UNITED STATES MISSILE RANGES: ORIGIN AND HISTORY

By David L. Skinner

Introduction

The immediate ancestor of missile testing facilities is the artillery proving ground. This was the result of surface-to-surface missiles, especially those of the liquid propellant variety, being developed to augment or supercede cannon-type artillery. The increase of range made possible by surface-to-surface missiles and the increase in altitude attainable by sounding rockets, were the primary causes of the growth and development of missile testing facilities.

A missile testing facility without instrumentation would be merely a patch of land or water. Proving grounds became ranges when on-board instrumentation and telemetry were added to the missiles being tested. Missile ranges thus include the launching facility and instrumentation needed to both track a missile and monitor its on-board systems during flight. The developmental history is therefore crucially a history of instrumentation at facilities which have met that requirement.

Range Instrumentation

Missile range instrumentation can be divided into four basic types: tracking, on-board instrumentation and telemetry, impact detection, and data recording and reduction. Data recording and reduction involves an accurate timing scale, communications between the various data recording sites, and calculation machines for accuracy and efficiency in data reduction. Data once reduced must then be displayed for real-time and post flight analysis. Instrumentation can provide information by either recording the data in flight and recovering the recording device, or by the use of radio telemetry to transmit the data during flight for recording on the ground. Radio telemetry was first developed in 1925 by Professor Pyotr A. Moltchanoff of Slutsk, Siberia, who tested the device on a balloon [1]. Radio telemetry permits the use of sea ranges for missile testing without the difficultics involved with missile retrieval. Tracking instruments, the other source of data for recording and reduction, take varied forms which are either optical or electromagnetic by nature. Electromagnetic tracking began with Radio Acquisition and Ranging (RADAR) which can be traced to 1922 when A. H. Taylor and L. C. Young of the United States Navy noticed the effect of a ship passing through a high frequency radio wave transmission [2].

The data that is recorded and reduced is applied to two major uses. One is the immediate use of tracking information for range safety. The compilation of a real-time state vector from position and velocity data allows impact prediction. This permits missile destruction by ground-to-missile telemetry if its actual trajectory and designed trajectory differ substantially, and especially if populated areas are threatened. The second use of the reduced data is in post-flight analysis to perfect the missile system.

CAPE CANAVERAL as observed by an Earth Resources Technology Satellite. Original is a colour composite taken about 11 a.m. local time on 6 September 1972 from an altitude of 560 miles (910 km).

National Aeronautics and Space Administration

Congreve and Goddard

The first use of a designated area for testing missiles was at Woolwich Arsenal, an artillery proving ground in England where Sir William Congreve began his experiments in 1791 [3]. This first missile proving ground transformed earlier 1,000 yard bombardment rockets into the famous Congreve rockets, the larger of which had ranges of 5,000 yards, a range not to be exceeded by rockets until after World War I. This is despite the fact that William Hale in the interim between Congreve and Goddard contributed spin-stabilisation to rocketry. Hale's rockets, however, did not exceed the 5,000 yard range of the larger Congreve rockets [4]. The testing technique used by Congreve resembled the artillery method of launching several rounds for accuracy, making a correction, and firing several more rounds for comparison. At this early date spyglasses were perhaps the only instruments involved.

Dr. Robert H. Goddard initiated the development of a liquid propellant rocket at Clark University at Worcester, Massachusetts. In these investigations Mrs. Goddard operated a Ciné-Kodak motion picture camera [5] in the first historical example of data-recording optical instrumentation. The devices used at Worcester also included an ordinary theodolite and "recording telescope" to determine missile altitude, as the first historical examples of metric optics [5].

> "Metric optical instrumentation is photogrammetric, i.e., precise measurements of length are made against imagery recorded on film or glass plates" [6].

Timing was provided by a stop watch [5]. These devices were more than adequate to measure the 41 ft. altitude of the first liquid propellant rocket launched on 16 March 1926 [4].

On 17 May 1929 Goddard launched the first rocket with on-board instrumentation, a parachute-recoverable barometer photographed by a camera when the rocket reached its zenith. To avoid densely populated areas and to have maximum favourable weather, Goddard moved his experiments to Mescalero Ranch near Roswell, New Mexico, in the 1930's where the camera and barometer were replaced by a barograph. By definition since radio telemetry was lacking, both facilities remained only missile proving grounds. The highest altitude reached by a Goddard rocket at Mescalero Ranch was between 8,000 and 9,000 ft. [5].

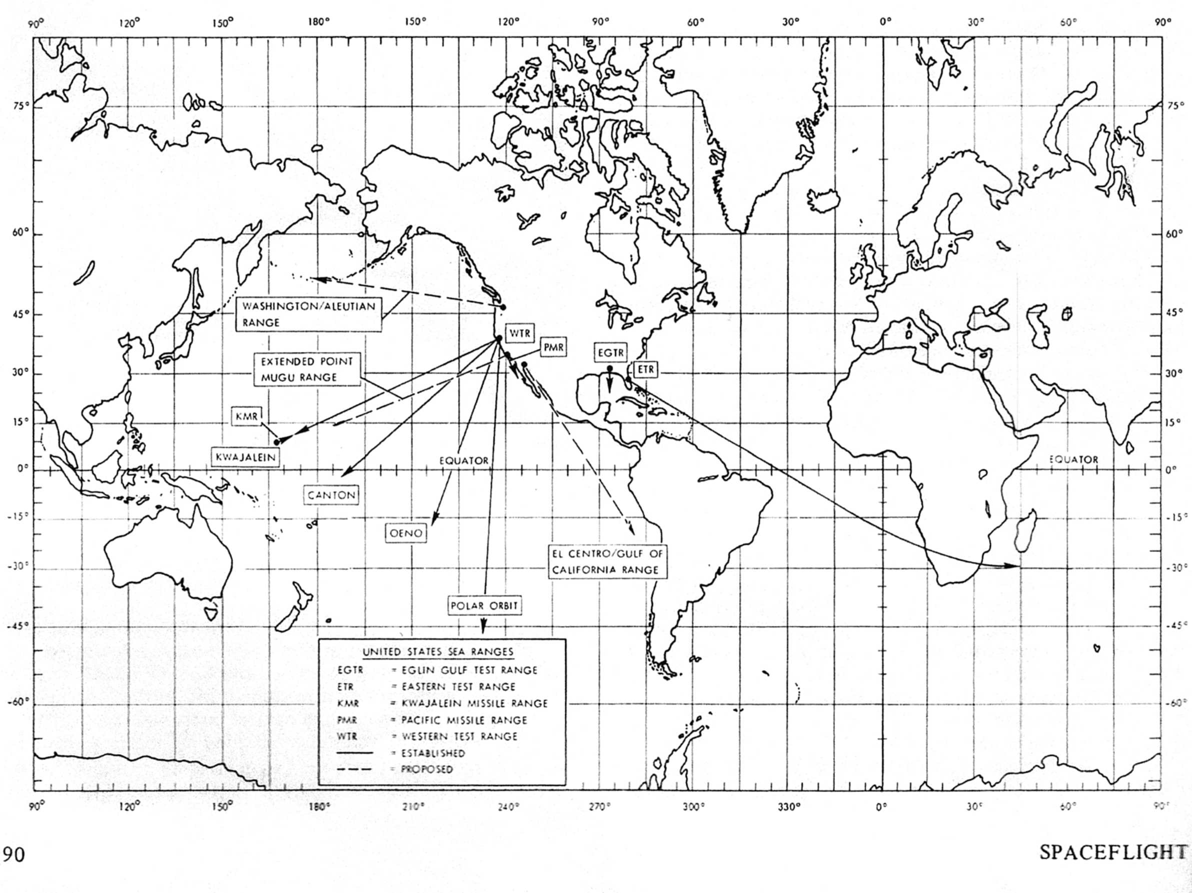
Peenemünde

The next major contributions to range instrumentation occurred at the German missile testing facility at Peenemünde, established in the spring of 1937 [4]. The German Army Weapons Department used Peenemünde to develop the 200-mile range liquid propellant rocket called the V-2, also known as the A-4. The first missile launched at Peenemünde, the A-3, had a maximum altitude of 7.5 miles and a maximum range of 11 miles [7]. To test the A-3, Peenemünde was equipped with theodolites and various cameras. These were similar to Goddard's devices, but had come from the Kummersdorf Artillery Proving Ground 17 miles south of Berlin and its launch facility on the Island of Oie in the Baltic where the forerunners of the A-3, the A-2 and A-1, were developed. Timing apparatus was adapted from previously existing high-speed mechanical, electromagnetic, and photographic devices.

> "Time was measured in terms of vibration periods of a tuning fork which were recorded together with screen signals by means of mirror oscillographs on moving photographic paper, or records were made by printing devices on ticker-tape recorders, by sparks recording on waxed paper moving at a known speed, or by the old familiar Boulengé chronograph in which marks are made on a rod falling under the influence of gravity" [8].

One new device did emerge at Kummersdorf and Oie however; the phototheodolite or plate camera originally used for artillery ballistics research [8].

The expected range of the V-2, twenty times the maximum range of the A-3, promoted the development of three important new pieces of range instrumentation at Peenemünde. The first was the cinetheodolite, a motion picture camera combined with the azimuth and elevation measuring surveying instrument [8]. The second was a two-way Doppler radar system which provided position, velocity and acceleration data once the V-2 left the visual range limitations of the cinetheodolites. The Doppler system consisted of a Wurzburg antenna [9] which transmitted a 23 MHz signal to a transponder on-board the V-2. The transponder amplified, doubled the frequency, and retransmitted the signal for ground station reception and analysis. The third, and most important contribution to range instrumentation was the first on-board engineering measurement and telemetry system, which evaluated the performance of the V-2 and transmitted the data back for recording. The telemetry



system consisted of a commutator on-board the V-2 which sampled each of twelve useful channels plus a calibration channel 500 times per second. The signals were then transmitted using amplitude modulation for ground reception where the decoded results were recorded on one or more six-channel Siemens Universal Oscillographs. A unique method to manually reduce telemetered data recorded on oscillographs was used at Peenemünde [8].

> "The receiver was set up in a lighthouse tower, and the graph allowed to hang down the central hole of the circular staircase. The technicians would then clamber up and down the steps in order to read the applicable portions" [10].

According to Leslie Simon "without the telemetered measurements the V-2 could not have been developed" [8]. The use of on-board instrumentation and radio telemetry transformed Peenemünde into the first missile range.

American Missile Proving Grounds

During World War II the United States first began to build upon the Goddard instrumentation technology. In the east, missile proving grounds were established at the artillery testing facilities at Dahlgren, Virginia and Indian Head, Maryland [11]. By 1944 these two facilities had been replaced by the Alleghany Ballistics Laboratory (ABL) at Pinto, West Virginia [4, 11]. In the West, the military missile effort utilised the Mojave Antiaircraft Artillery Range at Camp Irwin, California which was soon replaced by the more famous adjacent Goldstone Lake [11]. The need for additional missile testing facilities led to the establishment of two new missile proving grounds in the summer of 1943 at the Marine reservation at Camp Pendleton, California and the Naval Ordnance Test Station (NOTS) at Inyokern, California [11]. During this period Dr. Bowen of the California Institute of Technology (CIT) used the facilities at Goldstone Lake and NOTS [6] to develop the first ribbon-frame device, the CIT Acceleration Camera [11].

The so-called Goldstone Range was typical of the better equipped American missile proving grounds during this period. The dry lake bed had premeasured distances marked every 500 ft. which permitted observers in spotting towers equipped with theodolites to easily locate the missile. The exact impact point was determined by plotting the data from two or more spotters on a range map called a "plotting board". Post flight data came from surveillance and documentary motion picture cameras and the new CIT device. The missiles launched during World War II at facilities like Goldstone usually had ranges less than five miles since they were seldom of the surface-to-surface missile variety [11].

However, the V-2 caused the Army to initiate the Ordnance California Institute of Technology (ORDCIT) Project to develop long-range surface-to-surface missiles in late 1944. As a result of ORDCIT, two major additions to United States missile testing facility instrumentation occurred at the newly created Hueco Range at Fort Bliss, Texas in the spring of 1945. The first was the World War II aircraft-detection SCR-584 mono-pulse radar tracking system which was used to test 17 ORDCIT Private-F research rockets launched between 1 April and 13 April [1]. The second addition, which made the Hueco Range the first United States missile range, was the use of radio telemetry to report the forces acting on a model airfoil carried by a High-Velocity Aircraft Rocket [12].

White Sands Missile Range*

Adjacent to the Hueco Range, the White Sands Missile Range was formed for the same two reasons Goddard picked his New Mexico location – areas of minimum population and maximum good weather. This addition of land and facilities was the result of ORDCIT evaluations of the range capabilities of the V-2 [14]. The two ranges, though separate, worked together on missile testing under Army control.

When Operation Paperclip brought the German rocket scientists to the United States, the Peenemünde range instrumentation was also transferred. Yet, within a year of the war's end United States missile ranges had already modified, and gone beyond, the two World War II technologies. White Sands in 1946 contained examples of each type of optical tracking system, two of three types of radar systems, a more compact telemetry system, the first missile impact detection system, as well as an early attempt at calculation machines for data reduction and various mechanisms for displaying the reduced data.

Tracking metric optics change the exterior orientation of the camera during the data gathering process [6]. The only sorts of tracking metric optics available immediately after World War II were confiscated Peenemünde Askania cinetheodolites and makeshift American Akeley Bomb Scoring Theodolites which were designed and manufactured by the Mitchell Camera Corporation. In the area of fixed metric optics, the opposite of tracking metric optics, the ribbon-frame CIT Acceleration Camera was joined by the descendant of the German phototheodolite, the Trajectory Plate Camera. Surveillance motion picture cameras originally used by the Goddards had evolved by now into the Eastman Type-III and Western Electric Fastax high speed cameras. Even the first tracking telescope emerged at White Sands. The telescope was mounted on an electrically driven gun carriage and was pointed by an observer manipulating 20-power binoculars [15].

The frequency of the two-way Doppler radar system used on the V-2 at Peenemünde was increased from 23 to 36 MHz by the Ballistics Research Laboratory (BRL) at the Army's Aberdeen Proving Ground in Maryland and renamed DOppler Velocity And Position (DOVAP). DOVAP and the SCR-584 mono-pulse radar were the chief radar tracking devices at White Sands during the post-war period. A one-way Doppler system for short range measurements, called the Sperry Doppler Velocimeter Model-10 was also used at White Sands. The one missing radar device for range instrumentation was the phase-comparison radar. The V-2 launched at White Sands on 17 December 1946 which set an American altitude record of 115 miles was successfully tracked over its entire trajectory using the SCR-584 coupled with the AN/APN-55 beacon on-board the missile. By comparison, the one-way SCR-584 was limited to tracking the smaller WAC-Corporal, which did not carry a beacon, for the first 18 miles of its trajectory [16].

The tracking data of the SCR-584 one- and two-way mono-pulse radar systems were the primary sources of real-time information. The potentiometer voltage was displayed on a Plan Position Indicator (PPI) Scope or an A-Scope while it was also translated and displayed on two automatic plotting boards, the MC-627 and T14E, which replaced the manual Goldstone model [16]. The PPI scope represents a circular map of the area around the radar facility on which a line indicating the direction of the radar beam radiates outward from the centre of the display and rotates with the angular velocity of the actual antenna. As the line sweeps around the screen, light spots or "blips" representing targets appear at the proper range and direction on the ground map. The A-scope consists of a horizontal line on a cathode ray oscilloscope. The line will contain triangular deflections representing the transmitted pulse and the returning echo.

* *The original name for the White Sands Missile Range established 13 August 1945 was the White Sands Proving Ground, a name it would hold throughout the 1950's [13].*

The distance between the two deflections represents the range of the target [17]. The MC-627 was originally designed to plot an aircraft ground-track on a long-range remote-controlled bombing run. The T14E was originally designed for plotting altitude *versus* distance from the launcher on one plotting board and the ground-track on a second board for mortar shell tests. Both were manufactured by the Bell Laboratories. A third type of plotting board was used exclusively at NOTS [16].

The plotting boards were crude examples of analog computers and their accuracy was correspondingly low. One post-flight general purpose analog computer with adequate accuracy called the 200-Foot Slide Rule was being used in 1946 at the Hueco Range. It could attain an accuracy of one part in 20,000 by printing the scales on reels of 35-mm film for comparison [18]. Yet, in terms of accuracy the digital computer was far superior to its analog counterpart. The most primitive digital computers were the International Business Machines (IBM) electric adding machines which had been available since December 1944 at BRL at Aberdeen and at the Naval Proving Ground at Dahlgren. They were hampered by large errors due to manual transcription of data, to and from paper, between each calculation step. By the spring of 1946 some of this error was being reduced by the use of the new IBM punch card machine, the 603 Electronic Calculator, which could perform a series of calculations without manual intervention. At Dahlgren the IBM punched card machines were augmented by the electro-mechanical Harvard Mark-II [19] which could completely solve complex mathematical problems by a set of instructions given to the machine by a punched tape. This machine and its vacuum-tube counterpart, the first electronic digital computer, the Electronic Numerical Integrator and Computer (ENIAC), developed at Aberdeen were not used at American missile ranges during this period despite origins in ballistics research [20].

Data recording from the SCR-584 and DOVAP radars at White Sands for processing by the electronic adding machines and the IBM punch card machines was accomplished by photographing the needle deflections on the display dials at precise time intervals actuated by a timing signal continuously broadcast during the missile's flight. The Hueco Range had a slight modification on this system whereby the data was not photographed, but rather converted to type-like printing on tape. This primitive non-magnetic "tape recorder" was another product of the Bell Laboratories [16].

Impact detection was accomplished by radar, a technique developed at artillery proving grounds. The splash of soil and dust upon impact made a sizeable target. The original impact detection system at White Sands was the AN/MPG-1 pulse radar [16].

Telemetry had been added to the WAC-Corporal after tests on the WAC-B in December 1946 [21], thus building on the early Hueco and bulky V-2 efforts. The WAC-Corporal at White Sands was the namesake of the Private-F at the Hueco Range. Both were by-products of the ORDCIT Project. The WAC-Corporal telemetry had only five channels [21] as compared with twelve on the original V-2 system, but fitted the 25 pound [1] weight limit of its carrier rocket.

By 1950 the United States was testing missiles at seven ranges, the largest of which was White Sands in New Mexico operated by the Army. Another Army facility was the adjacent Hueco Range at Fort Bliss, Texas. The National Advisory Committee on Aeronautics (NACA) opened a range in July 1945 called Wallops Station at Wallops Island, Virginia which was inherited by the National Aeronautics and Space Administration (NASA) in 1958. The Navy retained the World War II developed Naval Ordnance Test Station at Inyokern, California and added the Naval Air Facility at Point Mugu, California in December 1945. The new facility, renamed Naval Air Missile Test Center (NAMTC) in July 1946 would eventually be the headquarters of the Pacific Missile Range beginning on 16 June 1958. The Army Air Corps, which became the Air Force in 1947, operated a range at Eglin Field (Eglin Air Force Base) in Florida after the war which eventually became the Eglin Gulf Test Range. The Air Force also operated a range at Holloman Air Force Base, New Mexico which, like Hueco, was adjacent to White Sands. White Sands range jurisdiction would include Hueco and Holloman by 9 August 1952 [22, 13, 23].

Because of its size White Sands was at the forefront of range instrumentation technology during the period from 1945 to 1950. This range, 100 miles in length, was the only one able to handle the V-2 with its phase-comparison DOVAP radar. However, not even White Sands could contain the V-2 if its full 200 mile range were utilised.

Eastern Test Range*

On 29 May 1947 a V-2 went out of control, travelling only 47 miles, but landing near Juarez, Mexico [14]. This flight together with the size constraints of America's largest missile range expedited the recommendations of the Committee on Long-Range Missile Proving Grounds of the Joint Research and Development Board of the War Department [26]. Within a month the committee responded with four proposed locations to permanently solve the missile range size problem.

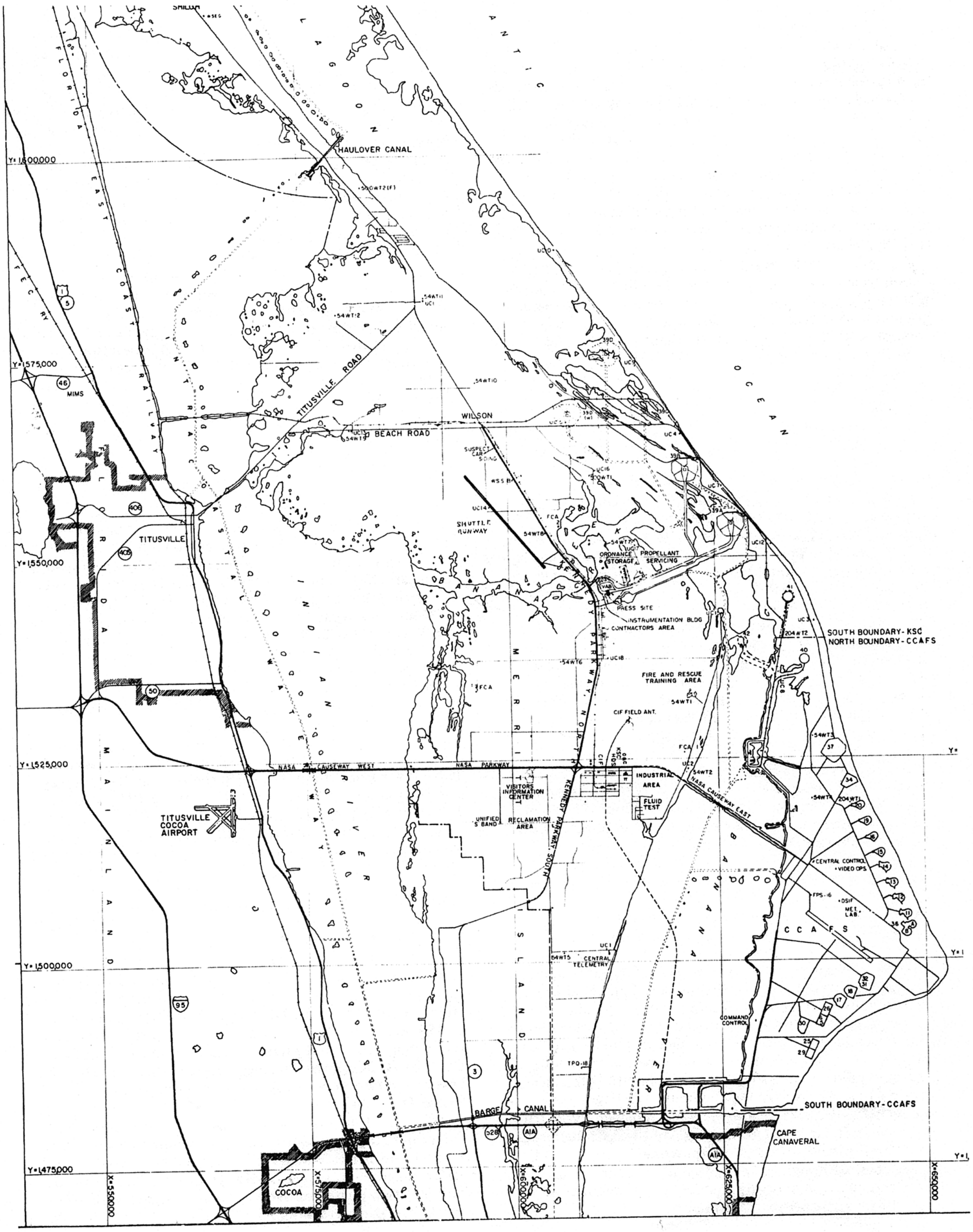
To avoid impinging on populated areas, a consideration which originally brought Goddard to New Mexico, the committee used the Peenemünde approach – sea ranges. The main problem with sea ranges which would eventually extend for thousands of miles was the location of permanent tracking facilities. Although ships could be used in open areas, the committee preferred chains of islands and other land masses at this early point in range history. The other Goddard consideration, favourable weather, also played a decisive role.

The selection of a launch facility in Washington State with tracking facilities along the Aleutian chain was relegated to fourth choice because of its adverse climate, while the possibility of expanding the Naval Air Missile Test Center at Point Mugu, California across the Pacific was relegated to third choice because of the lack of nearby land masses for tracking sites [27]. This left the first choice, a launch site at the El Centro, California Naval Air Station with tracking facilities on either side of the flight path down the Gulf of California to the South Pacific; and the second choice, a launch site on Cape Canaveral 18 miles north of the already existing Banana River Naval Air Station with tracking facilities on the British owned Bahama Islands. The first choice was abandoned after negotiations with the President of Mexico in December 1947 failed to secure sovereignty rights for tracking stations [26]. Great Britain was more cooperative, and the Florida choice became the first long-range proving ground. The range of the missiles being tested may have caused the selection of a sea range, but the need for tracking stations provided the specific key for its location.

The Eastern Test Range was not the first American sea

* *The Eastern Test Range was called the Long Range Proving Ground from its first launch, a V-2/WAC-Corporal, on 24 July 1950 through the end of 1951. The unofficial but nevertheless effective title from 1952 until 30 April 1958 was Florida Missile Test Range. When the Pacific Missile Range was formed on the west coast, the name Atlantic Missile Range was given to the east coast facility. Shortly after the National Range Division was formed on 15 May 1964 the name was changed to its present designation [24, 25].*

JOHN F. KENNEDY SPACE CENTER



range. That distinction was held by Wallops Station in Virginia. Wallops Station, a range by definition since it used telemetry, however, was not the first American missile test facility using the oceans. That distinction was held by the missile proving ground at Camp Pendleton, California [11].

The first year of launchings at the Eastern Test Range was without the assistance of telemetry, and by definition the Florida facility was not yet a range. The first two launchings from the new facility in July 1950 were V-2/WAC-Corporals as part of Project Bumper. The only instrumentation available at that time was temporary mono-pulse radar and optical tracking on-board two Navy destroyers, the USS Sarsfield and USS Foss. From July 1950 to June 1951 small Lark missiles were also launched using only Cape Canaveral based tracking. Finally, on 20 June 1951 the facility acquired its first downrange tracking station and by 31 December 1951 the first telemetry system was ready for use [28, 29].

The initial development of the Eastern Test Range was accomplished with winged missiles. The first use of Jupiter Inlet and Grand Bahama, which expanded range coverage to 200 miles, was accomplished with the launch of the first Matador missile on 20 June 1951. Eleuthera Island at 300 miles distance was soon added to the Matador testing programme. On 26 November 1955 a Snark was the first missile to use San Salvador, Mayaguana, and Grand Turk providing 700 miles of coverage. On 5 December 1956 Dominican Republic, Puerto Rico, and St. Lucia were added on another Snark flight stretching the range to 1500 miles, enough to handle Intermediate Range Ballistic Missiles (IRBM's). On 31 October 1957 yet another Snark made the first flight to Ascension Island opening the range to Intercontinental Ballistic Missiles (ICBM's) at 5,000 to 6,000 miles. The final addition, however, was made by a ballistic missile, an Atlas-D, which used the Pretoria, South Africa station on its flight to the Indian Ocean on 20 May 1960 opening the range to extended-ICBM's at 9,000 to 10,000 miles [29]. Optical systems provided a majority of the testing data during this period, due to the low altitude of the winged missile trajectories, but this trend changed in favour of radar tracking and telemetry as the high-arching ballistic missiles became predominant. The extensive use of radar and telemetry in the development of ballistic missiles at the Eastern Test Range matched a similar trend at Peenemünde where statistics indicate that 80% [30] of all V-2 flights were made without optical equipment.

The expansion of a range from one hundred to several thousand miles was accomplished through the development of new communications and timing techniques. The first 1,250 miles of the system to Antigua were connected by submarine cable while the outermost stations were reached by radio. Timing at the new range was accomplished by several independent signal generators which were synchronised with the US Naval Observatory, also by radio.

Another development in range instrumentation technique was the extensive use of ships and planes to fill the large gaps in the range especially between St. Lucia and Fernando de Noranha which are nearly 2,500 miles apart. The large gaps were initially filled by small picket ships, which were used to record incoming telemetry data. Six FS class picket ships were introduced for the Snark Program flights to Antigua and Ascension in October 1957 [6]. The St. Lucia-Fernando de Noranha gap happened to be located at the high point of an ICBM trajectory and thus telemetry reception was the priority requirement. After two years these picket ships were deactivated and replaced by instrumented aircraft. Instrumentation size and weight decreases, paralleling those occurring in computer technology, made this possible. Although an individual plane cannot carry the instrumentation of a ship, its use in remote areas is justified by its 10-to-1 increase in area coverage [31]. By 1968 eight modified C-135 [28] jet transports comprised the fleet of Eastern Test Range aircraft.

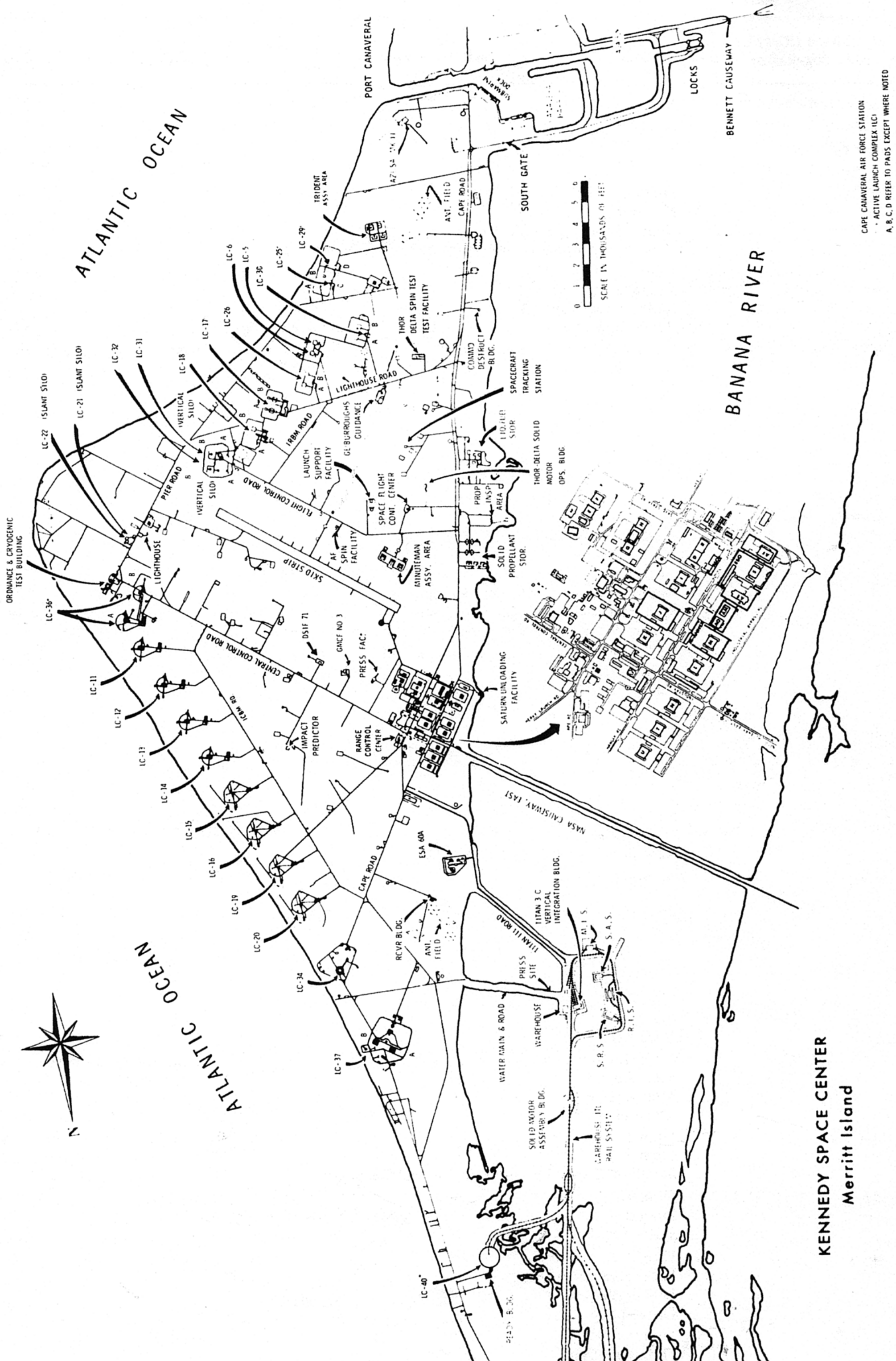
In the reentry areas at Grand Turk, Antigua, and Ascension instrumented aircraft and ships were used to augment the island based tracking and telemetry system. The first tracking and telemetry ship, the *Twin Falls* became operational on 30 October 1960 in support of the Pershing Program [6]. Tracking necessitated a precisely known position. When weather permitted, ships were located for tracking purposes by the star-tracking Ships Inertial Navigation System (SINS) which could be replaced by the older LOng RAnge Navigation (LORAN) system, a long range variation of the SHOrt RAnge Navigation (SHORAN) system of radio triangulation used at White Sands. LORAN and SHORAN involve a pulsed transmitter, a receiver at the location in question, and two transponder beacons at other known locations. Later versions of LORAN and SHORAN were the LOng Range ACcuracy (LORAC) and HIgh precision RAnge Navigation (HIRAN) systems, respectively.

Optical instrumentation at the Eastern Test Range began with transplanted White Sands devices. Tracking metric optics included later versions of the Askania and Mitchell cinetheodolites. The fixed metric CIT Acceleration Camera, sometimes referred to as the CIT-1 Bowen-Knapp, was replaced by the Clark and Hulcher ribbon-frame devices. These led to the CZR-1 Bowen-Knapp which has dominated that area of fixed metric optics ever since. The White Sands Tracking Plate Camera was soon transformed into the BC-37 which was eventually replaced by the BC-4. The BC-4 plate cameras at Grand Bahama, San Salvador, Grand Turk, and Puerto Rico provided extremely accurate acceleration data in the late 1950's by photographing night launched missiles carrying strobe lights. The White Sands Telescope had a counterpart at Cape Canaveral in the Gun Sight Aiming Point (GSAP) cameras which were eventually developed into the Intercept Ground Optical Recorder (IGOR) and Recording Optical Tracking Instrument (ROTI) [6, 32, 33].

Mono-pulse radar at the Eastern Test Range began with the World War II SCR-584 Mod-I which had a range of 190 nautical miles at a frequency of 2700-2900 MHz. The development of the SCR-584 Mod-II began in 1953 with a range of 400 nautical miles at the same frequency, and became operational at Grand Bahama in July 1955. That same year work on its replacement, the AN/FPS-16, with a range of 500 nautical miles at a frequency of 5400-5900 MHz began. The first operational AN/FPS-16 was installed at Patrick Air Force Base, formerly the Banana River Naval Air Station, on 27 November 1956. In the 1960's the AN/FPQ-6 and its portable equivalent, the AN/TPQ-18, obtained a range of 32,000 nautical miles by increasing the AN/FPS-16 antenna size from 12 ft. to 29 ft. in diameter, and operating at the same frequency [27, 28].

In the area of Doppler radar at the Eastern Test Range, DOVAP was not used until the Redstone was developed. The first DOVAP equipment arrived at Patrick Air Force Base on 8 March 1954. The problems with DOVAP were ionospheric refraction due to its low frequency (36 MHz) and second harmonic radiation interference. The first of these problems was overcome with the development of Ultra High Frequency (UHF) DOPpler, or UDOP which operated at 450 MHz. An Offset UDOP was developed to overcome the second problem. Finally, a new system called Offset DOPpler (ODOP) was developed to maximise the effectiveness of the two previous systems. ODOP operated at 890 MHz [6, 24].

While the transplanted White Sands optical, mono-pulse radar, and Doppler radar tracking instruments were refined at the Eastern Test Range, the new facility created a third electromagnetic tracking device, phase-comparison radar. The first two phase-comparison radar systems were AZUSA and COrrelation Tracking And Ranging (COTAR) developed



KENNEDY SPACE CENTER showing the location of launch complexes, see tables pages 96-97.

Cape Canaveral Launch Facility Utilisation.

LAUNCH COMPLEX (Pad designation)	USE (Chronological Order of First Appearance)	CURRENT STATUS
Launch Area A*	Matador	No longer used.
Launch Area B*	Matador	No longer used.
Launch Area C*		No longer used.
Launch Area D*		No longer used.
1**	Snark Matador Heliport for Project Mercury Range Measurement Laboratory Balloon Release Area	Dismantled.
2**	Snark Matador Heliport for Project Mercury Range Measurement Laboratory Balloon Release Area	Dismantled.
3**	V-2/WAC-Corporal (Bumper) Bomarc Matador Hugo X-17 Polaris Medical Support for Project Mercury Spin Balance Facility for Thor/Delta Range Measurement Laboratory Balloon Release Area	Dismantled.
4**	Bomarc Redstone Jason Hugo Medical Support for Project Mercury Spin Balance Facility for Thor-Delta Range Measurement Laboratory Balloon Release Area	Dismantled.
5	Redstone (Including Mercury/Redstone) Jupiter Juno Space Museum	Inactive.
6	Jupiter Space Museum	Inactive.
7	-	Never built.
8	-	Never built.
9	Navaho Project Rise Now site of Launch Complexes 31 and 32	Dismantled in 1960.
10	Navaho Jason Now site of Launch Complexes 31 and 32	Dismantled in 1960.
11	Atlas	Salvaged in August, 1965.
12	Atlas Atlas-Able Atlas-Agena	Deactivated in December, 1967.
13	Atlas Atlas-Agena	Active.
14	Atlas (Including Mercury/Atlas) Atlas-Able Atlas-Agena Atlas-ATDA	Deactivated in February, 1967.
15	Titan 1 Titan 2 Blockhouse used by NASA KSC as Office Space	Sold for salvage in June, 1967.
16	Titan 1 Titan 2 Static Test Facility	Inactive.
17A	Thor Thor-Able Thor-Delta Thor-Able-Star	Active
17B	Thor Thor-Able-Star Thor-Delta Thor-ASSET	Active.
18A	Viking Vanguard Blue Scout Jr	Deactivated in February, 1967.

18B	Thor Blue Scout Scout	Deactivated in April, 1967.
19	Titan I Titan II (Including Gemini/Titan)	Deactivated in April, 1967.
20	Titan I Titan IIIA	Deactivated in April, 1967.
21 (Slant silo)	Bull Goose Mace	Deactivated.
22 (Slant silo)	Bull Goose Matador Mace	Inactive.
23	(Proposed Test Site for Ship Launched Version of Jupiter IRBM)	Never built.
24	(Proposed Test Site for Ship Launched Version of Jupiter IRBM)	Never built.
25A	Polaris	Dismantled.
25B (Ship simulator)	Polaris	Salvaged in September, 1969.
25C	Poseidon Trident	Active.
25D	Poseidon Trident	Active.
26A	Juno Jupiter Redstone Space Museum	Inactive.
26B	Jupiter Juno Space Museum	Inactive.
27	-	Never built.
28	-	Never built.
29A	Polaris Trident	Active.
29B (Ship simulator)	(Proposed Polaris Launcher)	Never built.
30A	Pershing	Dismantled in February, 1968.
30B	Pershing	Dismantled in February, 1968.
31A	Minuteman	Deactivated in September, 1969.
31B (Vertical silo)	Minuteman	Deactivated in September, 1969.
32A	Minuteman	Deactivated in December, 1970.
32B (Vertical silo)	Minuteman	Deactivated in December, 1970,
33	-	Never built.
34	Saturn I Saturn IB	Salvaged in April, 1972.
35	-	Never built.
36A	Atlas-Centaur	Active.
36B	Atlas-Centaur	Active.
37A	Built for Saturn I but never used	Salvaged in April, 1972.
37B	Saturn I Saturn IB	Salvaged in April, 1972.
38	(Proposed Dual Atlas/Centaur and Atlas/Agena capabilities)	Never built.
39A	Saturn V Space Shuttle	Active.
39B	Saturn V Saturn IB Space Shuttle	Active.
39C	(Proposed Saturn V Pad)	Never built.
39D	(Proposed Saturn V Pad)	Never built.
39DW	(Proposed Saturn V Pad)	Never built.
40	Titan IIIC	Active.
41	Titan IIIC Titan IIIE/Centaur	Active.
42	(Proposed Titan IIIC Pad)	Never built.

* *Launch Areas had no permanent facilities and were used for mobile testing. The Launch Areas were located on the tip of the Cape in front of Launch Complexes 1, 2, 3, and 4.*

** *Launch Complexes 1, 2, 3, and 4 were located near the marked location of the Ordnance and Cryogenic Test Building in front of Launch Complex 36.*

in the 1950's for use on the impending IRBM's and ICBM's. AZUSA was deployed in the launch area to obtain accurate long-range velocity and position information, while COTAR functioned at the other end of the ballistic missile flight at Antigua and Ascension to give equivalent data on the re-entry portion of the flight [34]. Both systems required a transponder on-board the missile in a manner similar to the two-way Doppler systems. On 5 December 1955 [29] the first missile equipped for AZUSA tracking, a Redstone, was launched from Cape Canaveral to test the new system in preparation for the Thor, Atlas, and Titan ballistic missiles. The system was operational the following year. The AZUSA was also the first launch site phase-comparison system used to provide impact prediction data for range safety. Phase-comparison systems at the Eastern Test Range after AZUSA, which had an accuracy of 30 parts-per-million, and COTAR, which had an accuracy of 25 parts-per-million, were the AZUSA Mark-II and later MISTRAM. AZUSA Mark-II replaced its namesake in 1961 with an accuracy of 17.4 parts-per-million. The MISTRAM system development began in 1959 as part of the Minuteman Program. MISTRAM had an accuracy of 3 parts-per-million [27, 6].

Telemetry expanded its capability exponentially at the Eastern Test Range. Approximately 60% of all data collected on a given missile was telemetry data. The 12 engineering events sensed on the Peenemünde V-2 telemetry system grew to 400 events by the time the Atlas ICBM was tested in the late 1950's, and when the Titan II began its testing programme at Cape Canaveral in 1961, a 2000 event system was used [27].

The AN/MPG-1 pulse radars used for impact detection at White Sands were replaced by sonic systems at the Eastern Test Range. The Missile Impact Location System (MILS) installed at Grand Turk, Antigua, and Ascension [27] consisted of six hydrophones located on the ocean floor in the vicinity of the intended impact point. MILS was useful for accurate flights, but the Broad Ocean Area (BOA) system was the impact detector on flights where the missile strayed from its desired trajectory. The older BOA system had hydrophones placed at 3,000 and 4,000 ft. depths over thousands of square miles of ocean area, but depended heavily on the missile carrying SOund Fuzing And Ranging (SOFAR) bombs for success. Both systems used LORAN-type triangulation to obtain results [6].

Ships and planes used this precise impact location to retrieve the ablative nose cones and model warheads on many ballistic missile shots. Such recoveries were first undertaken with the short-range Jupiter-C launchings in support of the Jupiter-IRBM Programme. The first Jupiter-C nose cone recovery took place on 8 August 1957 after a three hour search. The first full-size Atlas nose cone recovery occurred on 21 July 1959 [29].

Data processing involved such quantities of information that the IBM punched card machines were soon replaced by the descendants of the ENIAC electronic digital computer. The development of the FLorida Automatic Computer (FLAC) the first missile range developed digital computer, began in April 1951 and on 1 August 1953 FLAC went into operation. Both ENIAC and FLAC were first generation, vacuum-tube devices. FLAC was donated to George Washington University on 20 May 1959 after being replaced by the IBM-7090, a second generation, transistorised computer [24]. The present real-time data reduction is performed on two CDC-3600's and a CDC-3100, which are third generation, printed-circuit machines [28]. The real-time use of computers includes analysis of AZUSA-type impact prediction data, and the flying of aircraft and missiles to their targets using the Semi-Automatic Ground Environment (SAGE) system originally tested at the Eastern Test Range on the Bomarc missile.

Western Test Range*

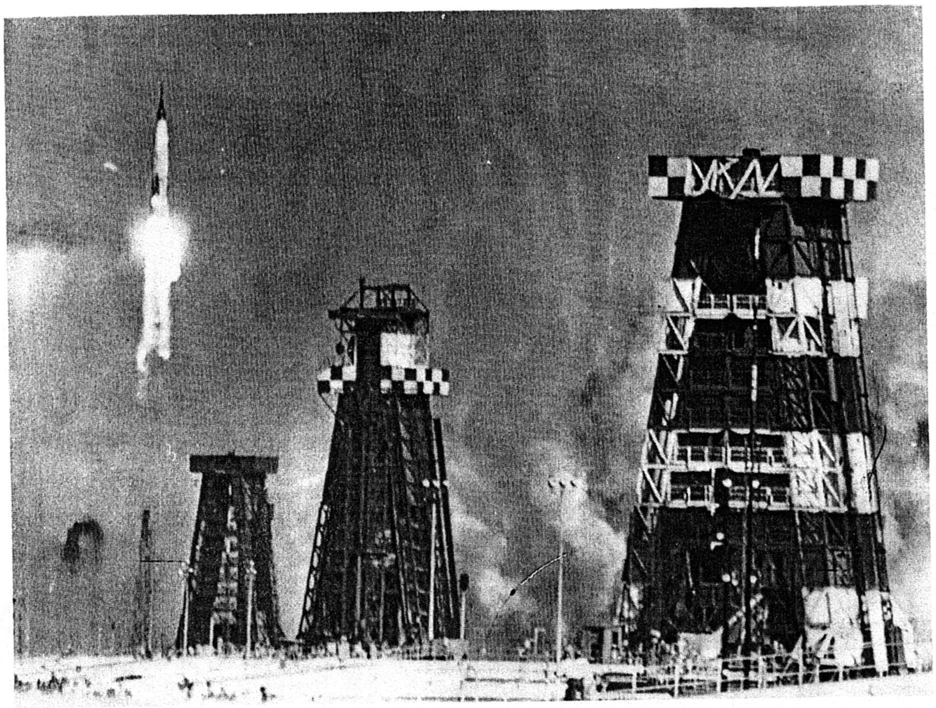
In 1958, the vast array of range instrumentation developed at the Eastern Test Range was the foundation of a new ICBM range for operational testing to take the work load off the east coast facility. The new range was a slight variation on the original Point Mugu proposal of the Joint Research and Development Board. The launching facility was established on the California coast at Point Arguello, and the new range extended west-southwest across the Pacific Ocean to the Kwajalein and Eniwetok atolls. Instrumentation sites were located at various points along the California coast as well as on Hawaii and various other Pacific Islands. Instrumented planes and ships were used to fill the gaps and augment coverage in the impact area. Virtually every type of range instrument at the Eastern Test Range was used to outfit the new facility.

The main contribution of the Western Test Range to range instrumentation was in the area of impact detection. Having acquired the MILS and BOA systems from the Eastern Test Range, the new range developed the Splash Detection Radar (SDR) and the Broad Ocean Scoring System (BOSS) from the old White Sands AN/MPG-1 impact detection radar. SDR and BOSS were developed in conjunction with the Army Kwajalein Missile Range and were the primary impact location systems for operational ICBM testing in the 1960's. SDR operates like MILS to detect accurate impacts by identifying a minimum splash of 30 ft. amplitude and two second duration [36]. BOSS acts like BOA to give a general landing location for stray missiles.

The Descendants and Spin-Offs

Range instrumentation was the basis for tracking in the space programme as well as in the early warning detection of missiles. Just as the Anti Ballistic Missile was being developed to neutralise IRBM's and ICBM's, the mono-pulse radar which contributed so heavily to their testing was developed in the Ballistic Missile Early Warning System (BMEWS) to give fore-warning of their offensive use, a long range equivalent to the airplane detection capability of the first mono-pulse radars in World War II. BMEWS also caused IBM to develop their first second generation computer, the 7090, later used at the Eastern Test Range [20]. The Doppler radar techniques were the basis for the satellite GLObal TRACKing (GLOTRACK) and DOPpler phase LOCk (DOPLOC) systems. MINITRACK, a NASA tracking system originally developed by the Naval Research Laboratory for the Vanguard satellite programme, capitalised on the angle-measuring phase-comparison systems like AZUSA and COTAR. A variation of MINITRACK called MICROLOCK

* *On 16 June 1958 the Pacific Missile Range was activated with headquarters at the old Naval Air Missile Test Center (NAMTC), later renamed Naval Missile Center, at Point Mugu, California. The new range included the Point Mugu range for short-range missile testing, an IRBM/ICBM and polar orbit insertion range with launch facilities at Vandenberg Air Force Base and adjacent Naval Missile Facility, Point Arguello, north of Point Mugu on the California coast, and an Anti-Ballistic Missile (ABM) range for the Army at Kwajalein Atoll. On 15 May 1964 shortly after the establishment of the National Range Division, the combined Pacific Missile Range was subdivided into three ranges. The short-range missile testing at Point Mugu retained the name Pacific Missile Range. The Army ABM testing facility was called the Kwajalein Test Site, a name it would retain until 15 April 1968 when it would receive its present title of Kwajalein Missile Range. The IRBM/ICBM and polar orbit insertion range was designated Western Test Range analogous to the Eastern Test Range [23, 25, 35].*



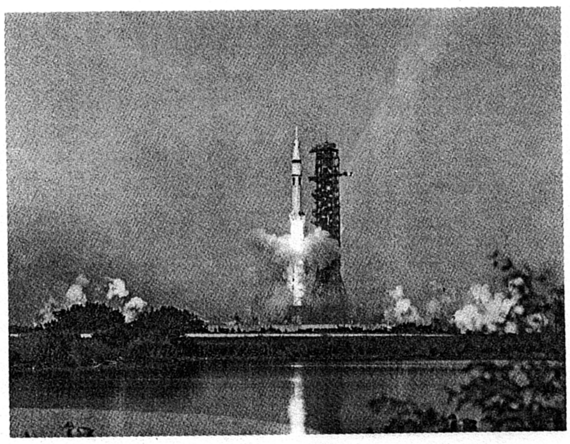
FIRST AMERICAN IN ORBIT. Major John Glenn starts his historic three orbits of the Earth from Cape Canaveral on 20 February 1962.

National Aeronautics & Space Administration

was developed for lunar and planetary distance tracking. Another descendant of MINITRACK was the Navy SPAce SURveillance (SPASUR) system. Even the optical tracking instrumentation of the missile ranges was converted to space programme usage; the Smithsonian Astrophysical Observatory operates Baker-Nunn 31 in. Schmidt-type telescopic cameras to track satellites.

With recoverable capsule-carrying reconnaissance satellites and manned flights, which use the retrieval techniques pioneered at the Eastern Test Range, comprising only 10% of all United States space launchings, the other most important range contribution to space research has been on-board instrumentation and telemetry. The United States orbited 32 capsule carrying reconnaissance satellites by 31 December 1973. During this same period 25 manned flights were made not counting the sub-orbital flights of Mercury/Redstone-3 and -4. This total of 57 was approximately 10% of the 558 total United States orbital launchings during the same period [37]. Obviously no satellite or spacecraft has ever flown without a telemetry system and for those hundreds of vehicles which are never deliberately returned to Earth, telemetry is their only means of providing useful information or receiving commands.

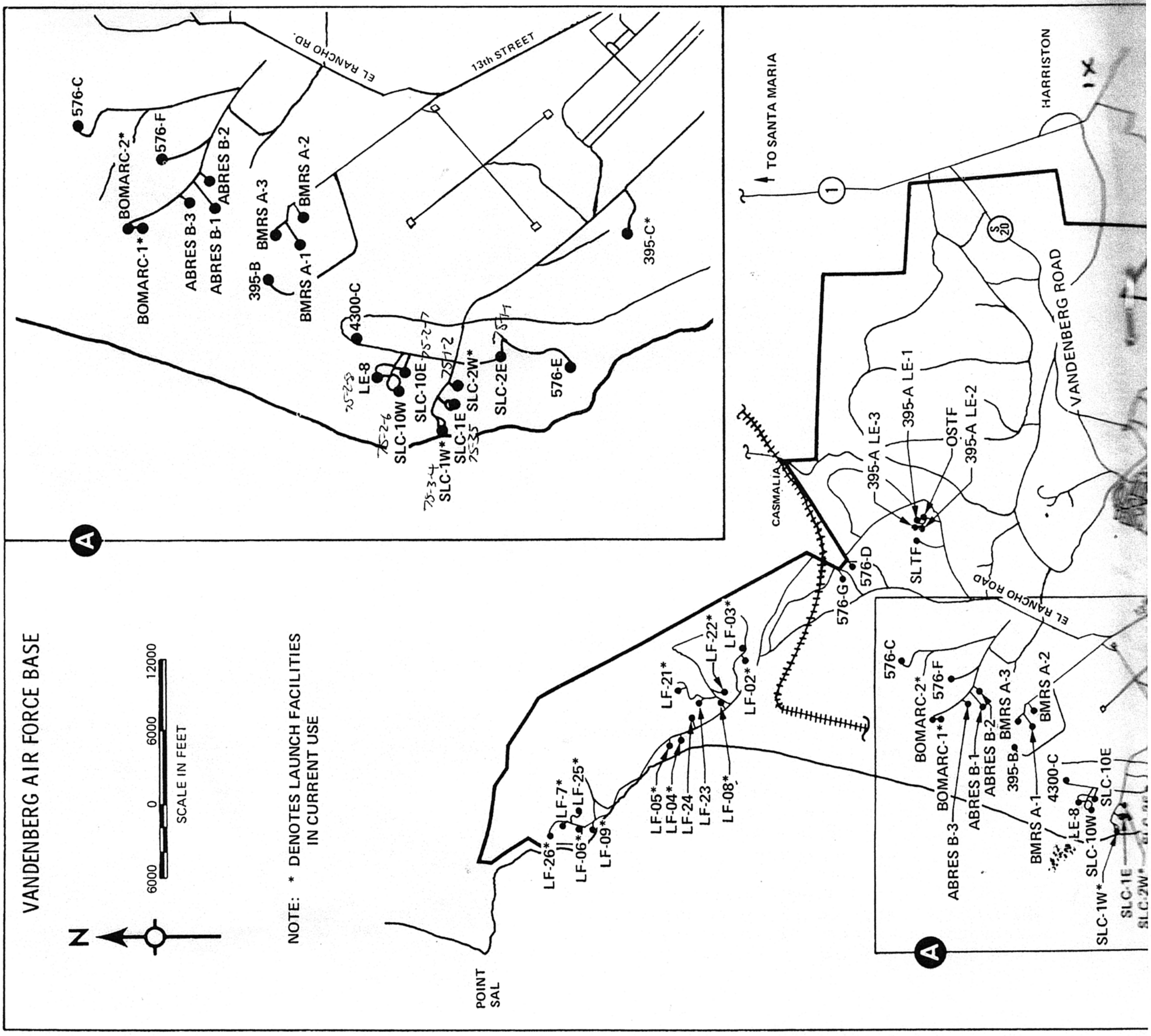
The tracking and telemetry techniques are combined to form the immediate descendant of the missile range, the tracking/telemetry network. The Space Tracking And Data Acquisition Network (STADAN) combines the MINITRACK, GLOTRACK, and DOPLOC systems and the Smithsonian Baker-Nunn cameras with a telemetry system to cover NASA Earth-orbital satellites. The descendants of MICROLOCK and the long-range telemetry techniques were combined to form the Deep Space Network (DSN) for NASA lunar and planetary flights. In fact, the California facility, one of the three primary DSN worldwide stations, is located at the site of the old Goldstone Range. The military equivalent to STADAN is the SPAce Detection And Tracking System (SPADATS) which combines telemetry with the tracking of Baker-Nunn cameras and radar systems like SPASUR. While the tracking capability of SPADATS, STADAN, BMEWS and all of the missile ranges combine to provide a general



SKYLAB 4. Third and last of three manned missions to the Skylab space station launched from the Kennedy Space Center on 16 November 1973. Aboard were astronauts Gerald P. Carr, Edward G. Gibson and William R. Pogue. Their mission lasted 2017 hours 15 minutes 32 seconds which stands as a world record to this day.

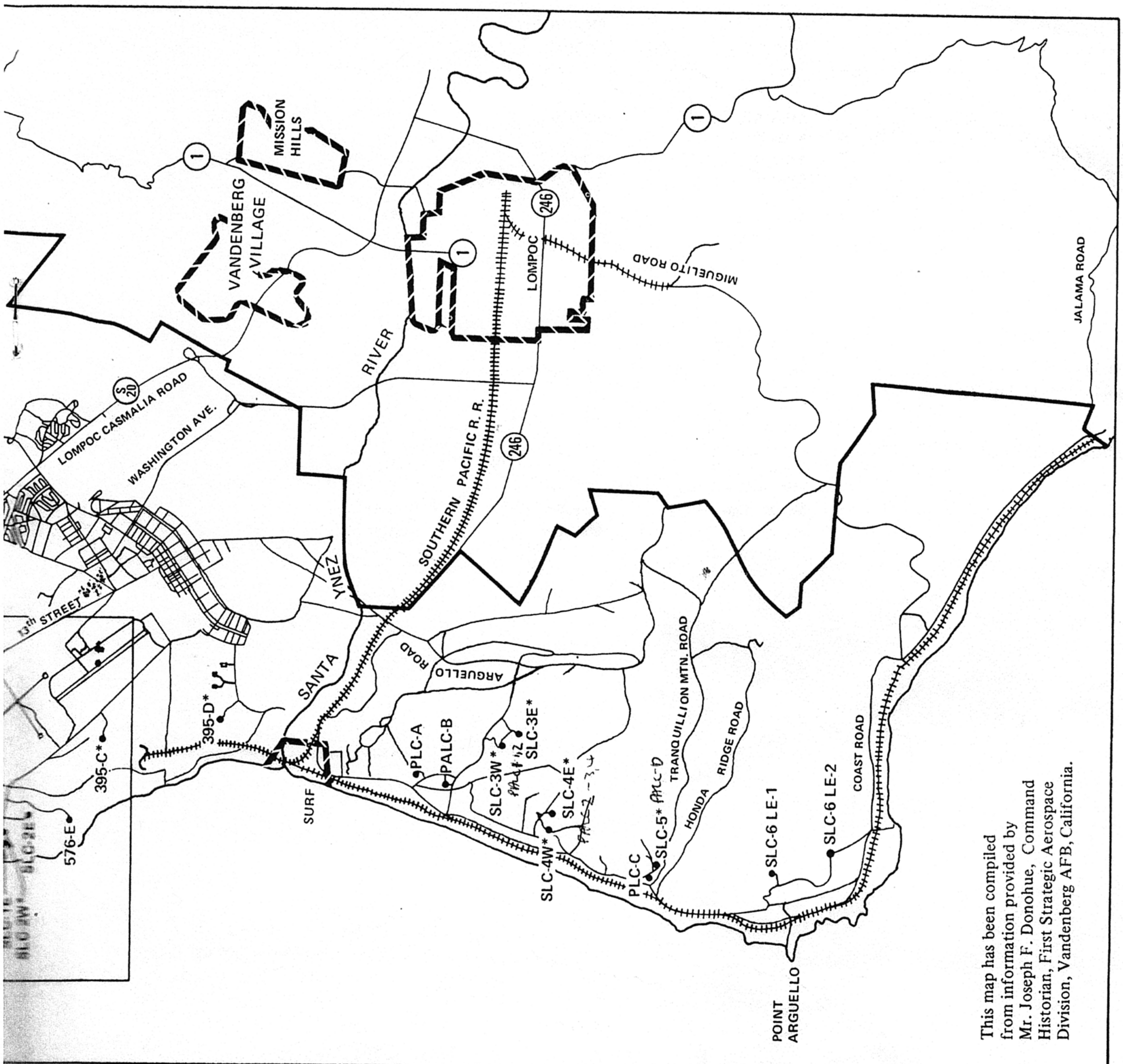
survey of all space vehicles for the North American Air Defense Command (NORAD), the telemetry capability of these networks provide the primary link in their testing and operational use.

The benefits of the United States missile ranges are not limited just to the missile and space efforts. The telemetry spin-offs include areas as diverse as stress-monitoring radio telemetry being used in the broken hips of orthopedic patients [38], and heat and pressure transducers being used to automatically control portions of factories. In the area of radar, distance-measuring phase-comparison techniques are used in extremely accurate satellite surveying systems



Vandenberg Launch Facility Utilisation

LAUNCH COMPLEX (Pad Designation)	USE (Chronological Order)	PREVIOUS DESIGNATIONS	CURRENT STATUS
395-A LE-1 (Vertical silo with lift)	Titan I		Decommissioned and stripped.
395-A LE-2 (Vertical silo with lift)	Titan I		Decommissioned and stripped.
395-A LE-3 (Vertical silo with lift)	Titan I		Decommissioned and stripped.
395-B (Vertical silo)	Titan II		Decommissioned and stripped.
395-C (Vertical silo)	Titan II		Active.
395-D (Vertical silo)	Titan II		Active.
576-C (Coffin-type)	Atlas E		Decommissioned and stripped.
576-D (Vertical silo with lift)	Atlas F		Decommissioned and stripped.
576-E (Vertical silo with lift)	Atlas F		Decommissioned and stripped.
576-F (Coffin-type)	Atlas E Nike X	OSTF-1	Decommissioned and stripped.
576-G (Vertical silo with lift)	Atlas-F	OSTF-2	Decommissioned and stripped.



VANDENBERG AIR FORCE BASE showing the location of launch complexes, see tables pages 100-103.

LAUNCH COMPLEX (Pad Designation)	USE (Chronological Order)	PREVIOUS DESIGNATIONS	CURRENT STATUS
4300 C	Scout Blue Scout Jr Scout/Scramjet		Decommissioned and stripped.
ABRES B-1 (Coffin type)	Atlas D Atlas/ABRES	576 B-1	Decommissioned and stripped.
ABRES B-2 (Coffin-type)	Atlas D Atlas/ABRES	576 B-2	Decommissioned and stripped.
ABRES B-3 (Coffin-type)	Atlas D	576 B-3	Decommissioned and stripped.
BMRS A-1	Atlas D Atlas-Burner-2 Atlas E Atlas F	576 A-1 4300 A-1 ABRES A-1	Decommissioned and stripped.
BMRS A-2	Atlas D	576 A-2	Decommissioned and stripped.

LAUNCH COMPLEX (Pad Designation)	USE (Chronological Order)	PREVIOUS DESIGNATIONS	CURRENT STATUS
BMRS A-2/contd.	Atlas/ABRES Atlas F	4300 A-2	
BMRS A-3	Atlas D Atlas E Atlas F	576 A-3 4300 A-3 ABRES A-3	Inactive.
BOMARC 1	Bomarc A Bomarc B		Active.
BOMARC 2	Bomarc A Bomarc B		Active.
LE-8	Thor	75-2-8	Decommissioned and stripped.
LF 00-02 (Vertical silo)	Minuteman II Minuteman III	394 A-1	Active
LF 00-03 (Vertical silo)	Minuteman I	394 A-2	Active.
LF 00-04 (Vertical silo)	Minuteman I Minuteman II Minuteman III	394 A-3	Active.
LF 00-05 (Vertical silo)	Minuteman I Minuteman II Minuteman III	394 A-4	Active.
LF 00-06 (Vertical silo)	Minuteman I	394 A-5	Active.
LF 00-07 (Vertical silo)	Minuteman I Minuteman II Minuteman III	394 A-6	Active.
LF 00-08 (Vertical silo)	Minuteman I Minuteman III	394 A-7	Active.
LF 00-09 (Vertical silo)	Minuteman I Minuteman III		Active.
LF 00-21 (Vertical silo)	Minuteman II Minuteman III		Active.
LF 00-22 (Vertical silo)	Minuteman II Minuteman III		Active.
LF 00-23 (Vertical silo)	Minuteman II Minuteman III		Decommissioned and stripped.
LF 00-24 (Vertical silo)	Minuteman II		Decommissioned and stripped.
LF 00-25 (Vertical silo)	Minuteman II		Active.
LF 00-26 (Vertical silo)	Minuteman II Minuteman III		Active.
OSTF (Vertical silo with lift)	Titan I		Destroyed in explosion 3 December 1960; deleted from real property records.
PALC-B	Kiva-Hopi		Decommissioned and stripped.
PLC-A	Blue Scout Nike-Javelin Super Loki Blue Scout Jr	PALC-A	Decommissioned and stripped.
PLC-C	Nike-Aerobee Paiute-Tomahawk Ute-Tomahawk	PALC-C	Inactive.
ALC-1E	Thor-Agena	75-3-5	Decommissioned and stripped.
SLC-1W	Thor Agena	75-3-4	Decommissioned and stripped.
SLC-2E	Thor Thor-Able-Star Thor-Agena Thor-Delta	75-1-1	Decommissioned and stripped.
SLC-2W	Thor Thor-Able-Star Thor-Agena Thor-Delta	75-1-2	Active.
SLC-3E	Atlas Atlas-Agena Atlas-SV-5D (PRIME) Atlas-Burner-2	PALC-1-2	Currently being modified.
SLC-3W*	Atlas-Agena Thor-Agena Thor-Burner-2 Atlas-Agena	PALC-1-1	Active.
SLC-4E	Atlas-Agena Titan IIID	PALC-2-4	Active.

LAUNCH COMPLEX (Pad Designation)	USE (Chronological Order)	PREVIOUS DESIGNATIONS	CURRENT STATUS
SLC-4W	Atlas-Agena Titan IIIB/Agena	PALC-2-3	Active.
SLC-5	Blue Scout Scout	PALC-D	Active.
SLC-6	Titan IIIM (Manned Orbiting Laboratory) Space Shuttle		Never completed; future construction for Space Shuttle conversion planned.
SLC-10E	Thor	75-2-7 LE-7	Inactive.
SLC-10W	Thor Thor-Agena Thor-Burner-1 (Altair) Thor-Burner-2 Thor-Burner-2A	75-2-6 4300 B-6 LE-6	Active.
SLTF (Vertical silo)	Titan I Titan II		Decommissioned and stripped.

* *SLC-3W was converted from Atlas/Agena facility to Thor-Agena and Thor-Burner-2 launch facility and then back to an Atlas-Agena launch facility.*

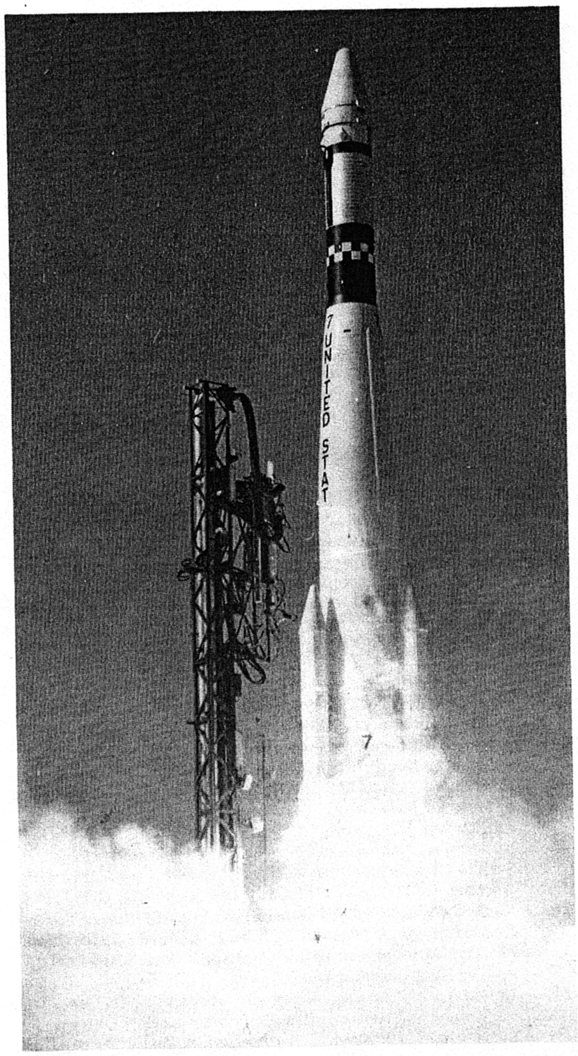
like Sequential Collation of Range (SECOR) and ELECTRO-TAPE [6], while Doppler systems are used to monitor the velocity of planes in flight to provide time-of-arrival predictions which parallel impact predictions made at the missile ranges [17].

The Future

According to John E. Naugle, the Associate Administrator of the National Aeronautics and Space Administration, ".... it may be better to conduct some of our industrial operations in space where there is abundant solar energy and an almost inexhaustible vacuum to act as a sink for thermal and chemical pollution" [39].

The future of American missile ranges will be greatly influenced by the new Space Shuttle, which will provide inexpensive transportation to and from Earth orbit, landing on a runway near its launch site like an aeroplane [40]. The Shuttle will soon dominate in the launching of space vehicles. In fact, the only launch vehicle presently scheduled to be used after the Space Shuttle becomes fully operational is the inexpensive Scout. The projected use of the Space Shuttle in space manufacturing, coupled with permanently orbiting space stations, may eventually transform the missile ranges into spaceports which handle passengers and cargo like their aeronautical counterparts. The declining missile range activity, as exemplified at the Eastern Test Range where the number of launchings dropped from a high of 201 in 1960 to a low of 20 in 1972, may be replaced by future growth away from their ballistic missile origins and building upon their space programme applications* [41].

* *With the coming of the Space Shuttle, the USAF contemplates closure of the Eastern Test Range in the mid-1980's. By that time the last of the expendable launch vehicles, probably the Titan 3C, will be retired from the ETR and only the Navy Trident development would remain. Shuttle operations at the Kennedy Space Center will not require downrange instrumentation "once the vehicle becomes fully operational in conjunction with the tracking and data relay satellite system."*



Right, a Thrust-Augmented Thor-Agena D blasts off from the Western Test Range, California, with the inflatable 100 ft. (30.5 m) Pageos 'balloon' satellite on 24 June 1966.

REFERENCES

1. Ley, Willy, *Rockets, Missiles and Men in Space,* New York, The Viking Press, pp. 668, 1968.
2. Page, Robert Morris, *The Origins of Radar,* Garden City, New York, Anchor Books, Doubleday and Company, pp. 196, 1962.
3. Stephen, Sir Leslie and Lee, Sir Sidney, editors, *Dictionary of National Biography,* Vol. 4, London, 1917, Oxford University Press, pp. 1392.
4. von Braun, Wernher and Ordway, Frederick I., III. *History of Rocketry and Space Travel,* New York, Thomas Y. Crowell Company, pp. 276, 1969.
5. Lehman, Milton, *This High Man,* New York, Farrar, Strauss, and Company, pp. 430, 1963.
6. Ehling, Ernest H., editor, *Range Instrumentation,* Englewood Cliffs, New Jersey, Prentice-Hall, pp. 634, 1967.
7. Huzel, Dieter K., *Peenemünde to Canaveral,* Englewood Cliffs, New Jersey, Prentice-Hall, pp. 247, 1962.
8. Simon, Leslie E., *German Research in World War II,* New York, John Wiley and Sons, pp. 218, 1947.
9. Dornberger, Walter, *V-2,* New York, The Viking Press, pp. 281, 1954.
10. Hall, Al, editor, *Peterson's Book of Man in Space,* Vol. 1, ("The First Small Step"), Los Angeles, Peterson Publishing Company, pp. 144, 1974.
11. Burchard, John E., editor, *Rockets, Guns and Targets,* Boston, Little, Brown and Company, pp. 482, 1948.
12. Emme, Eugene M., editor, *The History of Rocket Technology,* Detroit, Wayne State University Press, pp. 321, 1964.
13. Emme, Eugene M., *Aeronautics and Astronautics 1915-1960,* Washington, D.C., Government Printing Office, pp. 240, 1961.
14. Jarrett, Francis E., Jr. and Lindemann, Robert A., *Historical Origins of NASA's Launch Operations Center to 1 July 1962,* Cocoa Beach, Florida, John F. Kennedy Space Center, National Aeronautics and Space Administration, pp. text 81, 1964.
15. Pickering, W. H. and Young, J. A., *External Instrumentation for NAMTC: Optical Tracking Problem,* Progress Report 10-5, Pasadena, California, Jet Propulsion Laboratory, pp. 31, 26 June 1947.
16. Pickering, W. H. and Young, J. A., *External Instrumentation for NAMTC: The Radio and Radar Tracking Problem,* Progress Report 10-6, Pasadena, California, Jet Propulsion Laboratory, pp. 43, 14 August 1947.
17. *Above and Beyond,* **10**, Chicago, New Horizon Publishers, pp. 1721-1912, 1968.
18. Pickering, W. H., *External Instrumentation for NAMTC: Reduction of Data,* Progress Report 10-7, Pasadena, California, Jet Propulsion Laboratory, 11 August 1947, pp. 11.
19. Goldstine, Herman, H., *The Computer from Pascal to von Neumann,* Princeton, New Jersey, Princeton University Press, pp. 378, 1972.
20. Rosen, Saul, 'Electronic Computers: A Historical Survey', *Computing Sciences,* **1**, 1, Lafayette, Indiana, Purdue University, pp. 36, 1969.
21. Cummings, C. I., *Telemetring Nose Equipment for WAC-Corporal,* Progress Report 4-33, Pasadena, California, Jet Propulsion Laboratory, pp. 42, 21 July 1947.
22. White Sands Missile Range Information Office, *History of White Sands Missile Range,* New Mexico, Department of the Army, pp. 5.
23. Menkin, Arthur, *History of the Pacific Missile Range,* Naval Missile Center, Point Mugu, California, Pacific Missile Range, pp. introduction 11, 1959.
24. Patrick Air Force Base Historical Staff, *Chronology of the Joint Long Range Proving Ground, Florida Missile Test Range, and Atlantic Missile Range 1938-1959,* History Office, 6550th Air Base Group, Air Force Eastern Test Range, Florida, pp. 163, 1960.
25. National Aeronautics and Space Administration Historical Staff, Office of Planning, *Astronautics and Aeronautics 1964,* Washington, D.C., Government Printing Office, pp. 527, 1965.
26. Kennedy Space Center Historical Staff, *Utilisation of Cape Kennedy Launch Complexes,* John F. Kennedy Space Center, Florida, National Aeronautics and Space Administration, pp. 11, 1972 (unpublished).
27. United States Congress, House of Representatives, Committee on Science and Astronautics., Subcommittee on Manned Space Flight, *1963 NASA Authorisation,* Part 2, Appendices 8, 9, and 10 ("The AFMTC Story"), Government Printing Office, 87th Congress, pp. 1083-1171.
28. Patrick Air Force Base Office of Information, *Facts Book of the Air Force Eastern Test Range and Patrick Air Force Base,* 6550th Air Base Group, Air Force Eastern Test Range, Florida, pp. 163, 1974.
29. Whipple, Marvin R., *Index of Missile Launchings by Missile Program July 1950-June 1960,* Patrick Air Force Base, Florida, Office of Information Historical Branch, Air Force Missile Test Center, pp. 151, 1961.
30. Pickering, W. H. and Young, J. A., *External Instrumentation for NAMTC: The Instrumentation Problem,* Progress Report 10-2, Pasadena, California, Jet Propulsion Laboratory, pp. 29, 6 June 1947.
31. Morgenthaler, George W., editor, *Space Program Impact on Range Development,* **15**, American Astronautical Society Science Technology Series, Burgess, Eric, general editor, Washington, D.C., pp. 571, 1967.
32. Fisher, Allan C., Jr., assistant editor. 'Cape Canaveral's 6,000-mile Shooting Gallery', *The National Geographic Magazine,* pp. 421-471, 1959.
33. 'Missile Center Expands for Long-Range Flights', *Aviation Week,* pp. 170-184, 17 August 1953.
34. Anderton, David A., 'Patrick Prepares for Ballistic Missiles', *Aviation Week,* pp. 106-121, 6 August 1956.
35. Kwajalein Missile Range Directorate, *Kwajalein Missile Range Historical Summary July 1964-June 1970,* 1, Huntsville, Alabama, U.S. Army Safeguard System Command, pp. 127, 1972.
36. Space and Missile Test Center Headquarters, *SAMTEC Capability Summary Handbook,* Vandenberg Air Force Base, California, pp. 248, 1973.
37. Royal Aircraft Establishment, *Table of Earth Satellites,* Farnborough, Hants., England. Ministry of Technology, Vol. 1, pp. 197, 1970. Vol. 2, pp. 184, 1974.
38. Freese, Arthur, 'Space Age Spin-Offs for a New World of Medicine', *Science Digest,* pp. 33-34, April 1973.
39. Shapley, Deborah, 'Of Space Ships and Tall Ships', *Science,* **194**, 4260, p. 39, 1 October 1976.
40. Lindsey, Robert, " 'Roll Out' of Space Shuttle Hailed as Start of New Era", *The New York Times,* p. 8, 18 September 1976.
41. First Strategic Aerospace Division History Office, Vandenberg Launcher Status and History (Revised 1 March 1977), Strategic Air Command, Vandenberg Air Force Base, pp. 7.

MILESTONES *Continued from page 82]*

changes are caused in elementary living cultures by exposure to space radiation. Samples attached to the outside of the spacecraft will be compared with control samples inside the station.

10 Soviets launch Soyuz 27 from Tyuratam at 15.26 hr. (Moscow time) into orbit of 257 x 302 km inclined at 51.6 deg to equator; period 89.9 min. Cosmonauts are Lt-Col. Dzanibekov and flight engineer Oleg Makarov.

11 Soyuz 27 docks with Salyut 6 at 17 hr. 6 min. (Moscow time) using docking unit on transfer module used unsuccessfully by Soyuz 25 in October 1977. (On-board crew retreated to Soyuz 26 during the docking so they could break away in case of an emergency). Three hours later Dzanibekov and Makarov emerged into station to be welcomed by Romanenko and Grechko who received fresh food, mail and other cargo. They are scheduled to stay five days before returning in Soyuz 26 ferry.

12 Orbit of Soyuz 26/Salyut 6/Soyuz 27 combination is 334 x 367 km x 51.6 deg; period 91.3 min.