

# Historical Evolution and Legacy of NASA's Near-Earth Space Communications Networks

Sunny Tsiao\*

*ITT Corporation, Colorado Springs, Colorado 80949*

When the National Aeronautics and Space Administration celebrated its 50 Year Anniversary on October 1, 2008, there was one facet of the space program that received little attention. Behind the technology and teamwork that made the pioneering flight of John Glenn and the triumph of Apollo possible was a communication network known as the Spaceflight Tracking and Data Network (STDN). Tracing the history of the STDN is somewhat akin to tracing the history of America's presence in space. It spanned 50-years, experienced unparalleled successes as well as tragic setbacks, and pioneered household technologies before they became the everyday essentials they are today, spin-offs that we cannot live without. The STDN varied greatly over the years and underwent several evolutions. It spawned the 24/7 availability of space communications and set the pace for advances in computing power, signal processing and new digitizing techniques. The enabling capabilities in communications and computing technologies brought about by the STDN played an influential role in America's ventures into space. Consideration of the STDN provides a window into the work, benefits and lessons learned of building and operating an infrastructure necessary for spaceflight. Among them: inter-agency cooperation, diplomacy with and dependence on foreign states, the civilian/military balance, commercialization of space, and finally, public perception and the legacy of an enabling technology that today plays a unique role supporting space opportunities in the 21<sup>st</sup>-century.

## Acronyms

CCSDS	Consultative Committee for Space Data Systems
DAF	Data Acquisition Facility
DSN	Deep Space Network
EVA	extravehicular activity
GSFC	Goddard Space Flight Center
IOAG	Interagency Operations Advisory Group
ISS	International Space Station
ITU	International Telecommunication Union
Kbps	kilo bits-per-second
LEO	low-Earth orbit
Mbps	mega bits-per-second
MSC	Manned Spacecraft Center
MSFN	Manned Space Flight Network
NEN	Near Earth Network
NRL	Naval Research Laboratory
OSC	Office of Space Communications
OTDA	Office of Tracking and Data Acquisition
SCaN	Space Communications and Navigation
SN	Space Network
STADAN	Satellite Tracking And Data Acquisition Network
STDN	Spaceflight Tracking and Data Network
STS	Space Transportation System
TDRSS	Tracking and Data Relay Satellite System
TT&C	Tracking, telemetry and command
USB	Unified S-band

---

\*Principal Engineer, Advanced Engineering & Sciences Division. Member AIAA.

## I. Introduction

Much of what has been written on the topic of the National Aeronautics and Space Administration's tracking and communication networks have been on the Jet Propulsion Laboratory's Deep Space Network. This is perhaps understandable, as the DSN has played a central role on many of America's high profile planetary exploration missions. These include the early Pioneer probes, the Mariner missions of the 1960s and 1970s, Viking and Voyager, and more recently, Galileo, Cassini-Huygens and the new generation of Mars probes that are already returning the requisite data for eventual human exploration of the Red Planet.

Not as familiar but equally impressive in its track record has been the Spaceflight Tracking and Data Network, the near-Earth communications network established and operated by the Goddard Space Flight Center. Known as the STDN, the network was a critical part of the space communications infrastructure that evolved dramatically through the years. The network began humbly, tracking the first satellite in 1957 when the former Soviet Union shocked the world by launching *Sputnik 1* into orbit. At the height of the Space Race, 6,000 men and women operated the behind-the-scene "Invisible Network" central to the success of the Agency's missions.<sup>1</sup> In the ensuing five decades, the Network played a crucial role on every near-Earth space mission that NASA flew, not one of which was ever compromised due to its failure. It received the first television images from space, tracked Apollo astronauts to the Moon and back, and has evolved, today, into a national resource providing global, continuous space communications in the form of the Tracking and Data Relay Satellite System. This Space Network, along with a greatly reduced ground network (the Near Earth Network), work together providing 24/7 support to NASA and international partners in all near-Earth space communications activities.

Recognizing the need to preserve (and make available) this history, the Space Communications and Navigation Office at NASA Headquarters, working with the Agency's History Division, commissioned a project to chronicle the history of the STDN. This project focused on the evolution of the Network, from its earliest incarnation as Minitrack, to the expansive Satellite Tracking And Data Acquisition Network and the Manned Space Flight Network of the 1960s and 1970s, to today's TDRSS and NEN. The project culminated with the publishing of *Read You Loud and Clear! The Story of NASA's Spaceflight Tracking and Data Network*, the latest addition to The NASA History Series.

The impact of four central themes—1) Technology Expansion, 2) Commercialization in the Information Age, 3) International Cooperation, and 4) Human Factors—were interwoven into the chronology.

## II. Central Themes

### A. Technology Expansion

Societies have historically been far more adept at transferring technologies initially developed for other purposes than to have first envisaged that technology for its ultimate far-reaching benefits. Military progress has been at the root of such advancements for centuries. Space has come to the forefront in recent decades. When the STDN was first established, it was strictly a network of ground stations using analog technology of the time. Global communications were still in its infancy. NASA's space communication needs drove many of the early advances in this new and burgeoning technological arena. Genesis of the Network was directly tied to the Cold War and the Space Race borne from it. In the mid-1950s, even before NASA was formally established, the United States began building a network to track what it hoped to be the world's first artificial satellite launched as the U.S. entrant in the International Geophysical Year. Developed by the Naval Research Laboratory under the direction of John T. Mengel, Minitrack consisted of large radio interferometry ground arrays (150 by 150 meters) spread across 11 locations worldwide between  $\pm 35^\circ$  latitude. These football-field-sized antenna arrays received rudimentary, milliwatt-level radio beacon transmissions at the fixed frequency of 108 MHz. Acceptance by the science community of radio interferometry as a spaceflight tracking technique was tepid as the established method was, at the time, optical tracking.<sup>2</sup> Mengel, Roger Easton and others at the NRL had to not only miniaturize and harden the technology for spaceflight, but also sell the idea to an unconvinced community at large.<sup>3</sup> Although built to support Project Vanguard, the network ended up hastily tracking *Sputnik 1* as its first test on 4 October 1957.

In the early 1960's, the Network quickly blossomed to meet the growing satellite tracking requirements of the Agency, eventually peaking at some 50 sites on five continents. Minitrack set the stage for the greatly expanded Satellite Tracking And Data Acquisition Network, the STADAN. Led by the new Goddard Space Flight Center in

Greenbelt, Maryland—the first Field Center established after the formation of NASA—this much more evolved network became the centerpiece for all near-Earth tracking and space communication activities for the United States. Gimbaled, parabolic dishes up to 26-meters in diameter supplanted the linear dipole, metal frame skeletal arrays of Minitrack. Unified S-Band led the way in the mid-1960s. USB was revolutionary for its time, enabling transmission of spacecraft command, telemetry, voice and television using a single, combined data link. The technique was not entirely new to NASA, however, as the DSN had used it since 1958. USB was important on two fronts. First, it enabled the Agency to communicate with the large, data-intensive, observatory class satellites that GSFC was putting into orbit. Second, an Apollo flight to the Moon was on the horizon. Data Acquisition Facilities were constructed near Fairbanks, Alaska and Canberra, Australia to support spacecraft such as the *Nimbus* and *Alouette* in high inclination, high eccentricity orbits. The STADAN served not only NASA's own science and application satellites but also the first commercial satellites then being launched, including the COMSAT *Early Bird*—the world's first electronically active, commercial, communications satellite.<sup>4</sup>

Concurrent with the rapid growth of low-Earth and geosynchronous orbiting satellite presence of the early 1960s was the requirement brought about by the new and yet unknowns of manned (human) spaceflight. This altered the very fabric of the Network. To support this new national priority, GSFC, along with MSC (renamed the Lyndon B. Johnson Space Center in 1973) in Houston, Texas, developed a network that within eight years tracked American astronauts to the Moon and back. Initially called the Mercury Space Flight Network, or MSFN—the word Manned replaced Mercury at the conclusion of Project Mercury—it quickly became just as extensive as the STADAN, surpassing the latter especially in exploitation of then untried technologies and in the number of geographical locations around the globe. Much of its early requirements derived from experience gained from jet aircraft and missile testing and from the DSN's tracking of lunar and planetary probes. Leveraging this experience, network planners worked out solutions to the high data rate and bandwidth requirements needed for human spaceflight.

As the STADAN and the MSFN matured, the requirement for data in the right amount (bandwidth), at sufficient speed (rate) and accuracy (bit-errors) drove their evolution. TT&C at maximum data rate with minimum errors became the primary consideration. A human spaceflight tracking and data network presented unique challenges. Unlike everyday infrastructures like roads and bridges that rely on well-established technologies, capabilities for such a high mission assurance network were not yet well-demonstrated, requiring a migration from an unproven to proven status. A network failure on a robotic planetary probe mission may mean loss of data. A network failure on a human flight may be much more costly. The direction and pace of the underlying technologies—future capabilities, risks, cost—had to be anticipated. This presented another challenge: ill-defined requirements. The development time for new tracking and data transmitting capabilities often exceeded that of the spacecraft and its onboard instrumentation. The net result was the Network often had to evolve its enabling technologies prior to having defined user requirements.

One facet of change was not technological but philosophical. Network centralization had been practically nonexistent during Project Mercury. For mission assurance, Houston dispatched flight controllers to the primary network sites for real-time system evaluation of the spacecraft from the ground on a given pass. Astronaut Capcoms (Capsule Communicators) were also assigned to various voice sites. Here, the NASA culture drove network operations. For unmanned Earth science application satellites, there was no debate on ownership. GSFC was clearly in the lead and the STADAN was centralized at the Network Operations Control Center in Greenbelt. Less unambiguous, though, was network operations for human spaceflight where both GSFC and MSC had a stake.

Despite the fact that there was not always full agreement even within GSFC's own top management, who thought the Center should be devoted to scientific exploration and questioned whether it should be in the business of tracking human spaceflight, NASA Headquarters (under the direction of Edmond C. Buckley, the Agency's first Associate Administrator of OTDA) delegated GSFC with the full responsibility of running the MSFN prior to the first Mercury orbital flight. This decision was pragmatic and politically sound, alleviating MSC the responsibility of running a worldwide tracking network on top of its role as NASA's lead center for human spaceflight. History has shown that not a single mission—manned or unmanned—has ever been compromised due to network failure. Much of the success on what could have been a very divisive issue could be attributed to effective leaders who understood that expertise in the changing technologies resided at different NASA Field Centers.<sup>5</sup>

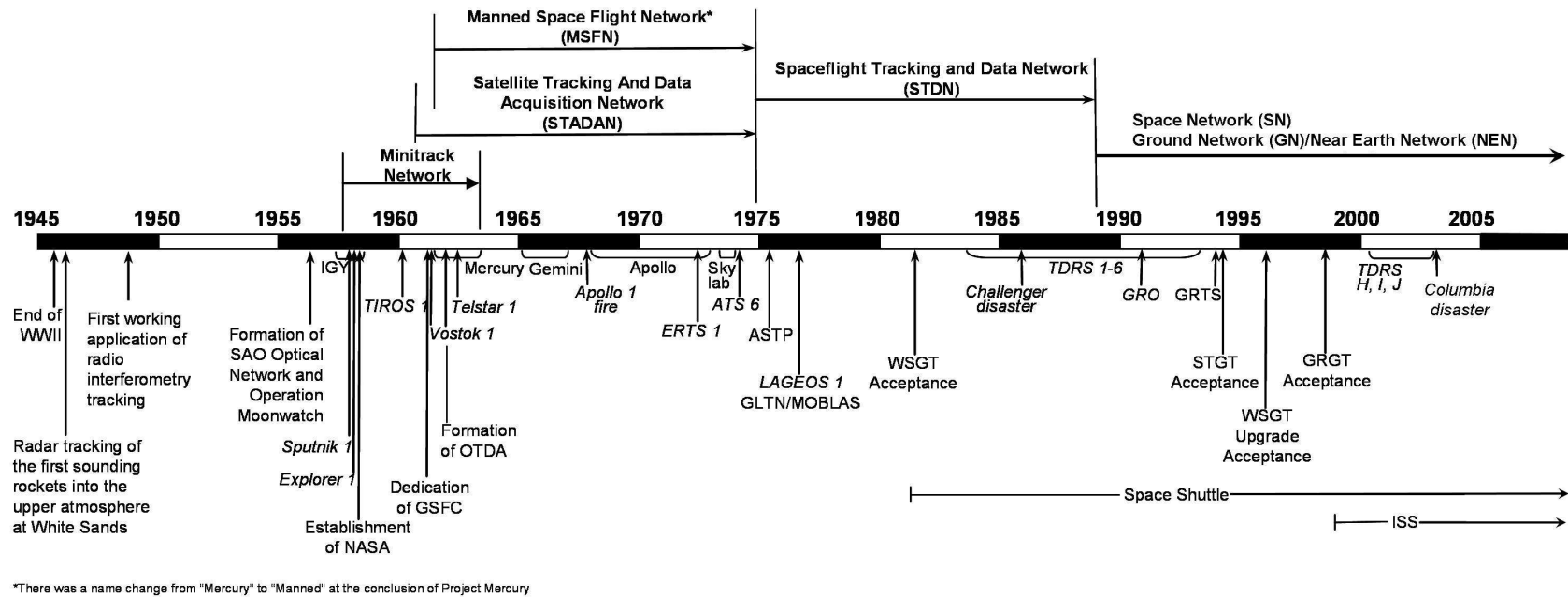
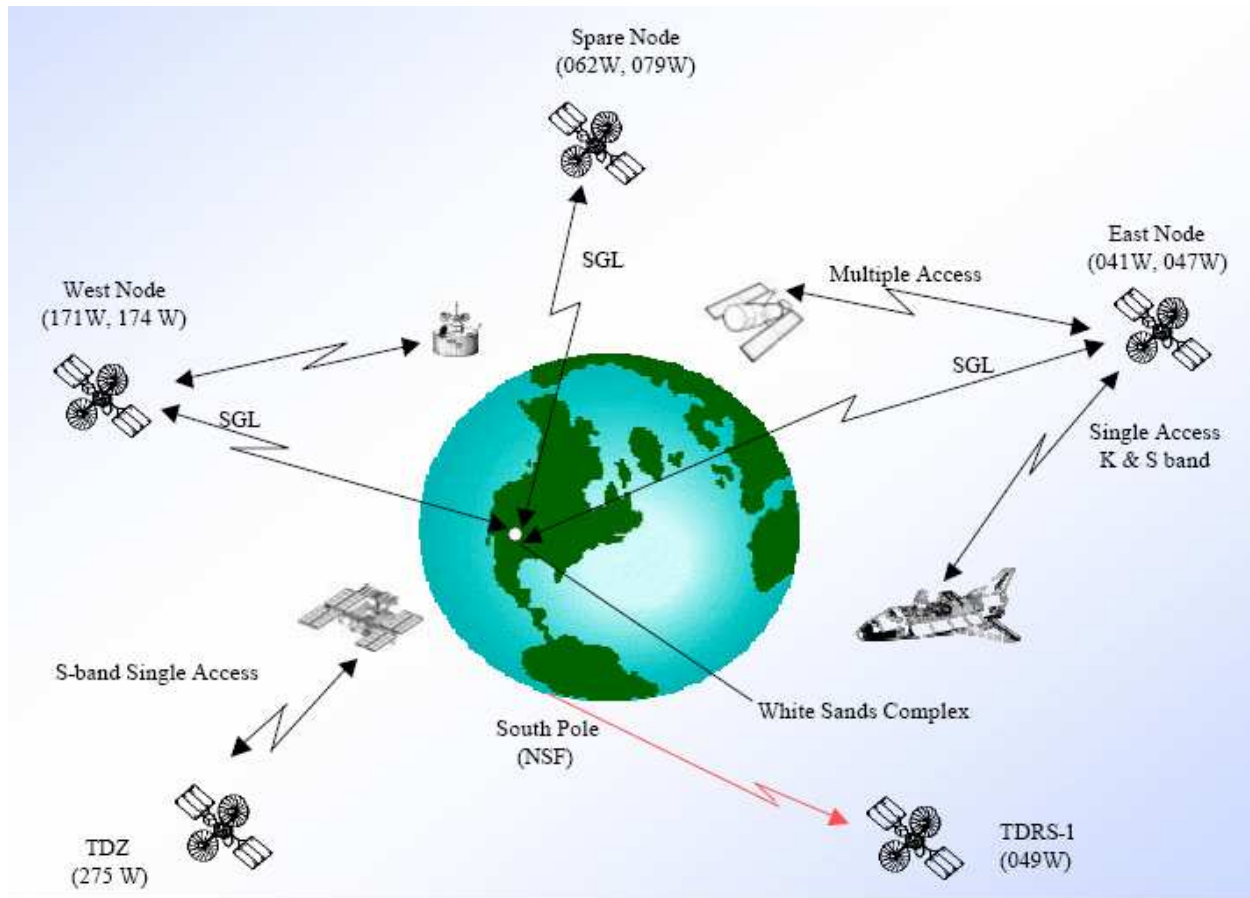


Figure 1. Chronology of NASA's near-Earth tracking and data networks.

A paradigm shift ensued in the cost conscious, double-digit inflation days following Apollo. This, coupled with leaps in digital signaling methods (spurred on in part by the space accomplishments that just took place), greatly impacted the way NASA conducted its tracking and data operations. But network growth and technology advancement could not defy the geographical line-of-sight limitation (curvature of the Earth) restricting coverage of a spacecraft in LEO to just 15-20% of its total ground track. With the Tracking and Data Relay Satellite System coming online in the mid-1980s and operational by 1989, NASA's near-Earth spaceflight tracking infrastructure was completely transformed. The STDN became a synergetic operation consisting of a Ground Network (now called the Near Earth Network) and a Space Network (SN) capable of providing nearly continuous coverage of spacecraft in LEO.

TDRSS was a revolutionary departure from the traditional, ground-based network. NASA has placed nine Tracking and Data Relay Satellites into orbit since 1983. The SN, now a full-fledged constellation anchored by two ground terminals at the White Sands Complex in southern New Mexico and one at the Guam Remote Ground Terminal, supports some two dozen Agency spacecraft, the Space Shuttle, the ISS and DoD satellites. Among the capabilities of the next generation TDRS spacecraft will be the use of Ka-band transmission. TDRS-K and TDRS-L are scheduled to join the constellation in the 2011-2012 timeframe with another two replacements (M and N) possible by 2016.<sup>6</sup> The availability of TDRSS to perform TT&C functions traditionally done by ground stations transformed the role of the remaining ground network. The NEN, with stations near the Arctic Circle and in Antarctica, now provides telemetry services for scientific sounding rockets, launch and range safety, and high inclination polar orbit communications. The SN and NEN can be utilized together. Earth orbiting spacecraft can, for instance, rely on the SN for its TT&C needs on missions that do not require continuous contact with the ground but opt to, mainly for cost reasons, transmit its science data via the NEN.



**Figure 2. The TDRSS Space Network.** Nine satellites in geosynchronous orbit make up the space segment. Two functionally identical terminals at the White Sands Complex and another at the Guam Remote Ground Terminal form the ground segment. (NASA Goddard Space Flight Center)

The ever-increasing demand for higher bandwidths (traffic) at lower bit-error rates (accuracy) in the information age explosion has led to the complete transformation of space communications. When Apollo 11 landed on the Moon in 1969, a 56-Kbps link to the ground was a big deal. Today, NASA hauls 4.5-terabytes a day back to the Earth at an average rate of 100-Mbps.<sup>7</sup> This follows the trend in space communications in which NASA has historically set the precedence but is now heavily influenced by the commercial sector. This leads to the next central theme.

## **B. Commercialization in the Information Age**

In the 1990s, “Faster, Better, Cheaper” drove much of the way business was conducted in the space industry, both commercially and in the government. Aside from geopolitics, the root-cause for such change can always be traced to two factors: technology and cost reduction. Few would be surprised that the demand for better technology is always a driver. In addition to better technology, as space moved from the realm of government sponsorship to being a commercial commodity, cost reduction of real-time global communications concomitant with high data demand became more exigent than ever. This approach impacted the space program in ways ranging from economics to performance and, some would argue, safety. New ground and space communication networks such as DataLynx and Iridium entered the playing field. These networks provided multi-mission ground terminals and satellite services that offered users the advantage of low-cost services: pay only for what you use. They targeted not only commercial users but also government users, including NASA. Commercial providers now routinely rely on the internet infrastructure for data access and file transfers—one challenge is to provide internet access on the ISS. So in a way, while NASA was building the network infrastructure that won the Space Race, the rest of the world caught up.

A key issue in commercializing space communications is spectrum sharing—the simultaneous support of several spacecraft transmitting on a common frequency. TDRSS was an early user of the technique. Direct Sequence Spread Spectrum Code Division Multiple Access, or DSSS CDMA, now enables everyday use of cellular telephones in the United States. (Other parts of the world utilize a different sharing technique.) Since its early use by NASA, the commercial sector has evolved the technique into a resource that is essential for daily living in the information age.

But as important as spectrum sharing is, spectrum *management* is perhaps even more critical in the globalization of space communications. Since the RF spectrum is finite, allocation becomes paramount. This realization is not new as the International Telecommunication Union (ITU) was formed in 1865 and expanded its charter in 1927 to standardize and regulate the global usage of the spectrum for telecommunications. The ITU today has more than 190 member states.<sup>8</sup> In the United States, the Federal Communications Commission serves a similar role for domestic commercial usage while the National Telecommunications and Information Administration coordinates government usage. To this end, NASA routinely participates in government, commercial and international forums seeking equitable allocation of this invaluable natural resource. The Glenn Research Center, in particular, has been a Center of expertise for this very specialized activity. NASA Headquarters has also contributed significantly to this effort. The role of OSC was important in obtaining the international spectrum authorizations for commercial LEO satellites at the 1992 World Administrative Radio Conference in Spain—invaluable to the commercial communications industry.<sup>9</sup>

The development of TDRSS is a good case study in how government influenced the commercialism of space. Although it is today a national resource, TDRSS had its growing pains, starting with the radical procurement approach (called innovative by proponents at the time). In an effort to get the project started without committing to a future purchase of a suite of satellites, NASA decided to *lease rather than buy* TDRSS. Deemed a support program, NASA considered leasing to be a viable option that was no riskier than buying.<sup>10</sup> Thus in a reversal of the traditional customer-client relationship, the space agency became a customer of private industry. Impetus for this fundamental departure in the way NASA did business came down to cost. By obtaining this capability from industry on a long term, fixed-price service basis, the Agency hoped to save money, while at the same time, spur on the commercial space sector. When the time came to implement the system, however, NASA, by selecting a prime contractor (Western Union Space Communications, Inc., aka Spacecom) with no previous aerospace experience, nearly doomed TDRSS before it had a chance to prove itself. While the tactic did not work well, it *was* innovative and ahead of its time as commercialization has today undeniably become a part of the Agency’s modus operandi.

NASA, in recent years, has sought to play an anchor tenant role to facilitate development of the private sector and the use of commercial assets (communications equipment, reusable launch vehicles, spaceports). Although success has been limited, cost has been reduced by sharing resources with foreign agencies and, to a lesser extent, contracting entrepreneurial startups. TDRSS was implemented as a cost-effective alternative to expanding the ground stations to meet STS requirements—this being *the* primary reason for TDRSS.<sup>11</sup> The more tangible outcome, though, has been the greatly increased productivity of low-Earth orbiting science programs and defense applications. Even though a major

commercial space industry has yet to materialize, NASA's greatest legacy may not only have been to blaze the trail of leading-edge technologies but in knowing when to step back to enable industry opportunities.

### C. International Cooperation

Prior to an operational STDN, the degree-of-success of the STDN hinged on international cooperation. The global nature of the Network necessitated developing international relationships with foreign nations. Putting a station in South Africa, where political and human rights policies did not align with those of the United States, required much diplomacy and perseverance. Conversely, other places such as Australia, where as many as 10 sites operated during Gemini and Apollo, enthusiastically embraced the opportunity to participate in this new frontier and to share in its exploits—adopting the American space program as its own. Australia's Parkes Observatory was selected by NASA (with great national fanfare), to help receive the Apollo 11 EVA telemetry. The Canberra Deep Space Communication Complex on the outskirts of the Australian capital remains active to this day as part of the DSN. The ability to cater to the sensitivities of dissimilar cultures was important. NASA found that the single, best way to accomplish this was to invite foreign nationals to join in the operation of the tracking network, providing them with a sense of ownership and become partners in the space effort. "Nationalizing the stations" from the early days of the Network left an indelible legacy around the world, one that established friendships extending beyond just space exploration.

The years have only deepened this requisite for collaboration. International cooperation has today become the hallmark of space as NASA routinely works with the Europeans, Russians and Japanese on a diverse range of programs including the ISS, Earth science research, and planning of future space communication needs. Santiago, one of the original Minitrack sites established in 1957, perhaps best illustrates this. Half a century later, it is still run entirely by the University of Chile.

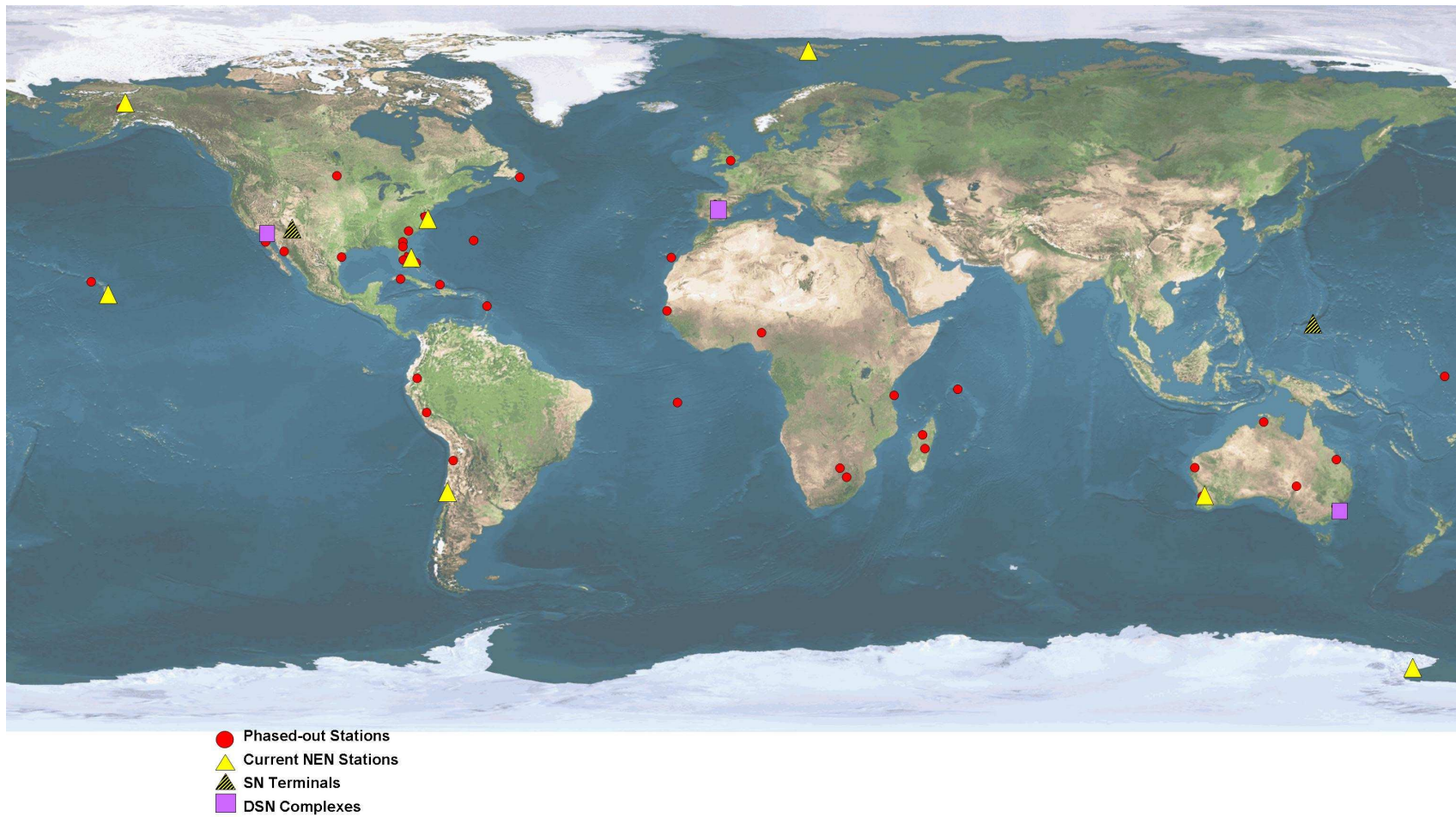
A ground station was often the only tangible "face" of the U. S. space program in a foreign country. Tracking required optimal geographical locations. The State Department was invaluable as a facilitator to the Agency, intermediating discussions at the highest levels of government. With this liaison, officials could much more effectively manage NASA operations when geopolitical unrest occurred. During the pioneering flights of Project Mercury, for instance, Mexican troops had to be deployed by the host country to protect the Guaymas tracking station against unruly mobs espousing anti-U.S. sentiment.<sup>12</sup> Preparing for the Apollo-Soyuz Test Project, OSC led delegations in 1975 to tracking stations in Eupatoria, Ukraine and Ussuriysk, Russia. This was before the collapse of the Soviet Union. Such experiences facilitated international exposure and self-awareness in the world arena on the part of the host country providing experience and models later adopted for broader space relationships and cooperative endeavors like the ISS.<sup>13</sup>

A case in point was the U.S.-Mexico relationship mentioned above. A Guaymas Tracking Station was considered critical by the Tracking and Ground Instrumentation Unit of Langley, which was then responsible for planning the MSFN. Establishment of the station, though, turned out to be an arduous process, one that required great patience and perseverance. Mexico has always had a deep government bureaucracy based on traditional Latin American heritage. Internal political strife and open anti-American sentiment were prevalent in the late 1950s. Talks began in the spring of 1959 but it was not until June of 1961 before the station opened, and only after the appointment of a carefully selected, ad hoc Mexico-U.S. Commission for Space Observations. While Mexico's position rested firmly on mutual scientific cooperation, it was personally obvious to Buckley that the actual possibility for mutually beneficial scientific cooperation of the sort desired by the Mexicans would be for projects *other than* Mercury. But with the first orbital flight then scheduled for the following year, Buckley felt that collaboration was necessary considering the geographical importance of a station in Mexico (it would be the first to see the Mercury spacecraft after crossing the Pacific following loss-of-signal at Hawaii).<sup>14</sup>

Science notwithstanding, the agreement establishing a NASA tracking station in Mexico was quite significant, as it was the first real cooperative project (on any level) between the two neighboring states since before World War I. Both the State Department and the U.S. Embassy hailed the agreement as momentous, representing a big step to bettering relations with our southern neighbor—one that went beyond merely space exploration and Project Mercury.

On the domestic front, success of the STDN hinged on teamwork and cooperation amongst the stakeholders. Not only did the diverse personnel working a ground station have to work together day-to-day, cooperation was also needed on the much larger, agency-to-agency level. Over the years, teamwork among the triad of NASA, the DoD and the State Department, has been crucial to the success of the nation's space activities. To NASA, the Air Force, with its





**Figure 3. Current and former NASA tracking and communication network stations.**



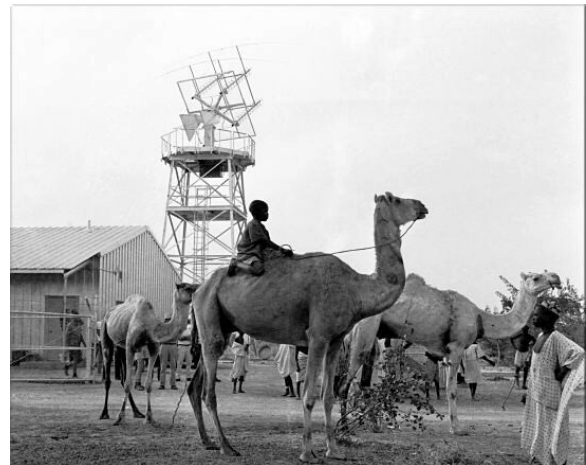
launch facilities and worldwide network of radar installations, was a huge asset. In addition, help from the Navy enabled tracking and recovery operations to be conducted in all three major oceans. The NASA/DoD cooperative was not without its share of problems during the STDN years, however. One example was that the Agency's desire to work with the Air Force was often tempered by the fear that the Defense Department might try to "elbow in" on the fledgling agency's new, and in many ways, more glamorous programs. Congress, too, was sensitive to the NASA/DoD relationship. Many questioned the duplication of facilities. Influential members on the Hill played the role of watchdogs to make sure that NASA remained true to its civilian charter. Despite constant budget and political battles, Congress generally understood that it, NASA and other government offices simply had to work closely together in order for America to succeed in space at a time when such success (or failure) became very much the standard by which national prestige was measured.

Today, space agencies around the globe advocate the use of standardized approaches to handle space communications. As with spectrum sharing and spectrum management, a primary objective of standards is to reduce cost and enable interoperability by controlling interfaces and adopting compatible procedures. Although all electronic communication and data formats are by nature somewhat similar, the standards activity for spaceflight communications is more complex. On its own initiative, OTDA became a founding member of the Consultative Committee for Space Data Systems that is now supported by more than 30 space organizations and industry associations from across the international space community. Acting as a technical arm of the International Organization for Standardization, CCSDS generates world standards in the field of space data and information transfer. In 1999, the Interagency Operations Advisory Group, of which NASA is a charter member, was formed to provide a forum to identify common needs across multiple international agencies to coordinate space communications policy, high-level procedures, technical interfaces, and matters related to interoperability. This laid a common framework enabling synergy and cooperative efforts among all the international partners.<sup>15</sup>

#### D. Human Factors

A direct benefit of the STDN was promoting goodwill through humanitarian workmanship. The United States was responsible for everything needed to operate a station on foreign soil. This included building roads and supplying water and electricity if there were none. Stations also had some form of medical staff and facility on hand. This was a great windfall to the local populace, especially in under-developed nations like Botswana, Nigeria and Peru. "Nationalizing the stations", as mentioned above, by hiring as much as practical from the local workforce, benefited both NASA (cost) and the host. Technical training and certification programs were offered in subjects like electronics, computers, radars and radios. Many of the workers later achieved positions of prominence in the business world and at the universities as a direct result of having received American training by working in the Network. Former NASA Associate Administrator Gerald M. Truszynski spoke of this very point: "An important element in the success of our operations was the good international cooperation we enjoyed where we were required to establish tracking stations in foreign countries. We, at the outset, always approached each country involved as partners, never attempting to or even suggesting that we establish 'Little Americas'. We encouraged the active participation of the host country in the planning, construction, and subsequent operation of the tracking stations."<sup>16</sup>

As often as space is rightly associated with "hi-tech", it is still people who moved the program, who led the day-to-day operations of the Network, and who left behind the legacy. This human element was central to the history of the STDN. The program relied heavily on domestic and foreign contractors, people with the required skill-set to perform under level-of-effort contracts. The direct use of U.S. government civil service personnel was in fact quite limited. Although numbers varied over the years, the contractor-to-government ratio was roughly 10-to-1.<sup>17</sup> Images of engineers manning consoles in control rooms might conjure up the idea of a large contingent directly participating in mission operations. In reality, only a small percentage of people occupied console positions. Most were devoted to support roles: mission planning, scheduling, facility maintenance, management, logistics, and overhead work. This beckoned back to that



**Figure 4. Cultural dichotomy.** *The MSFN station in Kano, Nigeria was an object of curiosity for the Hausa villagers. (NASA Headquarters)*

“invisible” aspect of the Network. Like the flip of a light switch, NASA’s space communications networks were always reliable, often went unnoticed but remain indispensable to the Agency’s successes.

A look at how the Network was organized is revealing. The STDN was orchestrated by leaders able to grasp contemporary needs and develop future possibilities. Edmond Buckley spearheaded the organization early on,



**Figure 5. Edmond C. Buckley.** *6,000 men and women wrote the enduring legacy of the ‘Invisible Network’. (NASA Headquarters)*

consolidating NASA’s three tracking networks—the DSN, MSFN, STADAN—under him to form OTDA in November 1961. In doing so, Buckley was able to take advantage of the limited pool of personnel knowledgeable in the relevant technology. But for a ten-year period from 1996 to 2005 when the Agency consolidated all space operations under the Space Operations Management Office, Buckley’s model stood the test of time. The endurance of this framework needs to be recognized in its proper context: convincing very competent, territorial-minded and strong peers to adhere to this approach to best serve NASA. This structure has in fact served the Agency well for nearly 40 years, cost-effectively providing communication services for essentially all its missions as technology changed. Cost has steadily decreased (almost linearly) from some 10% of the Agency appropriation down to just over 5% over the first three decades. The tremendous advances in communications and data handling experienced during this time were not coincidental.<sup>18</sup>

Human factors can also be measured in terms of cost. On 25 May 1961, President Kennedy committed America to a Moon landing “before this decade is out.” But in another, long forgotten portion of that speech, he also committed the country to build a global satellite communications network. His schedule for this massive undertaking not only inspired a sense of urgency, it also

saved cost. Had he said “two decades,” the cost would undoubtedly have doubled. This, however, also spawned a culture of “technical excellence at any cost,” an attitude extending well beyond priorities such as human flight safety. Obtaining capital for modernization was only a minor impediment. Constraints placed on modernizing and streamlining were, in reality, much more complex to execute than simply taking advantage of the new technology. Progress could be viewed in two ways. First, operating costs were continually reduced even while technical performance standards were being raised. In addition, technology offered cost saving opportunities by streamlining and modernizing the Network workforce. With the push for lights-out operations (unattended autonomous operations), what does the future hold for the human ingredient that penned the 50-year history of the STDN?<sup>19</sup>

Those who built the Network were really building an enabling capability for the future. In the same way, those who now operate the SN, NEN and DSN are advancing that same infrastructure to support planned, future space endeavors. The history of America’s global spaceflight tracking network ultimately comes down to the men and women who made space communications a reality before it became the daily essential it is today. It provides connectivity for people around the world in ways not possible before. Few may know that NASA was instrumental in bringing the internet to the South Pole. “Invisible” is often used to describe NASA’s space communications and tracking programs. These electronic highways linking orbiting spacecraft to the ground have been and will be essential to the success of America in space. The thousands who dedicated much of their careers to making this capability a success understood and accepted the fact that their success was measured by remaining invisible. They were the “unsung heroes of the space program.”

### III. Conclusion

For an in-depth treatment of the subject, the author refers you to his book *Read You Loud and Clear! The Story of NASA’s Spaceflight Tracking and Data Network* (U. S. Government Printing Office, ISBN 978-0-16-080191-4).

## Acknowledgment

Sunny Tsiao thanks James Costrell of the Space Communications and Navigation Office at NASA Headquarters and Steve Garber of the NASA History Division for their kind support and sponsorship of this project.

## References

- <sup>1</sup>Mogan, K. M., Mintz, F. P., "Keeping Track, A History of the GSFC Tracking and Data Acquisition Networks: 1957 to 1991," Contractor Report, NASA Goddard Space Flight Center, Greenbelt, MD, 1992.
- <sup>2</sup>Optical systems suffered from limitations imposed by weather and lighting. They, nevertheless, proved very useful for tracking satellites with expired or failed beacons. By obtaining highly accurate readings of satellite positions, the optical sites could provide information on changing global elevations caused by movement of the Earth's crust. One of the final functions of the original Smithsonian Astrophysical Observatory optical network was to serve as a progenitor to the GSFC Laser Crustal Dynamics program.
- <sup>3</sup>Mengel, J. T., Herget, P., "Tracking Satellites by Radio," *Scientific American*, Vol. 198, No. 1, Jan. 1958.
- <sup>4</sup>Rosenthal, A., "Vital Links, The First 25 Years of NASA's Space Tracking, Communications and Data Acquisition: 1958-1983," NASA Goddard Space Flight Center, Greenbelt, MD, 1982 (unpublished).
- <sup>5</sup>Prior to formation of OTDA, there was considerable debate about the most effective way to organize Headquarters management. Some preferred a functional management structure (propulsion, research, etc.) while others wanted project type management with special offices for human spaceflight, scientific satellites, and so on. The final decision favored a project management structure.
- <sup>6</sup>Berger, B., "NASA To Order Replacement TDRS Satellites in 2007," *Space News*, 29 Nov. 06.
- <sup>7</sup>Bill Watson interview, Washington, DC, 27 Oct. 05.
- <sup>8</sup>ITU website, URL: <http://www.itu.int/net/about/index.aspx> [cited 18 April 2009].
- <sup>9</sup>Force, C. T., "Foreword to *Read You Loud and Clear!*," February 07.
- <sup>10</sup>Stock R. L. to record, "Senate Space Committee Inquiry Re: TDRSS," 7 Sep. 73.
- <sup>11</sup>Fletcher, J. C. et al, "TDRSS Economic Benefit/Cost Analysis," Memorandum, 5 Apr. 74.
- <sup>12</sup>See note 4.
- <sup>13</sup>See note 9.
- <sup>14</sup>Buckley E. C., "Review of Some of the Inter-governmental Agreements for the Mexican Station," Memorandum to Director, Office of Space Flight Programs, 23 Apr. 61.
- <sup>15</sup>IOAG website, URL: <https://www.ioag.org/default.aspx> [cited 24 April 2009].
- <sup>16</sup>Gerald Truszynski interview from Rosenthal.
- <sup>17</sup>Rumerman, J. A., *NASA Historical Data Book*, Vol. VI, U. S. Government Printing Office, Washington, DC, 2000, Chap 4.
- <sup>18</sup>See note 17.
- <sup>19</sup>See note 9.