frontiers during Apollo; to wit:

FY 1967

- Completed implementation of high-speed data terminals at various locations to place the NASCOM worldwide high-speed data network into operation.
- Implemented a conversion of the Goddard Switching Computer system from 490 to 494 central processors to provide greater capabilities and capacities.
- Implemented Phases I and IIa of the automatic data switching system providing automatic message switching for high-speed digital data.
- Established new NASCOM communications control centers at Madrid, Guam, and Cape Kennedy.

FY 1968

- Completed HF radio and wireline data installations at remaining MSFN and STADAN sites, and conducted test and improvement programs for 2400 bit-per-sec data.
- Established SCAMA facilities at the Guam switching center; and replaced SCAMA facilities at Canberra, Honolulu, and Madrid with new improved units of greater capacity.
- Integrated the DSN into the NASCOM network automatic teletype message-switching system.
- Completed extensive tests on new high-rate data modems at transmission rates between 3600 and 9600 bits-per-sec on voiceband circuits for possible application in the NASCOM network.
- Added a third 494 Switching Computer for "standby" redundancy and improved system reliability.
- Completed arrangements and implementation of diverse and alternate route configurations for various remote Apollo USB and other sites.

- Discontinued Adelaide as a NASCOM switching center, shifting switching and technical control functions, and routing circuits directly to the Canberra switching center.

- Rerouted circuits within Australia directly to Canberra to bypass Adelaid Switching Center. This shifted the switching and technical control functions to the Canberra Switching Center, resulting in economies.

FY 1969

- Established a new, reliable route for voice, data, and teletype channels to the STADAN and DSN sites in South Africa via submarine cables through Ascension and the Canary Islands, replacing radio communications with these sites.

- Established a full-duplex 48-kHz channel between Goddard and the Madrid Switching Center.

- Set up a West Coast Switching Center at JPL to provide more flexibility and consolidation of voice and teletype channels from the western U.S.

- Upgraded the wideband links between Goddard and Houston from 40.8 to 50 kilobits/sec.

- Arranged for part-time television services from Madrid and Honeysuckle Creek sites to Houston via Intelsat.

- Expanded MSFN communications to include an additional high-speed channel for telemetry from each USB site.

FY 1970

- Established new NASCOM patch facilities at Carnarvon, Ascension, Grand Canary Island, Johannesburg, and Tananarive for greater control flexibility on long-haul channels.

- Established a NASCOM Video Control Center at Sydney, Australia, for the Apollo program. Center processes sequential color signals, scan conversion, and switching between the Parkes 64-m and Canberra 26-m MSFN antennas to Houston, Australian ABC, and the commercial TV network.

- Set up standard SCAMA interface facilities and four-wire intercom key systems at STADAN sites.

- Set up an emergency communications center at Goddard to back up the primary NASCOM switching center.

- Effected considerable cost reductions through temporary circuit close-downs on voice channels to Australia, Madrid, South Africa, and JPL.

- Reduced the activities and manpower at the Guam Switching Center to the status of a Network Patch and Test Facility.

FY 1971

- Implemented 4800 bit/sec high-data-rate transmission capability to all DSN and MSFN sites in support of Apollo and the Mariner-Mars missions.

- Installed 7200 bit/sec transmission capability at all STADAN sites except Tananarive, Mojave, and Kauai.

- Established NASCOM teletype terminal and voice distribution facilities at the San Marco Launch Complex (on equator in Indian Ocean) in support of SAS, San Marco, and SSS satellite projects.

- Set up 50,000 bit/sec wideband data links between Hangar AO, at Cape Kennedy, and JPL's SFOF via NASCOM Goddard Tech Control in support of the Mariner-Mars missions.

In addition to the new satellite relays, new stations, such as Guam, were added; the Apollo Wings were built at the DSN stations; eight aircraft and five ships were assigned to the injection and reentry regions. From the bandwidth standpoint, television transmissions were planned and the new USB equipment installed throughout the MSFN could collect data at a faster rate than the old Gemini equipment. STADAN and the DSN, too, required more data-flow capacity from NASCOM. (Fig. 6-12)

Goddard's NASA Communications Division had been preparing for Apollo for years--like the rest of NASA. Although the Apollo Program was the most influential in terms of

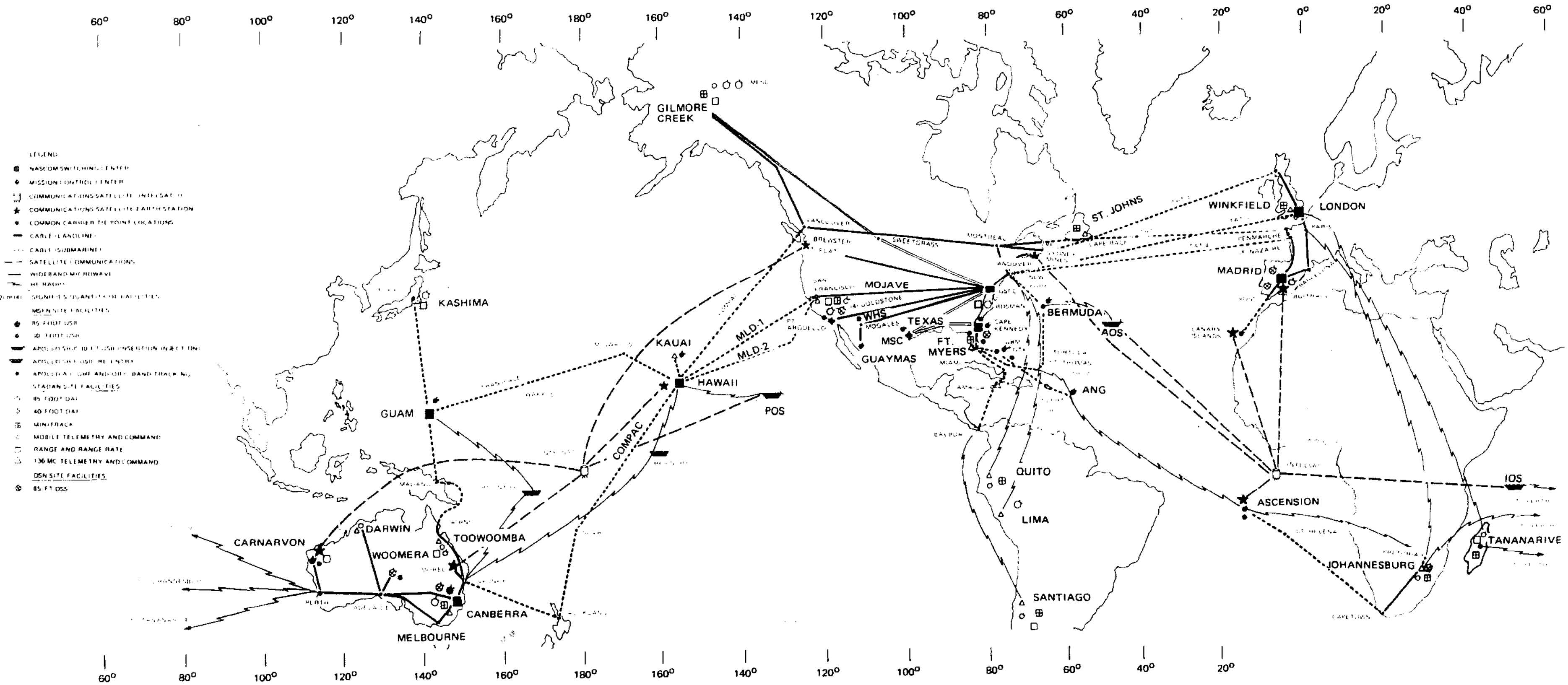

Figure 6-12. Major NASCOM communication links as of mid-1971.

NASCOM's configuration, the NASA Communications Division was organized functionally rather than by project. When the Tracking and Data Systems Directorate was split in July 1967, the NASA Communications Division became part of Ozro Covington's new Manned Flight Support Directorate. The primary reason for this change was to balance the two Directorates involved at about 500 personnel each. The Communications Division could have gone either way from the functional point of view, but it was perhaps more at home with the MSFN group which levied the most challenging requirements on it.

Historical Trends Within NASCOM

It is difficult to separate NASCOM trends from those of the three networks it serves; therefore, the reader will notice some redundancy with the summary sections of the preceding chapters.

1. Whereas NASA's three networks began with three separate communications systems, these were merged in mid-1963 into a single, more flexible, reliable, and economic network -- NASCOM. NASA's management at Goddard was likewise centralized in the NASA Communications Division.
2. The technological trend has been toward ever-wider-bandwidth circuits, operating over larger geographical areas, in more nearly real time.
3. NASCOM adopted digital communications and computer switching controls during the early 1960s.
4. Reliability and the high cost of overseas service forced NASCOM to adopt the policy of providing overseas switching centers.
5. NASCOM helped pioneer the use of long lines and communication satellites in wide-band data transmission.

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APPENDIX A

GLOSSARY OF MSFN AND STADAN STATIONS

AHMEDABAD — STADAN

A collateral station in India. Operational during 1962. Collateral stations are operated by foreign nationals, although NASA usually supplied some equipment. Such stations are not regularly scheduled.

ALASKA — STADAN

Officially called Ulaska (for University of Alaska) before 1961. Also called Fairbanks, a more general appellation, which includes the Gilmore and College sites. Located at Gilmore Creek, 22 km north-northeast of the city of Fairbanks, Alaska, in a small valley which used to be a placer mining site. The so-called Gilmore site of **NOAA** is only 1000 m away. Alaska was the first DAF site, with a 26-m antenna becoming operational in March 1962. The high-gain, multiple-frequency antenna was required for the polar-orbiting Nimbus satellites and the POGOs. A 12-m antenna was added in August 1966. In late 1966, the Minitrack array at College was moved to Alaska to consolidate Alaskan tracking operations. The site is on Federal land assigned indefinitely to NASA by the Department of the Interior.

AMERICAN MARINER — MSFN

A DOD instrumentation ship employed during the MA-8 mission.

ANNOBON ISLAND — MSFN

An island off the west central coast of Africa. Proposed in S-45 as a Mercury tracking station. Grand Canary filled this position in the final network.

ANTIGUA — MSFN, STADAN

Antigua is a small island (280 square kilometers) in the British West Indies (480 km east of Puerto Rico. Minitrack tracking facilities were at Coolidge Field, where the U.S. conducted military operations. Antigua was one of the original Minitrack sites. It was installed in October 1956. Interferometer arrays were installed to track Vanguard launch vehicles approaching and leaving along the Atlantic Missile Range. The site was operated jointly by the U.S. Navy and Air Force on land leased from the West Indies Foundation. A Microlock station with interferometry and Doppler tracking was also installed on Antigua. The Minitrack site was closed in July 1961.

Antigua was also the site of a DOD station which was employed during Gemini and Apollo. NASA operated an Apollo USB installation here for monitoring S-IV cutoffs. The Apollo equipment was needed originally because of the large azimuth window (72°-108°) of the Saturn V. As this window narrowed with experience, the USB station was deactivated. However, launch delays on Apollo 12 increased the Saturn-V azimuth to where Antigua was reactivated temporarily. See Chapter 3 for the discussion regarding the colocation of NASA and DOD facilities.

ANTOFAGASTA STADAN

A Pacific port in north Chile. The Minitrack station was located at a spot called Salar del Carmen. Antofagasta was one of the original prime Minitrack IGY sites set up along the 75th meridian. It became operational during August 1957. On Chilean soil, the station was initially operated by the Army and then by a joint NASA-Bendix-University of Chile team. With the improved capabilities at Santiago and Quito, Antofagasta became redundant and was closed in July 1963.

ARIA MSFN

Apollo Range Instrumented Aircraft. See Chapter 5 for details. The ARIA are modified C-135A jet aircraft.

ASCENSION MSFN

A rocky British island in the South Atlantic 8300 km downrange from the Cape. Site of a DOD range station. Used during Gemini and as a primary USB station during the near-Earth phases of Apollo. NASA now operates its own network facility there. See Chap. 5 for controversy regarding collocation of NASA and DOD stations. A dual USB system with a 9-m antenna is located here. JPL also operates a DSN station at Ascension.

BARBUDA STADAN

A small island in the Leeward group southeast of Puerto Rico; once important in the slave trade. Barbuda was suggested as a Minitrack site in the early NRL reports and proposals (see NRL Memo 548). Because of difficult terrain (logistics), Antigua and Grand Turk were chosen instead as downrange Minitrack sites.

BARSTOW

See GOLDSTONE.

BERMUDA MSFN

Situated in the Atlantic Ocean about 1200 km southeast of New York City, Bermuda has been a primary MSFN station from Mercury on. Bermuda tracking data are needed to confirm the orbit and help make the go-no go decision. During orbital flight, Bermuda provides an extension of the coverage available from continental stations. In the case of an Atlantic recovery Bermuda can provide reentry tracking. Because of communication difficulties between Bermuda and the mainland, a computing and control center was built during Mercury. When network communications to Bermuda were improved with the installation of a submarine cable, the Mercury computer was removed. Mercury equipment was installed at Town Hill, the highest point on the island, and on Cooper's Island, six air miles away. During Mercury, it was impossible to find a local contractor who would commit himself to the Mercury schedule. Burns and Roe therefore built the station with their own crews. During Apollo, Bermuda was a prime USB site, with an FPQ-6 radar and a USB system with a 9-m antenna. Bermuda's special role was the monitoring of the launch-ascent phase, preceding orbital insertion. It also supported the near-Earth phases of the Apollo missions.

BLOSSOM POINT STADAN

Blossom Point, Maryland, on the Potomac River is 57 km southeast of Washington, D. C. Blossom Point was the first operational Minitrack station. It was ready at the time of the first Sputnik, in early October 1957. In fact, a special 40-MHz cross array was quickly installed at Blossom Point to track the Sputniks. Blossom Point was the "prototype" Minitrack station and was used for research, development, and equipment testing. Minitrack crews were trained there during the IGY days. On a site leased from the Army, Blossom Point was first operated by Navy personnel and then taken over by a Bendix crew. Blossom Point was closed on Sept. 30, 1966 and its equipment was transferred to Network Test and Training Facility (NTTF) at Goddard.

BRAZILIA STADAN

During the prosecution of Project SERB (Study of the Enhanced Radiation Belt) in 1962, STADAN telemetry reception equipment was installed near the Brazilia airport to record measurements made by various satellites carrying radiation monitoring instrumentation. Because of the configuration of the Earth's magnetosphere, the trapped radiation was particularly intense over Brazilia. The equipment was transferred to Majunga in 1963.

CANAL ZONE STADAN

A Canal Zone Minitrack station was proposed by NRL in the Vanguard proposal. Sites in Panama proper were also examined (see Panama); but because of electronic interference and poor sites, no tracking stations were built either in Panama or the Canal Zone.

CANARY ISLANDS

See GRAND CANARY.

CANBERRA

See HONEYSUCKLE CREEK.

CANTON ISLAND MSFN

A small coral atoll in the Phoenix Island Group about halfway between Australia and Hawaii under condominium status with U.S. and British commissioners. Site was used during Mercury and Gemini, but was phased out before Apollo. The original Mercury site was built by U.S. Seabees, who set up a "package village" more or less to keep themselves in practice. Canton Island had no regular air or ship service during Mercury; a special ship had to be hired to transport station material. The island has no natural source of fresh water, and the salt air is extremely corrosive. Canton Island was phased out Dec. 31, 1967.

CAPE CANAVERAL/CAPE KENNEDY MSFN

The "Cape," located on the central east coast of Florida, has been the site of all Mercury, Gemini and Apollo launches. Site of Mercury Control Center. In addition, the Cape was a primary launch and near-Earth tracking station during all manned space flights. The equipment at NASA's Merritt Island and DOD's Patrick Air Force Base are considered part of the Cape complex. NASA operates a dual USB system with a 9-m antenna. DOD provides Azusa and ODOP nagigation support during the launch phase. See also: MERRITT ISLAND and PATRICK.

CARNARVON MSFN, STADAN

The NASA site is 31 km souteast of Carnarvon, in northwestern Australia. The STADAN equipment installed here consists only of a Goddard range and range rate unit. The MSFN operates a prime USB Apollo site here to support the near-Earth phases of the missions. Prior to Gemini, the Mercury stations at Muchea and Woomera were consolidated at Carnarvon in order to obtain better rendezvous coverage of the more variable Gemini orbits. Carnarvon received the first FPQ-6 radar assigned to the MSFN.

CHRISTMAS ISLAND MSFN

A Pacific atoll near the equator. Suggested in S-45 as a Mercury station, but no usable site was available. The proposed station was eventually shifted to Canton Island.

COASTAL SENTRY QUEBEC MSFN

The original Indian Ocean Ship, the Coastal Sentry was stationed between Zanzibar and Muchea during the early Mercury shots. Ship was repositioned for MA-8, MA-9, and the various Gemini shots. The ship was originally a Cl-M-AVI class freighter that had been converted for tracking on the AMR. Considerable modification was necessary before the ship met Mercury standards. Not used for Apollo.

COLLEGE STADAN

Also called Fairbanks, a more general appelation that includes Gilmore and Alaska sites. The NASA equipment was on a state-owned site six miles north of the city of Fairbanks. College was added to the original IGY Minitrack network in 1960 when it became necessary to track high-inclination satellites, such as Nimbus and POGO. The station has been operated by personnel from the University of Alaska. In late 1966 the Minitrack equipment was transferred to the Alaska site.

COLLEGE PARK STADAN

In 1962, telemetry receiving and tape recording equipment was installed at a NASA data processing facility in College Park, Maryland, near Goddard. Telemetry tests were conducted at College Park. It was not a regularly scheduled STADAN station and was phased out in 1964.

COOBY CREEK

See TOOWOOMBA.

CORPUS CHRISTI MSFN

A primary MSFN station since Mercury. The station was set up at Rodd Field, a deactivated airfield 11 km southeast of Corpus Christi, after negotiations with the General Services Administration. An existing hangar was converted for Mercury use. This site has experienced considerable trouble with local sources of radio noise and uncooperative business concerns. Corpus Christi was a prime USB station required to support the orbital phases of Apollo. A 9-m antenna and a single USB system are located here.

DARWIN STADAN

On the north coast of Australia. Darwin has been the site of special OGO facilities.

EAST GRAND FORKS STADAN

The NASA site was 16 km northeast of East Grand Forks, in northwestern Minnesota. The East Grand Forks Minitrack station was added to the original Minitrack network in 1960 to track high-inclination satellites. The equipment was on a leased private site and was operated by Bendix personnel. This station was phased out on July 30, 1966 as part of NASA's program relying on fewer, better-instrumented tracking stations.

EAST ISLAND, PUERTO RICO MSFN

A DOD FPS-16 radar located here was used during MA-9.

EGLIN MSFN

A MSFN station during Mercury days. The site is 76 km northwest of Panama City, Florida, and is located at site A-20 of the Air Force Eglin Gulf Test Range. Existing buildings and services were diverted to NASA use.

EMPALME

The Mexican name for the Guaymas site. See GUAYMAS.

ESSELEN PARK

See JOHANNESBURG.

STADAN

FT. MYERS

NASA facilities are located 11 km south of Ft. Myers, on the Gulf Coast of Florida. The Ft. Myers Minitrack site was added in November 1959 to replace the Ft. Stewart station that was converted to an Active Minitrack (SPASUR) station for Air Force use. Ft. Myers received most of its equipment from the Havana station when it was removed after the Cuban revolution. The site is on leased private land and is operated by Bendix personnel.

STADAN

FT. STEWART

Ft. Stewart, Georgia, was the site of one of the original IGY Minitrack arrays. In 1958, the site was modified for use by the Air Force in the East-West Active Minitrack fence (SPASUR). The passive Minitrack equipment was transferred to St. Johns, Newfoundland, in July 1959.

STADAN

GILMORE

Often called Fairbanks in the literature and sometimes Alaska (in error), the name "Fairbanks" actually includes all Alaskan STADAN facilities. Gilmore is the site of a second Alaskan 26-m antenna, which was built in 1962 for the U.S. Weather Bureau (now part of NOAA). The Gilmore antenna is now operated by NOAA. See also the discussion under ALASKA.

MSFN, STADAN

GOLDSTONE

The area around Goldstone Lake, about 73 km north of Barstow, California, supports the largest concentration of NASA tracking and data acquisition equipment. The Deep Space Network (DSN) alone possesses three 26-m antennas (Pioneer, Venus, and Echo sites) and one 64-m dish (Mars site). The MSFN station has another 26-m dish, while the STADAN station uses a 12-m paraboloid and a Minitrack interferometer array. The MSFN dual USB equipment and 26-m antenna were built especially for the support of Apollo during the translunar and lunar phases of the missions. The DSN Pioneer station at Goldstone is equipped with an Apollo wing so that its 26-m antenna can work cooperatively with that of the MSFN station some two miles southwest. The MSFN, DSN, and STADAN stations are all located on a 173-square-kilometer tract within the Fort Irwin Army Reservation.

The STADAN station at Goldstone (often called Mojave or Barstow in the literature) did not become operational until 1960, when the Minitrack equipment originally installed at Brown Field Naval Auxiliary Air Station at Chula Vista, California, was transferred out to electronic quiet created by the Goldstone's remoteness and encircling mountains. The 12-m dish was installed later. In the middle 1950s, a Microlock interferometer was installed at Goldstone.

GRAND BAHAMA ISLAND MSFN

Grand Bahama is vital to the MSFN during the critical launch phase because of its strategic geographic location. In particular, it was required because there was fear that there might be communication dropouts at the MILA station from the Saturn V due to flame attenuation. Grand Bahama is a coral island 81 km east of Palm Beach, Florida. It is 133 km long, with a maximum elevation of 7.6 m. It is also the site of DOD range equipment. Grand Bahama has been used by NASA from the first Mercury shots on. Grand Bahama supports Apollo during the launch and orbital phases with a C-band radar and a single USB system with a 9-m antenna. The Apollo USB equipment is transportable.

GRAND CANARY MSFN

Owned by Spain, 285 km northwest of the African coast and only 45 km north of the equator. Grand Canary was essential during Mercury and Gemini for tracking in case Bermuda commanded an abort. The station is the first to validate Cape Kennedy and Bermuda orbital data. The site was used in both Mercury and Gemini. During Apollo it was a prime USB site with a 9-m antenna. The site of the Apollo equipment was moved about five miles from the old Gemini station. (See Chapter 5 for details.) Grand Canary is also a station in the Solar Particle Alert Network (SPAN).

GRAND TURK MSFN, STADAN

Grand Turk (the "Rainless Isle") is one of the Turks and Caicos Islands in the British West Indies. Special Minitrack equipment was installed on Grand Turk during the IGY to track the Vanguard third stage. Minitrack equipment consisted of an array of Yagi antennas looking downrange. Grand Turk was phased out during July 1961 as other tracking equipment on the Atlantic Missile Range took over during the ascent phase of satellite launches. A Microlock station was also installed on Grand Turk and tracked military vehicles as early as 1956. Grand Turk was also employed to provide radar coverage during the final phase of reentry during Mercury and Gemini. DOD equipment is located here.

GREENBELT See NTTF.

GUADALCANAL MSFN

An island of World War-II fame in the Solomons group. S-45 specified this island for the Mercury Network but it was dropped on Sept. 25, 1959 for reasons of economy--the additional third orbit coverage was not worth the cost.

GUAM MSFN

A U.S. island in the Marianas group. NASA built a new MSFN site here for the Apollo Program after surveying Saipan and Tinian. Guam is a prime USB site supporting the near-space phases of Apollo. A dual USB system and a 9-m antenna were installed here.

GUAYMAS MSFN

Near the Mexican towns of Guaymas and Empalme on the east coast of the Gulf of California. Mexicans called the station Empalme or Empalme-Guaymas. (See text for discussion of negotiations with the Mexican government.) Guaymas was a primary network site during Mercury, Gemini, and part of Apollo. It extended the length of solid tracking and data acquisition coverage during the orbital phase westward, permitting more time for critical tests, maneuvers, etc. During the first portion of the Apollo program, Guaymas was fitted with a 9-m antenna and a single USB system. In addition to political problems, it was difficult to purchase parts locally and import U.S. parts during the implementation stage. Guaymas was dropped from the network because the stations on Hawaii and the U.S. mainland were found to provide adequate coverage.

HARTEBEESTHOEK

See JOHANNESBURG.

HAVANA STADAN

Minitrack equipment was placed at Batista Field, 52 km west of Havana. One of the IGY prime Minitrack stations was installed at Havana in January 1957. Anticipating harassment and interference after the Cuban revolution, NASA moved the station's equipment to Ft. Myers in 1959.

HAWAII

See KAUAI.

HONEYSUCKLE CREEK MSFN

The NASA facilities are located near Canberra, in southeastern Australia. The Apollo Network station opened officially on March 20, 1967. Used to support the deep-space and lunar portions of the Apollo missions, the Honeysuckle Creek site possesses a 26-m dish with dual USB equipment. The antenna is colocated with the DSN Tidbinbilla 26-m paraboloid, which is actually 98 km from the MSFN site. Tidbinbilla has a DSN wing.

HOUSTON MSFN

The site proposed for a 26-m USB antenna for Apollo in 1962. This station was never built because it was too close to Goldstone which already had 26-m antennas for backup purposes.

HUNTSVILLE MSFN

A TAGM-7 class DOD instrumentation ship employed during the MA-8 shot. The Huntsville was a 6- class Victory ship later modified to support Apollo. One of the original five Apollo ships, it was equipped with radar and USB gear.

JOHANNESBURG STADAN

The names Esselen Park, Pretoria, Hartebeesthoek, and Olifantsfontein have all been used to designate NASA tracking facilities in the Johannesburg area. The reasons for this confusion are evident in the following discussions. All STADAN equipment is now located at Hartebeesthoek thirty-eight miles northwest of Johannesburg on a 68,000 **square** meter site which is part of a 20square-kilometer tract set aside for the Radio Space Research station. Minitrack equipment was installed at Johannesburg during the IGY to pick up satellites as they were placed in orbit along the Atlantic Missile Range. At first, the equipment was placed at Esselen Park, 29 km northeast of Johannesburg, where it was operated by the National Telecommunications Research Center, temporarily located at the National Railway College. When the Minitrack equipment was converted to 136 MHz in 1960, the site was moved to Hartebeesthoek. The original Esselen Park site was close (6 km) to the Olifantsfontein site of one of the SAO Baker-Nunn cameras. Hartebeesthoek is also the location of the DSN 26-m paraboloid.

KANO MSFN, STADAN

Kano is a city in northern Nigeria. ISIS telemetry and command equipment was installed at Kano to get better geographic coverage during this ionospheric research program. The Kano site was turned over to the MSFN in 1966, which had conducted Mercury operations here. Gemini was also supported from Kano, but the site was dropped from the MSFN when it was not required for Apollo.

The original Mercury installation was divided between two sites five miles apart because large pieces of land cost too much, especially in view of the fact that the transmitting and receiving sites had to be well-separated to avoid radio interference. Most construction work was done by hand; any skilled labor had to be imported. Nigeria was unsettled politically during the late 1960s--a factor militating against large investments in tracking facilities.

KASIMA MACHI STADAN

A collateral station in Japan. Operational since 1967.

KAUAI MSFN, STADAN

The STADAN site is 26 km northeast of Kekaha, near Kokee State Park, on Kauai, one of the Hawaiian Islands. ISIS telemetry and command equipment was installed at Kauai to get better geographical coverage during the ionospheric research program. Kauai has also been a prime MSFN site from Mercury on. It was vital for setting Mercury capsule timers prior to retrofire. During Apollo, Kauai was a prime USB station, supporting near-Earth phases of the missions. A dual USB system and 9-m antenna are located here.

KOKEE PARK

See KAUAI.

KWAJALEIN MSFN

DOD provided voice facilities during MA-9.

LIMA STADAN

The Minitrack station was at Pampa de Ancon, 37 km northwest of Lima, Peru. Lima was the site of one of the prime IGY Minitrack installations along the 75th meridian. It became operational during August 1956. Originally run by the U.S. Army, the equipment was subsequently operated by a team made up from NASA, Bendix, and scientists from the Geophysical Institute of Peru. Lima was one of the sites where special antennas were installed to track the Sputniks, which transmitted at 20 and 40 MHz instead of the 108-MHz Minitrack design frequency. The land is provided by the Government of Peru. The station was placed on inactive status in October 1969 because the improvements of other STADAN stations made it redundant and because of the completion of the Biosatellite program. Much of the equipment was relocated at other stations, and the station is now closed out as a network facility.

MADAGASCAR

See TANANARIVE.

MADRID MSFN

For the Apollo program, NASA collocated a 26-m dish with dual USB equipment with the DSN's Robledo 26-m antenna. The Robledo station possesses a DSN wing. It is about 11 km from the MSFN site. Madrid supported the translunar and lunar phases of the Apollo flights.

MAJUNGA STADAN

On the west coast of Madagascar. Several satellites, such as the Alouettes, were injected into orbit over the Indian Ocean at points below the horizon for the Johannesburg Stadan station. Telemetry reception equipment from Brazilia was installed at Majunga in 1963 near the city's airport to monitor spacecraft housekeeping telemetry in order to verify boom deployment, etc. The Majunga station was not regularly scheduled and was removed in 1964.

MAYAGUANA STADAN

Mayaguana is an island in the Bahamas group. Originally, Mayaguana was slated to receive a modified Minitrack station to track the Vanguard third stage; but, since the Antigua and Grand Turk sites seemed adequate, the station was eliminated from the network in September 1957. The equipment that was destined for Mayaguana was sent to San Diego.

MERCURY MSFN

An Apollo instrumentation ship. It is a 19-class converted tanker.

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MERRITT ISLAND MSFN

Adjacent to DOD's facilities at Cape Kennedy, Merritt Island is NASA-owned and operated. (See Chapter 3 for discussion of the NASA-DOD interface.) During the near-Earth phases of Apollo, Merritt Island was a prime Apollo station with a dual USB system and a 9-m antenna. The old Mission Control Center at the Cape (MCC-K) was abandoned and converted into a museum.

MOJAVE

See GOLDSTONE.

MUCHEA MSFN

The Mercury station was located approximately 65 km north of Perth, in Western Australia. Australian personnel built and operated the station. Muchea equipment was moved to Carnarvon after Mercury.

NEWFOUNDLAND

See ST. JOHNS.

NTTF MSF,STADAN

The Network Test and Training Facility is located adjacent to Goddard at Greenbelt, Md. Various equipments employed in the various NASA networks are installed here for purposes of testing and/or training. In effect, the NTTF "looks like" a real STADAN or MSFN station to a spacecraft.

OAHU MSFN

Originally, the Mercury Hawaiian site was to be colocated with DOD facilities on this Hawaiian Island. In the end, the location was changed to Kauai.

OLIFANTSFONTEIN

See JOHANNESBURG.

ORRORAL VALLEY STADAN

Sometimes called Canberra, the STADAN equipment is located 57 km southwest of Canberra, Australia. The Orroral Valley site was added to STADAN in 1965, when a 26-m DAF dish was placed in operation. Like the other Australian tracking installations, Orroral Valley permits more frequent telemetry readout of satellites and also helps determine the precise shape of the Earth with geodetic measurements from the South Pacific. Minitrack equipment from the Woomera site was moved to Orroral Valley in late 1966.

PALERMO MSFN

The site proposed for a 26-m USB antenna for Apollo in 1962. Ultimately, the Apollo station required in South Europe was placed at Madrid.

PANAMA STADAN

The Panama site, at Rio Hata, was to have been one of the prime Minitrack stations along the 75th meridian during the IGY. The Panama government wished the site located at a military base, where there would have been serious electronic interference. This fact, combined with frequent thunderstorms, reduced the desirability of a site in Panama. When it became apparent that the Antigua and San Diego stations would suffice for tracking and data acquisition during satellite passes over this region, the Panana station plan was abandoned.

PARKES MSFN

West of Sydney, Australia. The Australian 64-m radio telescope located here was used to support the Moon walk during the Apollo-11 mission. See Chap. 5 for details.

PATRICK MSFN

Patrick Air Force Base, near Cape Kennedy, has supported NASA missions with radars and other electronic gear since the beginning of the space program.

PERTH

See Muchea.

POINT ARGUELLO MSFN

About 64 km northwest of Santa Barbara on the California coast and part of DOD's PMR, now the Western Test Range. NASA used a site at South Vandenburg as a secondary site during Mercury, Gemini, and Apollo for C-band radar and communications support.

PRETORIA MSFN

During Gemini and Apollo, NASA obtained C-band radar and telemetry coverage from this DOD site in South Africa.

QUITO STADAN

The STADAN site is at Mt. Cotopaxi, 56 km south of Quito, Ecuador. Quito was one of the prime IGY Minitrack stations along the 75th meridian. The station is on a leased private site. Originally set up and run by the U.S. Army personnel, it is now operated by Bendix. In addition to the Minitrack interferometer, a 12-m dish is now installed.

RANGE TRACKER MSFN

A DOD radar-equipped ship used during Gemini and MA-9.

REDSTONE MSFN

One of the five instrumented Apollo ships. The Redstone is a 19-class converted tanker. (See Chapter 5 for details.)

ROBLEDO MSFN

See MADRID.

ROSE KNOT VICTORY MSFN

The Rose Knot was the original Mercury Atlantic ship. Located between Bermuda and Grand Canary during the early Mercury shots the Rose Knot provided telemetry and voice capabilities on all three passes.

ROSMAN STADAN

The STADAN site is located near Rosman, North Carolina, about 80 km south southwest of Asheville. Rosman, one of the newer STADAN stations, was dedicated on Oct. 26, 1963. The first 26-m DAF dish went into operation in July 1962, the second in August 1964. The site was established specifically for receiving high-data-rate telemetry from Observatory-class satellites. Located on National Forest land, the station is shielded from radio interference by hills. Important factors in the selection of Rosman was lack of high voltage transmission lines and commercial circuits as well as proximity to Goddard. Rosman also has range and range rate equipment and is an ATS site, but there is no Minitrack interferometer.

SAN DIEGO STADAN

The Minitrack station was located at the Brown Field Naval Auxiliary Air Station, Chula Vista, California. The prototype Minitrack equipment manufactured by Bendix was installed at San Diego in 1957. Navy Electronics Laboratory personnel operated the station for NRL. The imminent closure of Brown Field stimulated the move of the station to Mojave in Aug. 1960. San Diego also received modifications that permitted reception of the Sputnik 20- and 40-MHz signals in late 1957.

SAN NICHOLAS MSFN

DOD provided voice coverage for MA-9 from this island off the California coast. The station is a part of the Pacific Missile Range.

SAN SALVADOR MSFN

One of the Bahama Islands. Specified as a Mercury site in S-45, the location was changed to Grand Turk Island.

SANTIAGO STADAN

The STADAN station is located at the Peldehue Military Reservation, 48 km northeast of Santiago, Chile. Santiago was one of the prime Minitrack sites established along the 75th meridian during the IGY. It has been enlarged considerably with the addition of a 12-m dish, range and range rate equipment, and, in 1957, modifications to permit the tracking of Sputnik 20- and 40-MHz signals. The station is on land leased from the University of Chile. The U. S. Army originally operated the station, but the operating team is now made up of NASA, Bendix, and University of Chile personnel.

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SINGAPORE STADAN

A "collateral" station at Singapore provides telemetry support for STADAN on occasion. The station is operated by foreign nationals.

SOLANT STADAN

A STADAN "collateral" station located in the Falkland Islands in the South Atlantic. NASA provided telemetry equipment while the British Government supplied manpower. Solant mainly worked British and Canadian satellites.

SOLOMON ISLANDS

See GUADALCANAL.

SOUTH POINT STADAN

A collateral station located in Hawaii. Operational 1961-1966.

SOUTH VANDENBURG

See POINT ARGUELLO.

ST. JOHN'S STADAN

The STADAN station site is 23 km north of St. John's on Newfoundland's eastern tip. This Minitrack station was added to the network in 1960. The station, on Canadian land, was operated by Canadian personnel. St. Johns was closed in March 1970 because adequate coverage was available at other STADAN sites.

TANANARIVE STADAN

The STADAN site was 32 km southwest of the city of Tananarive, in central Madagascar (now the Malagasy Republic). Site is collocated with the MSFN installation. The STADAN station increases tracking and data-acquisition coverage in the southern hemisphere. Range and range rate equipment was installed in 1965. In 1966, SATAN Minitrack equipment and a 12-m antenna were added.

When the MSFN station was withdrawn from Zanzibar, some of its functions were carried out by adding equipment to the STADAN station located here. During Apollo, a Capri C-band radar and telemetry recording equipment were employed at times.

TEL-IV

A DOD telemetry site at Cape Kennedy

TEXAS

See CORPUS CHRISTI.

TIDBINBILLA

See HONEYSUCKLE CREEK.

TOOWOOMBA STADAN

A STADAN station is located here, some 130 km west of Brisbane, Australia, at Cooby Creek. Transportable ATS equipment, including a 12-m antenna, was installed in 1966. The station was deactivated in October 1969 following the launch of ATS-E. The equipment was shipped back to the United States for refurbishment and eventual relocation.

TWIN FALLS VICTORY MSFN

A DOD radar-equipped ship employed during MA-9.

ULASKA

See **ALASKA.**

VANGUARD MSFN

An instrumented Apollo ship. The Vanguard is a 19-class converted tanker. (See Chapter 5 for details.)

WAKE ISLAND MSFN

In the central Pacific. DOD provided voice coverage for MA-9 from here.

WALLOPS ISLAND MSFN

On the Virginia coast. Used during the Gemini program for radar and communication coverage. Also, the Mercury Demonstration Site, where equipment and procedures were tested. (Fig. A-1)

WATERTOWN MSFN

A DOD ship during MA-8. The Watertown was a 6-class Victory ship, which was later instrumented for Apollo. As mentioned in Chapter 5, NASA released the Watertown to DOD in 1968.

WHITE SANDS MSFN

A MSFN site from Mercury on. The site is 73 km north of El Paso. White Sands is located on the Army's White Sands Missile Range. A prime site during Mercury and Gemini, White Sands provided only C-band radar support during Apollo.

WINKFIELD STADAN

The Winkfield station was 57 km southeast of London. Winkfield was a Minitrack site established in 1961. It was the only STADAN station in Europe. The equipment was located on British government land and operated by British personnel.

WOOMERA MSFN, STADAN

The U.S. tracking facilities were located about 13 km southeast of the Australian town of Pimba, in southern Australia. The major Australian rocket facilities at Woomera were northwest of the U.S. site.

The Woomera Minitrack Station became operational in August 1957. During the IGY its role was to obtain tracking data from the Southern Hemisphere for geodetic purposes. In 1957, The Woomera site received the 20- and 40-MHz modifications so that Sputnik signals could be received. In late 1966, the Minitrack equipment was moved to Orroral Valley. The Woomera site was also used to support Mercury, but all equipment (except for the C-band radar) was moved to Carnarvon for Gemini. It was not used at all for Apollo.

ZANZIBAR MSFN

An island in the Indian Ocean 19 km off the African coast. Mercury equipment was split into two parts, six air miles apart, near Zanzibar City. Zanzibar has no deep-water port, so all Mercury equipment had to be taken ashore in lighters. See text about Zanzibar revolution and the expulsion of the MSFN station. Equipment was moved to Tananarive for the Gemini program.

Figure A-1. Tracking and data acquisition facilities at Wallops Island.

APPENDIX B

MEMORANDUM OF UNDERSTANDING

between E.C. Buckley, Director of the NASA Office of Tracking and Data Acquisition and W.H. Pickering, Director of the Jet Propulsion Laboratory concerning the participation of the Deep Space Instrumentation Facility in the Manned Space Flight Program.

I. REASONS FOR THE MEMORANDUM

Participation of the Deep Space Instrumentation Facility (DSIF) in the Manned Space Flight Program represents a major program change for the DSIF and a new series of commitments for the Jet Propulsion Laboratory. New relationships are required with the Manned Spacecraft Center (MSC) and the Goddard Space Flight Center (GSFC).

The DSIF, as the tracking and data acquisition network for unmanned lunar and planetary projects, must continue to meet its commitments to these projects. There is every indication that DSIF utilization by these flight programs will increase markedly in the near future.

This memorandum is intended to assist all parties concerned by providing a description of the intended participation of the DSIF in the Manned Space Flight Program.

II. DEFINITION OF THE DSIF

The DSIF Program is an activity managed by the Jet Propulsion Laboratory for NASA/OTDA involving:

A. Research, technology, system analysis and evaluation in direct support of deep space tracking and data acquistion,

B. Engineering, procurement and installation of equipment for operational use throughout the network of DSIF tracking and data acquisition stations,

C. Supervision of, and participation in, operation of all DSIF stations.

For the purpose of this memorandum, the DSIF facilities include the present deep space stations at Goldstone, Woomera and Johannesburg; the spacecraft/DSIF compatibility stations at AMR; the deep space tracking facilities under implementation at Canberra and Spain; the 210-foot antenna station under implementation at Goldstone; mobile tracking and data acquisition equipments for spacecraft instrumentation early in flight; the remaining two 210-foot antenna facilities intended to complete a three-station network of these antennas; and such additions to the above facilities as may be required to alleviate overloading.

III. PRIORITIES

The program which the DSIF supports by providing tracking and data acquisition are, in decreasing order of priority:

A. Unmanned spacecraft flights to the Moon and beyond,

B. Manned spacecraft flights to the Moon, participating in a backup role (becoming first priority for participating stations during actual flight and immediate preparations therefor),

C. Assistance by post-injection tracking and data acquisition in the evaluation of launch vehicles intended for unmanned flights to the Moon and beyond (Centaur, etc.),

D. Assistance by post-injection tracking and data acquisition in evaluation of S-band tracking and data acquisition systems intended for use in manned flights to the Moon and beyond, and

E. Such earth satellite, unmanned and manned, as OTDA may direct which are within the equipment and scheule capability of the individual stations.

IV. RESEARCH, TECHNOLOGY, SYSTEM ANALYSIS AND EVALUATION FOR THE MANNED SPACE FLIGHT PROGRAM

The following research, technology, system analysis and evaluation activities are intended in direct support of OTDA's assignment in the Manned Space Flight Program above and beyond related activities in support of the Unmanned Space Flight Programs:

A. Orbit determination using the DSIF for monitoring DSIF tracking,

B. Selective telemetry reduction, for monitoring DSIF data acquisition,

C. Studies of the applicability of 210-ft diameter antennas in support of the Manned Space Flight Program,

D. Consultation as mutually agreed on modulation and demodulation techniques for use in S-band tracking and data acquisition, and

E. Consultation as mutually agreed on the use of S-band tracking and data acquisition as a radio guidance technique for manned flights to the Moon.

The above activities are necessary for efficient, proper utilization of the DSIF and for continuing equipment and management improvement within the DSIF. It is not intended that these activities restrict the operational utilization by MSC/IMCC of any DSIF data taken under the overall technical direction of GSFC and mission control of MSC.

V. ENGINEERING, PROCUREMENT AND INSTALLATION

The following activities are intended in direct support of OTDA's assignment in the Manned Space Flight Program above and beyond related activities in support of the Unmanned Space Flight Program:

A. Participation in, and concurrence with, such parts of the overall planning for the Manned Space Flight Network as affect the DSIF.

B. Development of OTDA-approved specifications for the integrated S-band subsystem and for the integration of manned space flight ground equipments into DSIF stations.

C. Development through demonstration at Goldstone of an integrated S-band subsystem according to OTDA-approved specifications. JPL will procure and install such equipments at the DSIF stations and such other stations as may mutually be agreed by JPL, GSFC and OTDA.

D. Integration into the DSIF stations of equipments peculiar to manned space flight to be compatible with both the standard DSIF equipment and the needs of the Manned Space Flight network. Procurement, installation and checkout of such equipments (equipments performing functions not carried out by standard DSIF equipments or the integrated S-band equipment) will be the responsibility of others; JPL will be responsible for providing the necessary space and logistic support at the DSIF stations for such equipments.

VI. OPERATIONS

A. JPL is responsible for the supervision of, and participation in, operation of all DSIF stations.

B. Operation of all equipment at DSIF stations should be the responsibility of JPL in the long run; however, initial operation of manned space flight peculiars will be the responsibility of others. The transfer of operational responsibility for the manned space flight peculiars will be at the initiative of others and with the concurrence of JPL.

C. Overall technical direction by GSFC and mission direction by MSC of the DSIF stations participating in the Manned Space Flight Network should be similar in authority and scope to the present functional direction of the DSIF by the Unmanned Space Flight

Program. Details should be worked out by JPL, GSFC and MSC.

D. The DSIF will establish resident engineers at GSFC and MSC for the purposes of continuing liaison and flight operations participation.

VII. RESOURCES

Participation by JPL in the Manned Space Flight Program is above and beyond present tasks and resources assigned to JPL. Participation will therefore require tasking, funds, space and manpower authorization from NASA Headquarters. JPL will reassign total resources to effectively carry out all tasks.

VIII. EXCLUDED SUBJECTS

This memorandum specifically and deliberately is not concerned with:

A. Responsibilities for system design and performance of the complete S-band flight and ground system.

B. Responsibilities for establishing and carrying out Apollo flight tests of the S-band system.

Neither of the above is assignable by OTDA alone nor acceptable by JPL in the established management framework.

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400 NETWORK SYSTEMS REQUIREMENTS

This section describes the ground network system established to meet requirements for the exchange of information between the ground stations and the space vehicle. These systems shall be compatible with the space vehicle receiving and radiating equipment. Specifications of the space vehicle equipment requiring interface considerations are listed in the appendices to this document. The acquisition of flight data by the Manned Spaceflight Network will be achieved through use of:

a. Network tracking systems
b. Telemetry systems
c. Voice communications systems
d. Updata systems
e. Unified S-Band systems.

401 Ground Data Acquisition Plan

The establishment of the data acquisition plan for a specific Apollo Flight Mission will be handled in a manner similar to that used for Mercury and Gemini. The Data Coordination Office will issue a specific data acquisition plan for each mission which utilizes the Manned Spaceflight Network. This plan will include the data channel allocations and the required distribution of the ground acquired data. The remote network station requirements to support the expected ground data acquisition plan are shown in the tables of Section 200. Detailed operational data requirements for the launch vehicle on a specific flight will be issued jointly with spacecraft requirements in the data acquisition plan. Detailed requirements for launch vehicle engineering data will be issued for each flight in an MSFC Data Acquisition Requirements Document.

410 NETWORK TRACKING SYSTEMS

The Apollo/Saturn V missions will require that tracking data be furnished to the RTCC at MSCC for trajectory determination, to assure a dynamic evaluation of the flight status of each mission during all mission phases (launch, earth orbit, translunar injection, etc.). C-Band radar and/or the Unified S-Band System will be utilized as the primary data source and will be supplemented as appropriate by other tracking systems such as MISTRAM, AZUSA, and Minitrack. Each of the various systems are outlined in the following paragraphs and for location of a particular system, refer to the tables of Section 200.

411 C-Band Radar System

The C-Band radars (AN/FPS-16's, AN/FPQ-6's, AN/TPQ-18's and AN/MPS-26's) will be utilized in tracking the CSM during earth orbital flights and will be utilized in tracking the S-IVB/IU during earth orbital and lunar flights. The C-Band radar provides vehicle position data (range, azimuth and elevation) in serial binary form to a Digital-to-Teletype (D/TT) Converter which converts this information to teletype format. This output from the D/TT converter is fed to the teletype equipment for transmission, once each six seconds, to the RTCC at MSCC. Major interfaces are: Tracking radar to D/TT Converter, D/TT Converter to ground communications link and ground communication link to the Communications Processor in the MSCC. Communication links are discussed in Section 500 and Appendix H of the PIRD.

412 Unified S-Band

The Unified S-Band system will be utilized in tracking the CSM and/or LEM during earth orbital and lunar flights. Certain stations, including the DSIF sites, will have the capability of simultaneously tracking two vehicles when they are within the beamwidth of the single antenna. The tracking system provides vehicle position data for transmission to the RTCC at MSCC by utilizing equipment integral to the Unified S-band facility. Range and range rate information, X and Y angular information plus timing is provided as inputs to a Tracking Data Processor System which formats this information for teletype and high speed data transmission. Major interfaces are Range and Range Rate System-Antenna Position Programmer-Timing System to Tracking Data Processor System, Tracking Data Processor to ground communication links, and ground communication links to the Communications Processor in the MSCC.

413 MISTRAM Equipment

This system, comprised of one station at Valkaria and a second on Eleuthera will provide high accuracy flight trajectory data to the Impact Prediction System during the earth launch phase of flight. This system is utilized by range safety and is included for reference only.

414 AZUSA Equipment

This system, comprised of a tracking station at Cape Kennedy, will be employed for coverage of the first portion of the earth launch phase of flight. Depending upon the implementation of ground instrumentation, either MISTRAM or an AZUSA transponder will be carried on the launch vehicle. This system is also utilized with the Impact Prediction System and is included for reference only.

415 Minitrack Network

This system of world-wide ground stations will be employed whenever a Minitrack beacon is carried on the space vehicle and will be utilized during the S-IVB/IU earth orbital portion of the flight. The data will be utilized for acquisition prediction, long term orbit prediction and atmospheric re-entry prediction.

416 Acquisition Aid Systems

The acquisition aid system being installed to support Gemini requirements and an additional acquisition aid system to be implemented with the Unified S-Band System will satisfy the Apollo/Saturn V requirements.

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420 TELEMETRY SYSTEMS REQUIREMENTS

421 Spacecraft

The telemetry systems to be utilized in receiving instrumentation measurements from the Apollo spacecraft are dependent upon the mission type being flown. During earth orbital flights, the CSM will utilize a VHF link (PCM/FM) and/or a Unified S-Band link (PCM/PM/PM or PCM/PM/FM) and the LEM will utilize a VHF link (designed for transmission of low bit rate data to the CM) and a Unified S-Band link (PCM/PM/PM or PCM/PM/FM). Upon initiation of the lunar mission the CSM VHF link will be deleted, the LEM VHF link will be utilized for transmission to the CSM only and the telemetry transmission to GOSS will be limited to the Unified S-Band links for both the CSM and LEM. Each telemetry ground station must be capable of processing and displaying real time PCM data from the CM and LEM. When real time data is not being processed, the ground station must be capable of processing and displaying recorded data. The display system at each site will conform to requirements stated in Appendix I. A flexible real time display system will be required such that a multiple selection of telemetry data from the CM and LEM may be displayed. The display implementation should allow changes to the nominal display configuration at any time without disrupting the continuity of the operational support. The required real time displays at each site will be presented as they are determined. Calibration techniques must be established and implemented.

422 Launch Vehicle

Certain additional requirements exist for support of the launch vehicle during powered flight and the S-IVB/IU during earth orbit and translunar injection. Support will be that of real time display of certain parameters on the S-IC, S-II and S-IVB/IU PCM links during the launch phase and on the Instrument Unit PCM link during S-IVB/IU orbital operations and translunar injection. All Saturn PCM links will be at a bit rate of 72 kilobits/sec.

423 Remote Site Processor

Each GOSS remote site with PCM telemetry capability will be equipped with a Remote Site Processor which will utilize a Univac 1218 solid state computer. The requirement for the on-site computer consists of data formatting for communications equipment and flight controller read-out. This telemetry-to-teletype conversion system is required to select, convert, format, and transmit received telemetry information in teletype form in near real time and in a method compatible with the existing communications circuits. The communications circuits are high speed data (HSD), 2 kilobits per second and teletype (60 and 100 words per minute). The HSD will be required from TEX and BDA and presents a real time data transfer. HSD may be required from other stations as lines are available. The system will automatically generate message formats, when requested by flight control personnel, and transmit them when circuits are available for use. The PCM ground station shall furnish all data to the conversion system which will select the required data. The outgoing summary

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message format will include the necessary directing codes, message identification, station identification, time tags, and the predetermined data in coded form. The data messages will be directed to the Real Time Computer Complex at the MSCC. Other requirements and operations of the on-site computer are defined in Appendix G of this PIRD.

430 UPDATA SYSTEM

At different junctures of an Apollo/Saturn V mission, the requirement will exist for the generation, processing and transmission of digital data commands to the space vehicle. The GOSS Digital Command System Network provides this capability with the RTCC at the MSCC as the primary originator of commands. The outputs from the RTCC are fed to the Communications Processor for buffering into the Master Digital Command System (MDCS) units or the Remote Site DCS units. Real-Time sites (Texas, Cape Kennedy and Bermuda) are operated directly from the MDCS units through the Communications Processor.

431 CSM Updata Link

The CSM Updata transmission link is the Unified S-Band system which operates in the 2000 Mc range. This link transmits intelligence to the CM by using a Phase Shift Keying (PSK) technique to place digital information on a 2000 cps audio tone which is combined with a second audio subcarrier of 1000 cps, added linearly, for bit synchronization. These two combined subcarriers are applied to the Unified S-Band equipment where they frequency modulate a 70 Kc updata subcarrier which in turn phase modulates the S-Band transmitter.

a. DCS Characteristics

(1) Memory Capability - The memory of the ground updata link is split into two separate sections (spacecraft and launch vehicle) with each section capable of storing approximately 182 different updata words.

(2) Word Format - Every command word is divided into address code bits and information bits. Each of these bits is divided into five sub-bits for security and error control.

(3) Updata Verification - Updata memory load initiated from [illegible] to the remote sites must be verified before acceptance by the DCS at the remote sites. The reception of the data word by the spacecraft is verified at the remote site which initiated the command.

(4) Transmission Modes - There will be three modes of transmission: Repetitive, unlimited - word transmission repeated until a reception is validated. Repetitive, limited - word transmission repeated up to a maximum of seven times before the next command word is transmitted if the word is not validated. Manual - transmission of a single word selected for transmission with or without validation before next word is transmitted.

(5) Data Presentation - To provide manual override indications, display lights may be used on functions such as message priority, transmission mode, and vehicle data reception verification. There is a requirement to record the telemetered indication of all vehicle events which occur as a result of up link transmissions and to record all mission data transmitted from the ground sites to the spacecraft.

b. Unified S-Band Characteristics

See paragraph 450.

432 Launch Vehicle Updata Link

The launch vehicle updata transmission link is a UHF link in the 406-450 Mc range and will consist of a modulator, an AN/FRW-2 transmitter, and a model 240-D power amplifier. The digital information from the RTCC or remote site DCS will be applied as an input to the modulator to frequency shift two oscillators, 400 and 450 Kilocycles respectively. A mixer in the modulator takes the difference of the oscillator frequencies (50 Kc with no modulation, 65 Kc for a binary one and 35 Kc for a binary zero) and the frequency-shift-keyed (FSK) subcarrier mixer output is used to frequency modulate the UHF transmitter.

a. DCS Characteristics

See paragraph 431a.

b. UHF Transmitter Characteristics

The transmitter is to be a dual configuration with automatic failover capability and selectability for "master" and "standby" units. Power output of 10 Kw will be required.

NOTE: Transmission of updata to two vehicles simultaneously is not required. The DCS equipment at the remote sites will be time-shared between the CSM and S-IVB/IU updata links.

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440 GROUND/SPACECRAFT VOICE COMMUNICATIONS REQUIREMENTS

The ground-spacecraft means of voice communications are dependent upon the mission type (earth orbital or lunar mission) and upon the mission phase (launch, earth orbit, re-entry, etc.). However, the spacecraft will have available VHF/AM, HF/SSB, and Unified S-Band systems. For remoting voice communication from the MSCC, the particular system (HF, VHF or Unified S-Band) will be tone keyed at the applicable ground station. The required voice communication links between GOSS and the spacecraft are as follows:

a. Earth Orbital Mission
   (1) Launch Phase
      (a) VHF - Simplex, GOSS to CM
      (b) Unified S-Band - Duplex, GOSS to CM
   (2) Earth Orbital Phase
      (a) VHF - Simplex, GOSS to CM
      (b) VHF - Duplex, GOSS to LEM
      (c) HF - Simplex, GOSS to CM
      (d) Unified S-Band - Duplex, GOSS to CM
      (e) Unified S-Band - Duplex, GOSS to LEM
   (3) Re-entry Phase
      Unified S-Band - Duplex, GOSS to CM
   (4) Recovery Phase
      (a) VHF - Simplex, GOSS to CM
      (b) HF - Simplex, GOSS to CM

b. Lunar Mission
   (1) Launch Phase
      (a) VHF - Simplex, GOSS to CM
      (b) Unified S-Band - Duplex, GOSS to CM

(2) Earth Orbital Phase

(a) VHF - Simplex, GOSS to CM

(b) Unified S-Band - Duplex, GOSS to CM

(3) Translunar Injection to Transearth Injection

(a) Unified S-Band - Duplex, GOSS to CM

(b) Unified S-Band - Duplex, GOSS to LEM

(4) Transearth Phase - Unified S-Band, GOSS to CM

(5) Re-entry Phase

Unified S-Band - Duplex, GOSS to CM

(6) Recovery Phase

(a) VHF - Simplex, GOSS to CM

(b) HF - Simplex, GOSS to CM

450 SPECIAL REQUIREMENTS

451 Unified S-Band System

The Unified S-Band communication link between GOSS and the spacecraft provides two-way voice communication between GOSS and spacecraft; range and velocity of spacecraft; spacecraft to GOSS telemetry, television and biomedical data; and GOSS to spacecraft updata. This will require the use of a minimum of three (3) Unified S-Band facilities with 85 foot antennas (DSIF sites) to support the lunar phases of the Apollo missions and several facilities with 30 foot antennas (NSIF sites) to support the near earth phases of the Apollo missions. Certain NSIF sites and all DSIF sites shall be capable of simultaneous support of two vehicles (CSM and LEM or CSM and S-IVB/IU) within the beamwidth of a single antenna. Other NSIF sites shall be capable of single vehicle support. For station location of dual and single facilities see Section 200. A system with single vehicle capability consists of the following:

a. Antenna System - The antenna system shall provide sufficient gain so that the Unified S-Band system at all NSIF sites will have communications capability of at least 15,000 NM and all DSIF sites will have communications capability to maximum lunar distances for all communication modes (ranging, range-rate, data transmission, and voice transmission). Provisions shall be made to operate the antenna in either the automatic tracking mode (independent of positional information from other sources), or in the slaved mode (dependent on positional information from remote sources such as the C-Band radar, VHF acquisition aid or the MSCC via communication links). The maximum tracking rate of the antenna system shall be compatible with the expected Apollo spacecraft positional and velocity components. A digital angular read-out subsystem will be required to provide angle tracking data in an acceptable form suitable for conversion and transmission. The tracking accuracy and precision of the Unified S-Band antenna shall be equal to or better than those defined for the FPS-16 C-Band radar antenna. Antenna boresight towers and associated test equipment will be provided for calibration and checkout purposes.

b. Acquisition Aid - The acquisition aid system will be an S-Band system capable of pointing the 30 foot or 85 foot antenna so that the spacecraft comes within the prescribed beamwidth.

c. S-Band Receiver - Each S-Band ground receiver will be a dual conversion superheterodyne type receiver using a narrow band phase-lock detection technique. A single carrier frequency is used in each direction for the transmission of all tracking and communications data between the spacecraft and ground with the voice and data modulated onto subcarriers and combined with ranging data.[1] The ground receiver will use suitable detectors for the demodulation of both frequency and

[1] Two separate RF carriers have been proposed for the CSM for transmission of recorded TLM data simultaneously with real time TLM data, voice and ranging. This configuration would require a dual receive capability by the ground station for single vehicle support.

phase-modulated subcarriers and for the frequency or phase-modulated carrier. The voice subcarrier will be 1.250 Mc and the PCM subcarrier will be 1.024 Mc. Provision will be made for conditioning and extracting the composite telemetry signal and routing the signal to the PCM telemetry system for further demodulation, processing, and recording. A preamplifier and subsystem will be provided to satisfy system performance requirements as indicated in Paragraph 451a. The receiver will extract the coherent two-way doppler shift for precision range-rate measurement, and adequate equipment for measuring and recording the doppler frequency will be provided. In addition to processing the down-link spacecraft telecommunications, the receiver will convert RF energy from the monopulse comparator into X, Y, autotrack information for the antenna servo.

d. Ranging Subsystem - The S-Band ranging subsystem will be required for unambiguous range measurements to the spacecraft. The ranging system required will be identical to the JPL-type of pseudo-random noise (PRN) code ranging system. The system will measure the time difference between two identical, separately generated, pseudorandom noise codes (one generated by a coder at the ground transmitter for modulation and the other at the ground receiver for correlation detection to represent range). The spacecraft transponder will use a "turn-around" technique by detecting the code modulation from the ground-to-spacecraft carrier and directly modulating the spacecraft-to-ground carrier with the binary code. The inherent accuracy of the PRN ranging system will satisfy earth-orbital tracking requirements.

e. S-Band Transmitter - The S-Band ground transmitter will consist of a low-level S-Band exciter and a high-power amplifier similar to the JPL DSIF transmitter used at Goldstone. The transmitter will derive its excitation from an ultrastable frequency standard to provide a precision frequency reference for the two-way Doppler measurement. The transmitter carrier will be phase modulated with the PRN ranging code, a 70 Kc data subcarrier and a 30 Kc voice subcarrier.

A suitable interface will be provided between the updata link equipment (DCS) and the S-Band transmitter for transmission of data to the spacecraft. Two combined tones from the updata link equipment (a 2000 cps information tone and a 1000 cps synchronization tone) will be used to frequency modulate the 70 Kc updata subcarrier which modulates the S-Band transmitter carrier.

f. Television System - Adequate ground equipment at the DSIF sites will be required to receive, process, display and record the real time video information transmitted via the Unified S-Band carrier. The analog video signal will be transmitted at a rate of 10 frames per second, 320 lines per frame, with a 500 Kc information bandwidth. The horizontal to vertical aspect ratio shall be 4 to 3.

g. A number of transmission modes for the spacecraft S-Band system have been selected to conserve transmitter power. These modes of operation and associated modulation techniques are included in Table I, Appendices A and B, to the PIRD. A summary of S-Band characteristics as presently planned is outlined in Table II of Appendices A and B.

APPENDIX D

February 5, 1963

MANAGEMENT PLAN FOR THE MANNED SPACE FLIGHT NETWORK

DEFINITION:

The manned Space Flight Network is defined as the individual ground instrumentation stations which function as an integrated network to meet the requirements of the Manned Space Flight Program. The ground instrumentation stations involved will include those currently used in the MERCURY Network, certain stations of the DSIF and Unmanned Satellite Networks, new land or shipborne stations which may be required, and the possible use of adaptable DOD facilities.

HEADQUARTERS RESPONSIBILITIES:

A. The Office of Manned Space Flight (OMSF), NASA Headquarters, has the responsibility for generating the ground instrumentation requirements for the Manned Space Flight Network in conjunction with the Manned Spacecraft Center (MSC) and the Marshall Space Flight Center (MSFC) and for ensuring compatibility and efficient integration between the spacecraft systems and ground instrumentation.

The requirements for ground instrumentation will generally include those necessary for tracking, data acquisition, command, ground-spacecraft-ground communication, and interstation ground communication and will specify the performance with regard to tracking accuracy, data rates, coverage, capability, reliability and availability dates. The instrumentation requirements will be formulated with the assistance of the Office of Tracking and Data Acquisition (OTDA), NASA Headquarters, the Goddard Space Flight Center (GSFC), and the Jet Propulsion Laboratory (JPL) to ensure the most efficient use of existing and planned ground instrumentation of the NASA and the DOD and to ensure the recognition of technological and availability limitations.

B. The Office of Tracking and Data Acquisition, NASA Headquarters, has the management responsibility for the generation, direction and execution of the ground instrumentation implementation plan for the Manned Space Flight Network. The implementation plan shall delineate such items as: equipment capabilities, station locations, subsystem specifications, funding, and scheduling.

The implementation plan will be formulated with the assistance of the OMSF, MSC and MSFC to ensure that the ground instrumentation requirements are met. After concurrence of the finalized implementation plan by the OMSF, it is the responsibility of the OTDA to carry out the implementation. The Office of Tracking and Data Acquisition will continue to maintain close liaison with the OMSF to ensure that additional or changed ground instrumentation requirements are promptly reflected in the implementation plan and that interface problems are resolved.

It is further the responsibility of the OTDA to provide the technical operation of the Network. This will include assessment and evaluation of Network performance and reliability for the OTDA program and for inclusion in the over-all reliability assessment program of the OMSF.

CENTER RESPONSIBILITIES:

Pursuant to the overall responsibilities of the OTDA previously specified, the following responsibilities are assigned:

A. Assistance by the GSFC and JPL to the OMSF, MSC and MSFC in the generation of the ground instrumentation requirements for the Manned Space Flight Network.

B. Generation by the GSFC of the detailed ground instrumentation implementation plan. The ground instrumentation implementation plan will be generated with the collaboration and concurrence of the JPL. Also, the GSFC will be further assisted in this responsibility by the OMSF, MSC, MSFC and other pertinent organizations to ensure that the ground instrumentation requirements are met.

C. Management, direction, and execution by the GSFC of the ground instrumentation implementation plan after approval of the plan by the OTDA and concurrence by the OMSF. This includes the responsibility for equipment procurement, installation and checkout. For those portions of the implementation plan being executed by the JPL, the GSFC is also responsible for co-ordination with JPL to ensure the integrated execution of the plan.

D. Mangement, direction, and execution by the GSFC of the technical operation of the stations in the Manned Space Flight Network, except for those backup Deep Space Network facilities which are the responsibility of JPL. The GSFC is also responsible for managing the overall Network technical operation and for the necessary co-ordination with JPL. Technical operation is defined in the attachment. Within the priorities established by the NASA Headquarters, the GSFC is responsible for the over-all Network scheduling. The Network will be scheduled by GSFC giving priority to manned space flight program support and providing maximum usage of the ground instrumentation stations for meeting requirements of other programs whenever feasible. The MSC will exercise operational control over the Network for mission simulations and mission operations.

E. Management, direction, and execution by GSFC of all ground communications between locations in the Manned Space Flight Network and the control centers. This is further described in the attachment.

F. Management, direction, and execution by the GSFC of the computation necessary for ensuring the Network technical operation, performance and integrity. Portions executed by the JPL shall be coordinated by the GSFC. For manned space flight missions, consideration will be given to the use of the operational computers at the Mission Control Center for these functions. The GSFC is also responsible for the computation necessary for mission control and mission simulations associated with the Gemini non-rendezvous and the unmanned orbital Apollo missions.

RELATED RESPONSIBILITIES:

The MSC is responsible for the planning, implementation and operation of the mission, launch and recovery control centers. This includes mission oriented instrumentation, computation and communications internal to these control centers. The MSC is also responsible for the computation necessary for mission control and mission simulations associated with the Gemini rendezvous and the manned Apollo missions.

ATTACHMENT

1. TECHNICAL OPERATION:

Technical operation is defined as the operation, maintenance, modification and augmentation of individual ground instrumentation stations to function as an instrumentation network in response to mission requirements. Involved in this are the development, implementation and updating of the following for each station: operational directives, calibration standards, logistic support, check-out procedures, equipment inventory, personnel support, equipment change control, technical documentation, cost budgeting, funding, etc. Technical operation also involves the assessment of over-all Network technical performance, reliability evaluation and availability status.

2. GROUND COMMUNICATION:

Ground communication includes the systems engineering, the routing of leased communication lines for maximum economy and the implementation of communication centers. The communication terminals at the control centers will be implemented by the GSFC to meet the requirements established by the MSC.

APPENDIX E

STADAN AND MSFN FINANCIAL SUMMARIES

STADAN FY 1956 through FY 1967[a]

(in millions of dollars)

	FY 61 and prior[b]	FY 62	FY 63	FY 64	FY 65	FY 66	FY 67	FY 68	FY 69	FY 70	FY 71
Operations	17.3	10.0	12.3	23.2	24.8	27.6	36.3	41.7	43.5	44.5	45.2
Construction and equipment	18.0	13.2	18.2	22.7	19.2	16.0	12.6	9.5	10.5	9.6	22.9
Total	35.3	23.2	30.5	45.9	44.0	43.6	48.9	51.2	54.0	54.1	68.1
Cumulative figures for construction and equipment	18.0	31.2	49.4	72.1	91.3	107.3	119.9	129.4	149.9	159.5	182.4

[a]Data provided by Roland Theisen and Joyce Killam, NASA Headquarters, Nov. 4, 1969.

[b]Preliminary Vanguard budget for "tracking and telemetering"; FY 56, 2.1; FY 57, 0.7; FY 58, 0.1. Total IGY expenditures for these functions: 2.9. No programs beyond Vanguard were contemplated. From NRL Letter C-7100-143/55: emc, Sept. 30, 1955. (In NASA Vanguard file.)

MANNED SPACE FLIGHT NETWORK

Financial Summary, FY 1959 through FY 1969[a]

	FY 61 and prior	FY 62	FY 63	FY 64	FY 65	FY 66	FY 67	FY 68	FY 69	FY 70	FY 71
Operations	0.3	16.0	16.5	17.9	23.4	38.2	63.7	71.8	81.4	76.9	67.7
Construction and equipment	53.2	12.3	30.4	207.2	116.1	61.3	30.8	22.5	9.2	11.4	12.7
Total	53.5	28.3	46.9	225.1	139.5	99.5	94.5	94.3	90.6	88.3	80.4
Cumulative figures for construction and equipment	53.2	65.5	95.9	303.1	419.2	481.0	508.7	533.8	543.0	554.4	567.1

[a]Data provided by Roland Theisen and L. Joyce Killam, NASA Headquarters, Nov. 4, 1969.

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