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QUEST

THE HISTORY OF SPACEFLIGHT QUARTERLY

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Cover Photo Credit

Left. *Apollo 5* on the launch pad—Frame ap5-onpad-noID
Credit: The Project Apollo Image Gallery

Right. *Apollo 5* launch—Frame apmisc-S68-19459HR
Credit: The Project Apollo Image Gallery

EARTHBOUND PIONEER (*EXPLORER 6*)

By Gideon Marcus

On 4 October 1957, the Soviet Union made history with the launch of *Sputnik 1*, the first artificial satellite. Less than a month later, the Soviets trounced their own accomplishment by launching a 500-kg capsule, complete with a canine cosmonaut. The free world was already two steps behind in the newly-minted "space race."

Shortly after the launch of *Sputnik 2*, engineers at Ramo-Wooldridge (RW), America's premier ICBM developer, conceived a booster system that could beat the Soviets to the next goalpost in the space competition. By mating the Thor IRBM with the second and third stages of the Navy's Vanguard rocket (together known as, "Able"), STL engineers believed the United States could launch a small probe toward, and even into orbit, around the Moon. RW spun off a division for the project and called it Space Technology Laboratories (STL). Motivated by the desire to beat the Soviets at their own game, and overflowing with Air Force funds, within 12 months STL had launched three missions on its Thor-Able booster. None of them made it to the Moon, but the second of them soared to an altitude of 113,800 km on its 11 October 1958 flight, and the third returned some valuable scientific data about the newly discovered belts of ionized particles surrounding the Earth.

Even as the three-mission project known as *Able-2* (*Able-1* was a series of Thor-Able nosecone tests launched in early 1958) came to an end in November 1958, plans were already underway for an even more ambitious successor program, one that would keep the Air Force in the civilian satellite launching and development business.[1] Without such a program, it was feared that the military would be shut out entirely with the formation of the new National Aeronautics and Space Administration in October 1958.[2]

STL's next big project involved an ambitious program of two flights to Venus—into orbit as permanent satellites, if possible. One was a 36-kg craft launched by the already-proven Thor-Able. The second, to be launched by the new Atlas Able, combined the Able upper stages and the then-unreliable Atlas ICBM. These spacecraft were completely unprecedented. No one had ever tried communicating with a spacecraft over the 40 million-km trek such a mission would entail. Only the Soviets had ever launched as massive a satellite as the one that would fly on the Atlas Able, at the time expected to weigh over 130 kg. By comparison, *Pioneer 0-2*'s weight was less than 40 kg. The development schedule was aggressive. The smaller craft was slated to launch on 3 June 1959. Its larger sister would blast off on an Atlas Able just four days later. The accelerated timeline was designed to take advantage of the favorable Earth/Venus alignments, which only occurred every 19 months. Both spacecraft would arrive at Venus in November 1959.

The Venus probes were so ambitious that STL decided there was a need to walk before running. An Earth-orbiting test bed probe was conceived, which would carry essentially the same experiment load-out as *Pioneers 0-2*, but test the Venus probe telemetry and power systems. The Thor-Able Venus probe would be adapted from the test bed satellite.[3] This bridge design was called *Able-3*, and the Venus probe project was called *Able-4*. There was no time to waste, however; *Able-3* would be developed *concurrently* with *Able-4.*

Able-3, conceived as a bridge, became a star in its own right. This article is about that inadvertent robotic hero of the early space race.

Paddlewheel Probe

The fundamental design for *Able-3* was essentially conceived in one marathon meeting in late 1958. STL engineer John Taber recalled his role in that pivotal moment:

> When we were trying to get that first *Explorer 6* together, they hadn't developed a project management group. There was a big meeting, and one of the guys, Bill Russell, a fellow in high middle management, said, "John, why don't you get this thing going?" I hadn't realized that I could do that. I didn't know I was supposed to be in charge! So I said, "Okay—let's look at this. What kind of weight can we get into orbit with the rocket?" and the orbital people replied. I asked, "Power people—how much power can you generate?" 'Depends on the weight,' was the reply. The experimenters wanted to know what the communications data rate would be. All of this information was traded off, and we developed a best guess of what the spacecraft design would look like. This tradeoff all happened at one meeting, a few hours long.[4]

The design that came out of the meeting was half revolutionary, half evolutionary. *Able-3* used the same booster as its predecessors. Its experimental payload was almost identical to that of *Pioneer 2*. In fact, *Able-3* was viewed as an opportunity to properly showcase all of the technology that had not been fully utilized in the Pioneer program.[5] By November 1958, STL had accumulated an impressive armory of experiments, but none had flown for more than a day. With its long-term, highly eccentric orbit, *Able-3* offered the perfect opportunity to map the still largely unmapped Van Allen Belts of trapped high-energy particles, discovered in January 1958 by *Explorer 1.*

It was there that the similarities between *Able-3* and *Able-2* ended. Their shapes were fundamentally different: *Pioneer* had been a gem-shaped, battery-powered spacecraft. The 26-inch diameter, 29-inch deep *Able-3* looked like a windmill or desk fan, with power provided by four paddlewheels, which extended in flight to capture the Sun's rays and convert them into energy. The paddles were covered with silicon solar energy converter cells manufactured by Hoffman Electronics Corporation, similar to those that had been proven the previous year by *Vanguard 1*, which was still active at the time *Able-3* was being developed. There were 210 modules, each with 100 photoelectric cells, converting the Sun's rays with about 10 percent efficiency (far lower than what is achievable today). Each module provided 3/4 watt of power.[6] Each photocell was fitted with a glass filter to shield it from UV.[7]

To convert the power generated by the solar cells into something usable by the spacecraft's systems, *Able-3* used three static converter power supplies manufactured by the Engineered Magnetics Division of Gulton Industries, based in Metuchen, New Jersey. The first provided a total of 5.2 watts for 10 outputs delivered on eight channels. The second converter provided continuous power output rating of 3.4 watts, with the ability to step up to 62.5 watts for a five-minute period every 10 hours. The third converter delivered rated power of 311 watts. In conjunction with these static converters, Gulton Industries Alkaline Battery Division furnished a supply of nickel-cadmium, hermetically sealed, rechargeable batteries. These rugged batteries, capable of high peak currents, were designed to outlast conventional batteries by as much as a factor of 20.[8]

All spacecraft have to deal with the difficult thermal conditions of operating in outer space. The prior *Pioneer* spacecraft (*0-2*) regulated their internal temperature through their specialized pattern of paint, optimized for each mission. *Able-3* had a projected lifespan measured in years rather than days and needed something more elaborate. As with its predecessors, space and weight were at a premium. This precluded an internal, electric cooling/heating solution.

STL engineers work testing and integrating *Explorer 6* components.
Courtesy of John Taber.

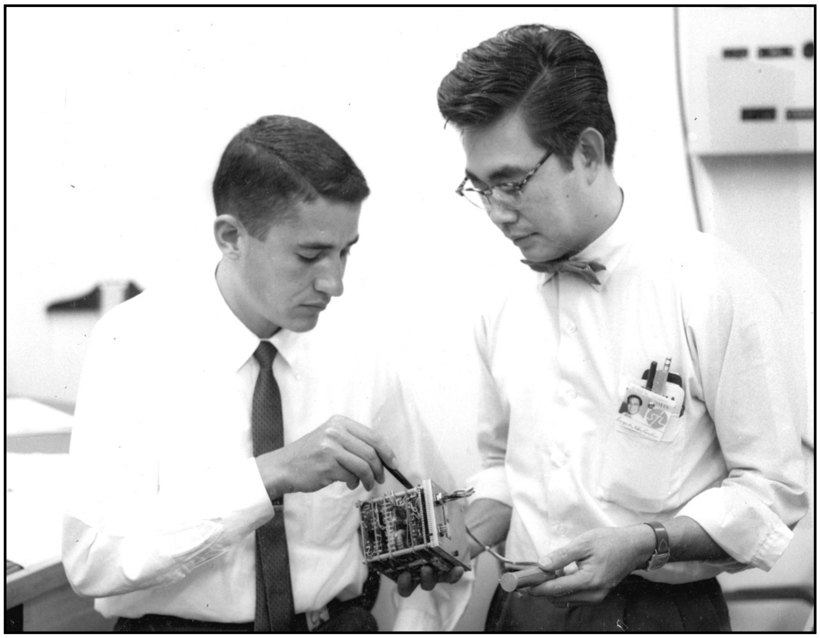
Instead, *Able-3* employed a new kind of system: it was studded with dozens of little propeller-shaped devices painted in alternating black-and-white. Their action was strictly mechanical. As the sun heated their mounts, wire coils inside expanded, causing the propellers to expose their white surfaces. This action reflected the sunlight and cooled the spacecraft. When the wire coils cooled, they contracted and exposed their black surfaces. This effect, in turn, absorbed sunlight. STL engineers made sure this system worked in flight by installing a photocell in place of one of the propeller's black surfaces. When it was exposed, the cell converted sunlight into an electrical impulse that was sent back to ground tracking stations.[9]

The Thor Able rocket had three stages. The previous *Able-2* series carried a fourth stage onboard: it was a solid-fuel retrorocket designed to slow the satellite into lunar orbit. *Able-3* did not need anything so large, but a small solid-fuel orbit adjustment rocket was included for last-minute adjustments to the probe's orbit.[10]

A Long-Range Telemetry System

The fundamental difference between *Able-3* and its predecessors was the way it talked to the world. Every satellite has a myriad of data to communicate back to Earth. In addition to results from the suite of experiments, they broadcast data on the voltage and current produced by their solar cells, net voltage and current in and out of the batteries, fuel level, internal temperature, etc. The closest Venus ever comes to Earth is about 40 million kilometers. As of the end of 1958, no one on Earth had ever built a telemetry system that could work at such great distances. The FM telemetry system that had been used in *Able-2* (originally developed for *Vanguard*, *Explorer 1,* and other early American satellites) was woefully insufficient. Digital telemetry, a brand-new concept, was to be used for the first time.

Compared to the analog case, digital communications have a number of advantages at multiple levels. Digital systems are better at rejecting noise. It is also much easier to detect and correct errors in a digital system. In an analog system one uses analog circuits to remove unwanted high- or low-frequency noise and to smooth over any irregularities in the output signal. However, these steps are just guesses; a low-pass filter removes all high-frequency infor-



Payload engineers Paul Coleman and George Takahasi.

Courtesy of John Taber

mation, regardless of whether it is noise or valid (but unexpected) data, and errors that even vaguely resemble data often get passed along to the output.

A digital system encodes all data into numeric values, which are transmitted as a stream of binary digits. It tends to reject noise since there are only two valid output states, zero or one. If a signal does not look like a zero and does not look like a one, then it is noise. Ideally a digital system transmits no data instead of bad data, but when errors do occur, zeros are received in place of ones or vice-versa. This kind of error is very amenable to detection and correction with mathematical algorithms. For example, parity bits and checksums can be used to detect errors, and more sophisticated approaches can actually correct errors in the data.

The next advantage is that digital data is very amenable to compression and other information-concentrating techniques. Digital data is particularly useful for TV cameras and other high-bandwidth devices. Even though every image a TV camera produces might always have the same number of pixels, no two images would contain the same amount of information. Sometimes the camera would be taking a picture of deep space, all black with only a few stars visible; other times it would take a picture of a planet with lots of detail in the frame. An analog system always uses the same amount of time and bandwidth to send these pictures. In a digital system, one can select from a variety of lossy or loss-less compression techniques to reduce the bandwidth needed for the picture.

Thus, digital data allows more efficient use of the limited bandwidth that is available. For example, compression of the data could be used to transmit more data using the same amount of time and bandwidth as the analog system. It is also easier to fit voltage and temperature measurements into a digital data stream.

Finally, digital data is typically very amenable to digital analysis. It does not have to be digitized before it can be processed, and it is generally in a format that can be easily manipulated. This reduces the number of human operations between the time of collection of data and its delivery to the final analysis.

Development of the digital telemetry system got a bit of a windfall as a result of internal reorganization in STL. During the development of *Able-3*, the Controls, Computers, and Communications Divisions was moved to the Canoga Park facility to separate it from STL proper. Four or five engineers did not want to go and transferred to STL. As a result, *Able-3* ended up with a very fine communications staff.[11]

The new digital telemetry system was called "Telebit," developed by STL engineers Bob Gottfried, Charlie Stephens, and Art Gold.[12] Previous telemetry systems relayed data to the ground the moment it was collected. Data was not processed in any way on the satellite and was a constant drain on the spacecraft's batteries. The new Telebit system stored and tallied data while the transmitter was turned off. Analog data was passed to Telebit from experiments and converted to digital form. Digital events, like micrometeorite strikes, did not require conversion. The total information was then transmitted to a ground station in a lump along with various spacecraft diagnostic measurements.

Telebit also allowed for flexible transmission rates, depending on range and power requirements. When a spacecraft was close to the Earth, it could send data at 64 bits per second. Further out, when more power was required to generate a signal that could be heard back home, data could be sent at 8 bits per second or even the glacial rate of 1 bit per second. Without Telebit's ability to store data between transmissions, such a slow rate of transmission would be useless.[13]

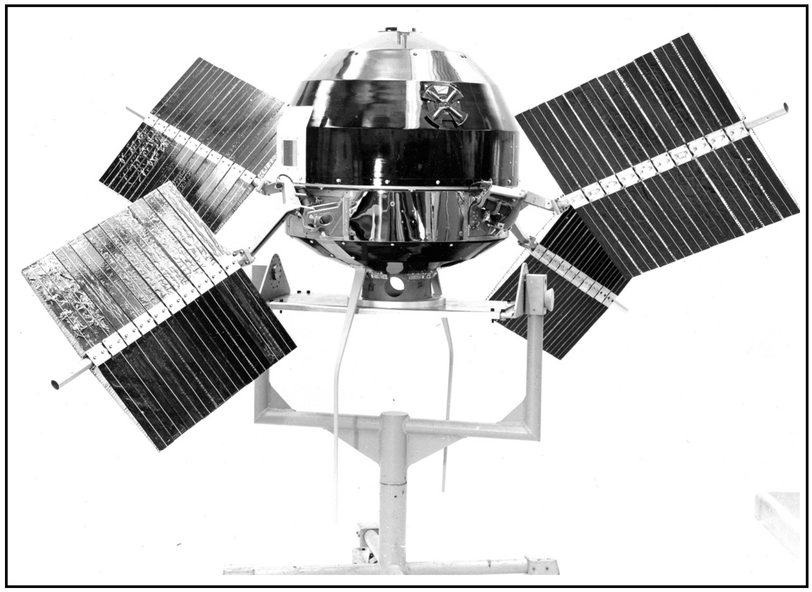
Telebit, essentially an onboard computer, was only possible thanks to the miniaturization afforded by transistors. Components were mounted on small print circuit boards and encased in light foam rubber. These little modules, the ancestors of integrated circuits, were then interconnected.[14]

With Telebit onboard, *Able-3* had the most advanced communications system of any satellite yet developed. STL engineers also installed a conventional FM telemetry system so the performance of Telebit could be analyzed on an apples-to-apples basis. *Able-3* was also the testbed for a new transmission frequency. The standard 108 MHz system could not produce a high enough gain (directivity of signal) to be heard all the way from Venus, at least with existing ground antennas. (The higher the frequency of an antenna, the higher the gain.) As a testbed for *Able-4*, *Able-3* was equipped with a UHF transmitter operating at an unprecedented 378 MHz. The FM telemetry system used a pair of standard VHF transmitters broadcasting at the established frequency of 108.06 and 108.09 MHz. Telebit used the 378 MHz transmitter.[15]

In addition to potentially enabling communications across interplanetary space, the new transmitter also solved a problem inherent in the 108 MHz system. The VHF system used a technique known as "phase lock" to keep the frequency steady. Phase lock actually required two frequencies, one for downlinked telemetry and one for uplinked commands. The two frequencies were both multiples of some fundamental frequency, and the fact that they were related kept either of them from drifting out of sync. Each acted like two singers of a barbershop quartet, making sure the other did not get out of tune.

The problem was, just as every musical note is really composed of infinite overtones or fractions of itself, dependent on the frequency (pitch) of the tone, every transmission contains fractional frequency transmissions. In the 108 MHz system, one of the overtones of one of the phase lock frequencies was equal to 108 MHz. This meant that there were times when both telemetry and command frequencies were identical, and the system locked up. No one had bothered to fix the system as not many commands were actually being sent to early satellites using the 108 MHz system. STL engineers did not try to fix the system for *Able-3*, either, as they knew it would not be used in *Able-4*. However, they did use that lesson to build a better system: for the 378 MHz antenna, the frequencies were given a 16/17 ratio to prevent such interference. As a result, the uplink frequency was 401.625 MHz.[16]

The 378 MHz transmitter was a 40 watt system, and it required more power than the batteries could supply. It was thus planned to only use the transmitter 1.5 out of every 6 hours. Onboard memory units would store experimental data in the interim.



Explorer 6 exterior. Courtesy of John Taber.

The frequency of the UHF transmitter was kept secret, partly as it was being used by the Air Force for other, classified projects, and partly just to keep other parties from deliberately or accidentally interfering with the spacecraft's command frequency.[17]

Ears on the Ground

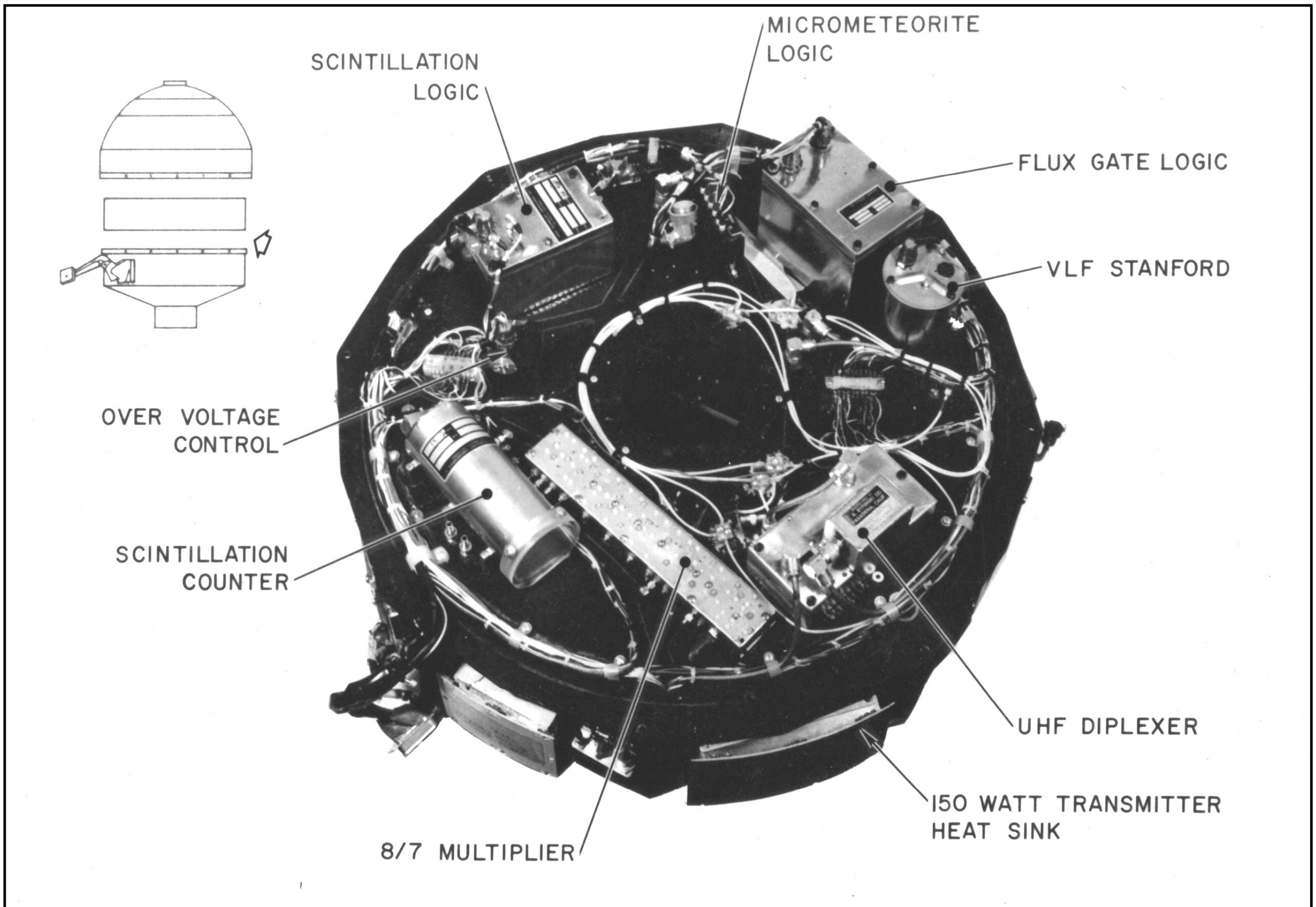
If *Able-3* was an opportunity to use experiments that had never been fully utilized in the early Pioneers, it was also a chance to use the worldwide tracking network (the first of its kind) developed for those lunar explorers. Stations had been set up in Los Angeles, Florida, Manchester, Singapore, and Hawaii to ensure 24-hour tracking of *Pioneers 0-2* as they zoomed toward the Moon (see Gideon Marcus, "Pioneering Space," *Quest: The History of Spaceflight* [summer 2007: Vol. 4, No. 2]).

The 60-foot antenna at Hawaii's Kalae field and the enormous 250-foot dish antenna at Jodrell Bank in Manchester, England, were equipped with a new device called a "Multiplexer"—a series of traps and filters that allowed simultaneous reception and transmission of the two-phase lock frequencies from the same antenna with a minimum of feedback from one circuit to another. Antennas equipped with this multiplexer could transmit radio waves at 10 kw power and simultaneously receive radio waves with the strength of just one billionth of a billionth of a watt. The sensitive antennas could measure the Doppler shift on the received/transmitted frequencies to track *Able-3*'s velocity with incredible precision.[18] Outside contractor Radiation Inc. designed and built the two technically challenging multiplexers within just three months.[19]

Radio receivers for tracking were provided by Motorola. Stationed in pairs less than a mile apart, they used the difference in time of reception of *Able-3*'s signals to determine the satellite's position. Motorola also designed and produced the telemetry receivers for *Able-3,* which received a large assortment of scientific and other data from the satellite. This equipment was among the most advanced of its time.[20]

Gilfillan Bros. of Los Angeles, known since the 1920s for their radios (and since World War II for their radars), was contracted to provide on very short notice the precision frequency synthesizers; multichannel frequency generators; minimal phase distortion, high video frequency amplifier units; and sub-carrier demodulation equipment needed to support ground transceiver equipment. Transistor technology, still in its infancy, was being incorporated into the UHF-band system.[21]

The brand-new Calabasas,



Courtesy of John Taber.

California-based Rantec Corporation provided four, 15-foot, sensitive helical antennas for the steerable receiver at Redondo Beach. Rantec also provided five helical antennas, which were placed at stations around the world for accurate tracking of the satellite's position.[22]

Space Electronics Corporation, based in Glendale, California, was subcontracted to make a new lightweight and rugged radio transmitter, part of a new guidance system employed in the Thor-Able's second stage. Over 10 times lighter than equipment previously available in the ballistic missile family, it was developed and produced in less than five weeks after receipt of contract. Eight were delivered.[23]

Hallamore Electronics Company was again tasked with systems integration of all of the new tracking, telemetry, and guidance systems incorporated in the *Able-3* experiment suite. This involved upgrading the equipment constructed for the *Pioneer 0-2* missions and stationed throughout the world at the various tracking installations run by STL. Five Hallamore trailers supporting systems integration of the new *Able-3* guidance systems were parked at Cape Canaveral.[24]

Experiments

The payload team for *Able-3* was largely the same group that had built the experiment and electronics package for the first three Pioneers. There were 10–15 STL engineers, with Charles (Chuck) Sonett as manager and Stuart Baker as a lead engineer. About 40 percent of the STL group was new to the company, some having joined specifically to work on non-military, scientific projects. A more extreme example was Paul Coleman, who went to work on the magnetometer. A physics graduate student who interviewed with STL on a lark after his roommate stranded him in California on vacation, he was seduced at his interview by a sneak peak at the newly completed Pioneer payload.[25]

Teams from the University of Iowa, the University of Minnesota, and the University of Chicago were asked to submit experiments, which were essentially duplicates of the ones they had contributed for *Pioneer 2*. By 1962, NASA affiliates like JPL and universities had started to dominate spacecraft payload development as they perfected their lobbying and trained their personnel, but at the beginning of the space race, payload construction was still the province of the R&D departments of the various military contractors like Ramo-Wooldridge, McDonnell Douglas, and Lockheed. The result was a complicated partnership between for- and non-profit entities.

Able-3 was tasked with the first comprehensive mapping of the newly discovered (Van Allen) belts of high energy particles, which seemed to surround the Earth. The data from *Pioneer 1* suggested that an astronaut could survive in these belts for several hours, but these meager results were far from conclusive. *Pioneer 1* had offered a tantalizing glimpse into the structure of these belts, suggesting that they extended from 1,000 to 58,000 kilometers above the Earth with peak intensities at altitudes of 4,200 and 16,700 kilometers; but *Pioneer 1* had only made two trips through the belts. *Able-3*'s was to be launched into a highly eccentric orbit, which would carry it through the entirety of the Van Allen belts twice a day for months.[26]

To that end, a Geiger-Mueller tube and ionization chamber experiment, similar to those flown on *Explorer 4* and *Pioneers 0-2*, was provided by the University of Minnesota to give an account of the absolute flux of particle radiation, from X-rays to Alpha particles. The two-pound device used 120 milliwatts of power. STL also provided a radiation counter in the form of a scintillator, a sensor that flashed when struck by an ionized particle. A photomultipler tube measured the flashes and an electronic amplifier then sent the data to the antenna for broadcast. The scintillator weighed three pounds and used 150 milliwatts of power.[27]

The University of Chicago team, comprised of John A. Simpson and Peter Meyer of the University's Encrio Fermi Institute for Nuclear Studies, and Charles Y. Fan, an engineer from Chicago Midway Laboratories, contributed a four-pound, 200-milliwatt, proportional counter encased in 5 millimeters of lead similar to the one that they had provided for *Pioneer 2*. This experiment intended to catalog incident particles exceeding a certain kinetic energy (protons in excess of 75 MeV and electrons in excess of 13 MeV), which would give an indication as to the general energy level of the particles in the spacecraft's vicinity and, perhaps, an idea as to their origins (terrestrial, solar, or galactic). An identical system was scheduled to fly on the upcoming *Able-4* deep space missions. The experiment on *Able-3* would thus act as a kind of control against which to measure the results of the counter carried on interplanetary missions. It would then be possible to determine which events were local to the Earth, and which were wider in scale.[28] The Fermi Institute's network of cosmic ray detection stations, spanning both American continents, was set up for 24-hour activity during *Able-3*'s flight to corroborate the spacecraft's findings.[29]

In addition to the instruments that directly measured the incidence of high-energy particles, *Able-3* was designed to use one-way transmissions from its two transmitters to indirectly measure the electron density of the space the spacecraft traveled through. The idea was simple: normally, the Doppler shift due to motion of the satellite would be expected to be exactly proportional to the frequency of the transmission, but the presence of electrons in the probe's vicinity could cause a measurable change to that Doppler shift; there would be a larger effect at low frequencies that at high ones. Studying the shift of the two widely separated frequencies (the VHF transmitter operating at 108 MHz and the UHF transmitter operating at 378 MHz) could provide a measure of electron density.[30]

Another experiment using the spacecraft's transmitters was developed for Stanford University by the Stanford Research Institute and Develco Inc., a small electronics manufacturing contractor. It involved the satellite's VLF (Very Low Frequency) radio receiver and a ground-based VLF transmitter operating at 15.5 kHz from Navy radio station NSS Annapolis. *Able-3* would pick up broadcasts from the Annapolis transmitter as it took off, and return data to ground regarding the signals' propagation through the various layers of the atmosphere. The spacecraft would also pick up natural VLF transmissions. Of particular interest were "whistlers," low frequency radio signals caused by lightning strikes. It was hoped that the experiment would pick up extraterrestrial VLF sources as well.[31] The device weighed 0.5 pounds and used 86 milliwatts of power.[32]

A third propagation experiment involved the amplitude and phase fluctuations of VHF transmissions in the ionosphere. For this one, *Able-3* would work in conjunction with two receivers at the National Bureau of Standards Laboratory in Boulder, Colorado.

The Earth's magnetic field, caused by the spinning of the planet's iron core, was another hot topic in the late 1950s. At the time *Able-3* was being developed, the prevailing view was that this field extended some 5 to 7 Earth radii during quiet periods, descending to perhaps 2 to 3 Earth radii during geomagnetic storms—massive fluctuations in the Earth's magnetic field with, as scientists of the time were just discerning, an extraterrestrial source. Scientists believed solar flares created a shower of particles known as the solar wind, which then crashed into Earth's magnetic field, pushing the barrier between the solar and terrestrial fields (called the magnetosphere) inward, causing beautiful aurorae and disruptions of radio communications.

Scientists hoped to find evidence of a ring current at high altitudes, an electric current carried by charged particles along Earth's magnetosphere. *Pioneer 1* had failed to find any on its 1958 trip, but that spacecraft had only made one passage through the magnetosphere and back, and that was done in the daylight during a geomagnetically quiet period.[33] There was elusive evidence for this ring current in the form of a magnetic anomaly discovered by the Soviet lunar probe, *Mechta*, launched in January 1959. This phenomenon was found at about 4 Earth radii above the surface.[34]

A thorough mapping of the terrestrial magnetic field was in order, and *Able-3* was equipped with a magnetometer to do just that. It was even hoped that *Able-3* would fly out of the Earth's magnetic field entirely and explore the interplanetary field. *Pioneer 1* had done just that a year before, finding the boundary at about 13.5 Earth radii. Of course, *Able-3*'s planned apogee was only 8 Earth radii, so hopes were not overly high.[35]

As in *Pioneers 0-2*, the magnetometer was a two-part experiment. The first component was a search-coil device (a simple device—literally, a wire-coil hooked to an electrical current meter whose readings would change as the spacecraft spun) weighing 1 pound and using 22 mw of power. The second component was a flux-gate device (a twin-coil system, which measured magnetic fields by detecting changes to a known alternating current that was fed into the experiment). This latter component weighed 2.2 pounds and consumed 160 mw.[36] STL engineer Darrell Judge developed the search coil experiment, while Paul Coleman and Chuck Sonett built the flux-gate device. Also like the earlier magnetometer, the experiment used a series of switched amplifiers to cover a wide spectrum of field strengths as no one analog to digital converter of the time had sufficient range to do so.[37]

A 0.7 pound, 24-mw piece phase comparator was developed by STL to measure the phase relationship between the output of a photoelectric diode (presumably the one relaying temperature information) and the search-coil magnetometer. This setup provided information on the direction of the horizontal components (parallel to the Earth's surface) of the magnetic field around the spacecraft.[38]

Space dust, a perennial worry in the early days of the space program, was measured by a micrometeorite sensor, similar to the one launched on *Pioneers 0-2,* developed by the Air Force Cambridge Research Center. The device weighed in at 0.7 pounds and consumed 70 mw of power.

The much maligned TV facsimile system, which flew with *Pioneer 2* with a bandwidth of 1 Hz, was scheduled to fly again on *Able-3*. Its goal was to take a picture of the Earth, a 5-mile-wide strip at a time, imaging the planet as it spun. The strips would then be assembled by hand later. The device had the virtue of being light, weighing in at just 2.5 pounds. It consumed 231 mw.[39]

All in all, the experiment packages cost around $5 million to develop.[40]

Development

Able-3 might have been a civilian mission, but STL was primarily a military contractor developing missile components. The politicians wanted to keep NASA programs isolated so they could be as "clean" as possible. This diversion was facilitated by STL's matrix-style organization. STL had engineer groups from various technical disciplines who could be assigned to any project. A program manager was assigned to head *Able-3* and several engineering teams were placed at his disposal. In this way, *Able-3* was kept separate in the management structure.[41] George Muller, project manager for *Able-1* and *Able-2*, was *Able-3*'s first project manager. The job later went to engineer Paul Glazer.[42]

With an eye toward keeping development time short, *Able-3* was built, as much as possible, from off-the-shelf components, which were especially used in ground operations where weight wasn't an issue. Not everything could be bought at the local hardware store, however; spacecraft telemetry equipment and the satellite's onboard transmitters and receivers, not to mention the experiments, all had to be built from scratch by STL or by subcontractor companies.

Able-3's development ended up being a slower process than its Pioneer ancestors. The original schedule, designed to support *Able-4*'s launch to Venus that summer, outlined two *Able-3* launches in February and April 1959. It was not long before STL engineers found that they had a host of technical hurdles to overcome, which were greater than they had first conceived, particularly the development of the long-range telemetry system designed to work as far out as Venus.[43] The slowdown was also caused by a change in management. In October 1958, all civilian probes fell under the auspices of the new National Aeronautics and Space Administration. This change had little effect on *Pioneer 2*, whose booster just got a new paint job, replacing the letters USAF with NASA. *Able-3* was another story. It was to be the first satellite program over which NASA had executive control (despite continuing heavy Air Force involvement), and there was a lot of learning to be done on their part.[44]

There was also starting to be a fundamental change in philosophy. The Pioneer program had been marred with problems. With the launch of *Sputnik 1* now more than a year in the past, there was less of a frantic impetus to get *something* up in space as quickly as possible. As the launching of satellites became routine for STL, and with STL's (and the Air Force's) role as a civilian space contractor reasonably secure, the emphasis began to shift from "getting it launched" to "getting it right."[45]

As a result, the development schedule slipped. By the end of 1958, the February probe was rescheduled for September 1959, *after* the planned *Able-4* launch date. The *Able-3* launch planned for April was pushed back to 8-May. In May, that flight was delayed again, this time to 7-August, and the September launch was postponed indefinitely (and as it turned out, permanently, although the payload was used for experiment testing purposes on the ground).[46] This delay killed any chance of getting *Able-4* launched in time for the 1959 alignment with Venus, and the next one did not come until February 1961. As a result, the Atlas-launched *Able-4* was redesignated a lunar probe set for mid-November, and the Thor-launched *Able-4* was sent off as a deep space explorer with no planetary destination (later known as *Pioneer 5*, launched on 11 March 1960).[47]

Lengthened deadlines or no, there was still a space race to be won, not just against the Soviet Union, but against rival developers, particularly STL's step-sibling across the valley, Jet Propulsion Laboratories. JPL was associated with Caltech and was a direct affiliate of NASA, whereas STL was a contractor for the Air Force. Both JPL and STL had raced for the Moon in 1958. In 1959, STL still had the technical lead. John Taber recalled an information-exchange conference with JPL engineers where they showed their lunar probe (eventually the marginally successful *Pioneer 3*, which flew in December 1958). Taber was shocked at the probe's small dimensions and presumed it was a model before he was assured that it was the real probe. Still, JPL was NASA's shop and thus favored. Moreover, it was only a matter of time before JPL would narrow the technological gap with STL.[48]

As had happened during the development of *Pioneers 0-2*, STL engineers were still often putting in 15-hour days, seven days a week. They weren't just developing *Able-3*; they were concurrently developing and assembling *Able-4*. So they ate in the company cafeteria and did not sleep much. Meetings were called at 2 a.m.—and they were well attended.[49] Paul Coleman, the experiment engineer who managed the construction of the spacecraft's magnetometer describes the rigor of the experience as akin to being back in the military. Balancing this heavy load was the general level of excitement. Everybody felt as if they were part of something historic. "People would have blood running down their cheeks and loving it," Coleman remembers.[50] Despite the grueling schedule, somehow the development team found time for fun, too.

"I would...work all day long, go get a bite to eat, go back to work. Get home at 'Dark Thirty.' We were all young punks and so we had plenty of energy. We'd carouse and raise hell," Coleman reminisced in an interview. "We worked hard and played hard. I look back and can't imagine how we survived, but everybody did."[51]

Not only did STL engineers have to build the satellite from the ground up, every one of its 100,000 separate components had to be tested. They were subjected to numerous environmental tests to simulate the harsh temperature and atmospheric conditions it would encounter during its flight. They were exposed to temperature ranges from -10 to +140 degrees Fahrenheit; they were also exposed to near vacuum for days on end; they were hooked up to a shake device, which produced vibrations from several to several thousand cycles per second to simulate launch.[52]

Despite this rigorous testing, and even with the more-realistic production schedule and increasing push for quality and accuracy, compared to today's standards the focus was still on hasty production rather than flawless performance. "The systems were not as accurately checked [as they are today]," Paul Glazer commented nearly 50 years later. "Quality control was sort of adequate but you can't do things today that we did then and expect to get away with it."[53]

The Flight of *Explorer 6*

By August 1959, the United States had already successfully launched several satellites. These included two Navy Vanguards, five Pioneers (JPL and STL lunar probes) and two "Explorers." The Explorer name was originally attached to Wernher von Braun's launching crew at the Army Ballistic Missile Agency. The Army counted the failed launches as well as the successes; thus, when NASA was created in October 1958, there had been five *Explorers*, even though only two of them (*1* and *4*) had been successes. NASA made Explorer the project name for all of its small orbital satellites, and *Explorer 6* was next in line. *Able-3* was almost *Explorer 7*; but a JPL-built satellite launched 16 July 1959 failed to make orbit, and NASA abandoned the practice of giving numbers to failures.[54]

Thor 134 (with Able second and third stages) is readied for launch. Courtesy of John Taber

At 10:23 a.m., 7 August 1959, after several technical holds (but none for weather), Thor-Able 134 blasted off from Cape Canaveral's Pad 17A with *Explorer 6* at its head. The Thor first stage, plagued during the earlier Pioneer series with a balky turbopump, which made every launch a game of Russian roulette,[55] was now a reliable piece of hardware. It functioned nominally through *Explorer 6*'s ascent, blasting from Florida at a heading of 48 degrees from true north, its course corrected by onboard gyros. The first stage ultimately splashed down 1,500 miles downrange, northeast of Bermuda. The second and third stages also functioned properly (the Smithsonian Astrophysical Observatory reported that its camera tracking team at Arequipa, Peru, had photographed the empty third stage at a height of about 5,000 miles),[56] and *Explorer 6* was delivered into orbit.

The spacecraft itself was invisible to the naked eye from the ground, covered as it was by its black silicon cells, but the tracking station at Manchester picked up the satellite's UHF and VHF transmissions 12 minutes after launch, and Singapore began receiving signals 40 minutes after launch. In accordance with the prescribed plan, the satellite's transmission was commanded off and on again 15 minutes after launch.[57]

The VLF transmitter experiment worked as planned, returning data up to an altitude of 160 km. A sharp drop-off in signal reception marked the edge of the ionosphere at about 67 miles up, confirming what sounding rockets had learned beforehand. Although no extraterrestrial sources were discovered in the data collected, the experiment did help refine the models of how Whistler-mode signals propagated through the ionosphere.[58]

On reaching orbit, the explosive bolts designed to move the photocell "paddle wheels" into position failed to work as planned, the paddles having been fouled in the cord that had held them down under the fairing.[59] This was a design problem rather than a quality control problem.[60] As a result, one of the "paddle wheels" did not deploy properly, with a resultant loss in regenerative capability of the solar energy conversion system—initially 63 percent of nominal. Power production only dropped from there over the life of the spacecraft. The decreased power caused a lower signal-to-noise ratio, particularly when *Explorer 6* was near apogee,[61] but not such that any of the experiments were rendered unusable. The battery charge current was lower than planned, however, limiting the lifespan of the satellite.

While the planned orbit for *Explorer 6* was supposed to have an apogee of 36,600 km, the spacecraft actually had an apogee of 41,600 km. This was not deemed enough to affect the mission, and the little "kick-motor" was never used to alter *Explorer 6*'s trajectory.[62] The spacecraft's perigee was an atmosphere-scraping 230 km, and the period of the satellite was 12 hours and 42 minutes. The probe rotated on its axis at a rate of 2.8 cycles per second.[63]

Battered but functioning, *Explorer 6* had made it. The next several weeks of its operation were an unprecedented boon to science.

Phototourism

The most accessible scientific result from the *Explorer 6* experiment array was "The Picture." The little TV camera (that barely could), actually worked as planned. For 40 minutes on 14 August 1959, at an altitude of 19,550 miles above the equator, *Explorer 6* scanned a picture of the Earth at the rate of one pixel every third of a second (one pixel per satellite rotation).[64] After 64 rotations (producing 64 pixels of one of eight varying degrees of brightness), *Explorer 6* sent a synchronization signal so that each line of pixels might be separated into sequential strips. The tapes of data were then flown to Los Angeles for processing.

On the ground, project lead Stu Baker was responsible for reducing the analog data to digital form. By calculating the position of the Sun relative to the Earth at the time, the picture was being taken and consulting a current weather map provided by BMD ground stations, it was possible to assemble a photo of sorts. It was an extremely ad hoc process: each photo strip began at the rim of the Earth, but there was no way to accurately gauge how each strip should line up with the others. "That is a priori assumption that you have to make, that the Earth is curved," Chuck Sonnet explained dryly at the press conference on 28 September 1959, where the picture was unveiled.

The result was something that could barely be called a photograph, one with several gaps where transmission had failed. There was virtually no detail, and any correlation with known weather from the BMD maps was fanciful at best. Press conference reporters could barely suppress their frustration as Sonnett evaded question after question as to the utility of the system.[65] At one Washington conference, a Goddard engineer accused, "This is all a fake!" "No, it's not a fake—but it's pretty limited," Sonnett conceded.[66]

While *Explorer 6* returned enough data to generate more pictures, none were ever assembled for public distribution. The famous picture remained a one-off stunt. Still, NASA (and STL) could claim that they had snapped the first photo of the Earth from space, and at that stage of the space race, every victory mattered.

First photo of Earth from *Explorer 6*. Credit: NASA

Mapping the Belts

Explorer 6's four particle detectors (the scintillation counter, the proportional counter, the Geiger counter, and the ion counter) recorded the density and character of incident charged particles (electrons and protons) as the spacecraft soared through the inner and outer Van Allen belts twice a day. *Explorer 6* passed through the outer belt a record 113 times—it had only been passed through five times before by four different satellites.[67] The result was a detailed map of a region which heretofore had only been sporadically essayed into by previous lunar probes and low-altitude satellites.

The first week of flight was a quiet one, geomagnetically speaking. The radiation fields *Explorer 6* traversed were stable. They were, however, quite a bit less radioactively intense than the belts that the Soviet lunar probe, *Mechta, Explorer 4* and JPL's lunar *Pioneers* (*3* and *4*) had gone through. In fact, it appeared the bands of charged particles fluctuated quite a bit—from the maximum observed by *Pioneer 4* on 3 March 1959 to the minimum encountered by *Explorer 6*. The other two flights (*Pioneer 3* on 6 December 1958; *Mechta* on 2 January 1959) recorded levels of in-between intensity.[68]

At 4:14 Universal Coordinated Time on 16-August, Earth was suddenly hit by a big geomagnetic storm, and the electron density beyond the interface between the Earth's and the interplanetary magnetic fields dropped by two thirds. The torrent of cosmic rays liberated electrons in the Van Allen Belts, sending them streaming down to Earth to make lovely aurorae visible from the ground. They also released a shower of X-rays, which *Explorer 6* dutifully measured, collecting data over a far wider range of altitudes and coordinates than had ever been possible (before *Explorer 6*, the data-collection instrument of choice was the high-altitude balloon). The storm lasted until 18-August and was followed by an increase in observed radiation levels.[69]

On 21-August, *Explorer 6*'s ion chamber stopped returning data, making it more difficult to determine the energy of particles impinging on the spacecraft. The next day, the Sun erupted into a high-intensity noise storm, the result of electrons flung at high velocity through the Sun's magnetic fields. It lasted several days. On 23-August, the spacecraft's UHF transmitter failed, but the redundancy between the two systems ensured continuous operation of the satellite.[70] The STL scintillation counter failed just after the start of another magnetic storm which lasted from 3-4 September.[71] The Geiger counter continued to return data, however, reporting another magnetic storm on 20-

September.[72] Further analysis of *Explorer 6*'s data revealed there had been minor storms on 9-August and 20-August.[73]

The University of Chicago's experiment gave tantalizing and seemingly contrary hints about the impact of magnetic storms on the outer Van Allen Belt. During the 16-August storm, there was an increase in the energy of the particles *Explorer 6* encountered in the outer belt followed by a gradual decline (the direct opposite of what was observed by the other particle detectors).[74] STL's scintillator addressed that mystery: while the other instruments were primarily responding to high energy electrons (> 1 MeV) or to the radiation emitted by the magnetic braking of such electrons (known as bremsstrahlung), only the scintillator was detecting lower energy particles (down to 200 KeV).[75]

But what was causing the increase in low energy particles? Was this the result of fresh particles flooding in from interplanetary space? The data suggested otherwise. What was more likely was that particles already trapped by Earth's magnetic field were being sped up during the storm, only to slow down as Earth's field recovered and expanded to its normal size. Further measurements by more refined instruments were necessary to prove the model, however.[76]

The Simpson team's scintillator also determined that the solar wind intensity was modulated not by Earth's magnetic field but by vast magnetic fields of the inner solar system; cosmic ray counts were similar both beyond the magnetosphere (the interface of Earth and the Sun's magnetic fields) and at the Earth's surface.[77]

Using data from *Explorer 6*'s two transmitters, the tracking station at Hawaii made eight indirect electron-density measurements between 13-23 August, each session lasting 20-70 minutes. The data collected on 13-19 August was unusable due to a weak VHF signal, and the rest yielded data of dubious value. The results suggested that the electron concentration in the vicinity of the spacecraft was higher than theoretically expected, perhaps a result of the 16-August geomagnetic storm, but the project director, Carl Graves, suggested that a more direct means of measuring propagation was desirable. The experiment officially ended on 23-August, with the failure of the spacecraft's 378 MHz UHF transmitter.[78]

The spacecraft's magnetometer did yeoman's work investigating Earth's magnetic fields. Out to 5 Earth radii, the experiment confirmed that the fields conformed to predicted theoretical values. Beyond, however, in the 5 to 7 Earth radii distance, the fields were prone to strong fluctuations, even on geomagnetically quiet days.[79] It was in that unstable region that *Explorer 6* found the predicted electric "ring current."[80] The spacecraft did not confirm the anomaly discovered by *Mechta*,[81] nor did it definitively encounter the interplanetary magnetic field (which was not unexpected as the spacecraft reached apogee on the "night" side of the Earth where the planet's magnetic sphere extended out the farthest).[82]

Explorer 6's micrometeorite experiment did not augment *Pioneer 1*'s data. Although pulses were detected, some 28 in the first two days,[83] these were insufficient to yield anything of scientific value, and no scientific papers on the data were ever published.[84]

On 6 October 1959, the power levels in *Explorer 6* reached a critically low level, due to the incomplete deployment of the spacecraft's paddles on reaching orbit two months before. The automatic undervoltage cutoff kicked in, shutting down transmissions and rendering the spacecraft mute. *Explorer 6* may have tried to talk to its home at a later time, but ground control was never able to reacquire a communications link. In all, *Explorer 6* returned some 827 hours of analog and 23 hours of digital telemetry.[85] This event did not mark the end of the probe's useful life, however.

Happily Ever After?

Shortly after *Explorer 6* lost the ability to communicate with its home planet, the Air Force launched a special, top-secret mission to "reach out and touch" the silent satellite. On 13 October 1959, the last of the 12 Bold Orion air-launched ballistic missiles (ALBMs) was launched from a B-52 on an intercept course with *Explorer 6* at perigee as a test of antisatellite technology. The missile was launched at an altitude of 10,700 m (35,000 ft) and successfully passed within 6.4 km (4 miles) of the satellite at an altitude of 251 km (156 miles), a feat confirmed via telemetry and visual tracking by ejected flares and radar.[86]

Even in death, the silenced spacecraft, tracked optically, yielded valuable information on the perturbing influence of the Sun and Moon's gravitational fields. *Explorer 6*'s eccentric orbit, reaching the highest apogee yet attained by an artificial satellite, rendered it more subject to lunar and solar perturbations than any prior probe. According to computer simulations run by Dr. Yoshihide Kozai of the Smithsonian Astrophysical Observatory, *Explorer 6*'s lifespan should have been more than two decades even considering atmospheric drag, but the gravity of the Moon periodically dragged down the hapless satellite's perigee causing its orbit to decay prematurely.[87] As a result, NASA's first satellite met its fiery end on 1 July 1961, less than two years after launch.[88] Even as it burned up, it returned yet more useful data, providing information on the density of the upper atmosphere.[89]

Explorer 6 was an undisputed success at a time when the United States needed space success stories. More importantly to STL engineers, Telebit worked, as did the new transmitter and the slew of experiments. The road to deep space had been paved. With the completion of the *Able-3* project, it was time to finish *Able-4* and send it where no probe had gone before.

About the Author

Gideon Marcus is a graduate of the University of California San Diego history department. He is working on a comprehensive recounting of the almost forgotten first days of the U.S. uncrewed space program, particularly the Space Technology Lab missions. Previous articles that have appeared in *Quest* include: "The Pioneer Rocket" (Volume 13 #4) and "Pioneering Space—Parts I and II" (Volume 14 #2 and Volume 14 #3).

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How General Dynamics Integrated the Cape

By Tom Leech

Editor's Note: An earlier version of this article appeared in the *San Diego Union*, 6 December 1998 as "Never a Vacancy: The Day San Diego Integrated the Cape." This article illustrates that not all stones from the space age have been turned over yet.

* * *

In the spring of 1963, Cape Canaveral, Florida, was a hotbed of activity for America's space and intercontinental ballistic missile defense test programs. The Cape was the site of Project Mercury, the program which had already placed John Glenn into orbit, and there were six other Mercury astronauts in line ready for their turns.

These were heady times at the Cape for the engineers, technicians, and scientists from all around the nation who regularly converged there to get rockets ready for launch or to make the final tune-ups on complex systems, which would soon be launched into space. On any given day, thousands of people scurried around the many launch sites, blockhouses, and readiness rooms.

And every evening many of those same people headed for the dozens of hotels, bars, and restaurants that had sprung up over the past decade since the U. S. missile and space programs made Cape Canaveral their central base of operations.

But there was one glaring exception to the camaraderie that pulsed through the space programs. None of the people staying in those hotels or served in those restaurants were black. Represented among America's finest technical professionals doing work all day long at the Cape were many black engineers, yet not one of them was able to spend the night in those hotels near the launch base until the day Everett Kaukonen, a white guidance engineer from General Dynamics, decided enough was enough and picked up the phone in his San Diego office. His call that day brought a swift end to the Cape's long-entrenched segregation system. That was the start of General Dynamics integrating the Cape.

Kaukonen had hired onto the General Dynamics Astronautics Division in 1961, following a tour of duty in South America with Chevron doing oil exploration. He was one of several members of the "Astro" team who headed to the Cape and its West Coast counterpart, Vandenberg Air Force Base, whenever an Atlas missile was nearing launch. They were responsible for final checkout of the guidance and computer software systems, which steered the Atlas along its proper path.

Wayman "Mac" McIntosh was a black software engineer and computer specialist assigned to Kaukonen's team. A native of the Chicago area, McIntosh had come to Astronautics in 1960 from Systems Development Corporation in Los Angeles. Mac had traveled to the Cape with the team before 1963 for final guidance system checkout. But he never spent the night near the site. "I would fly to Miami," he said. "All the others would fly to the Cape. Then each day I commuted 200 miles from Miami to the Cape."

The program underway in spring 1963 was called Project FIRE. Part of the Apollo Moon landing program, it was an early test to make sure the Apollo astronauts could safely reenter the Earth's