Bell Laboratories **RECORD**

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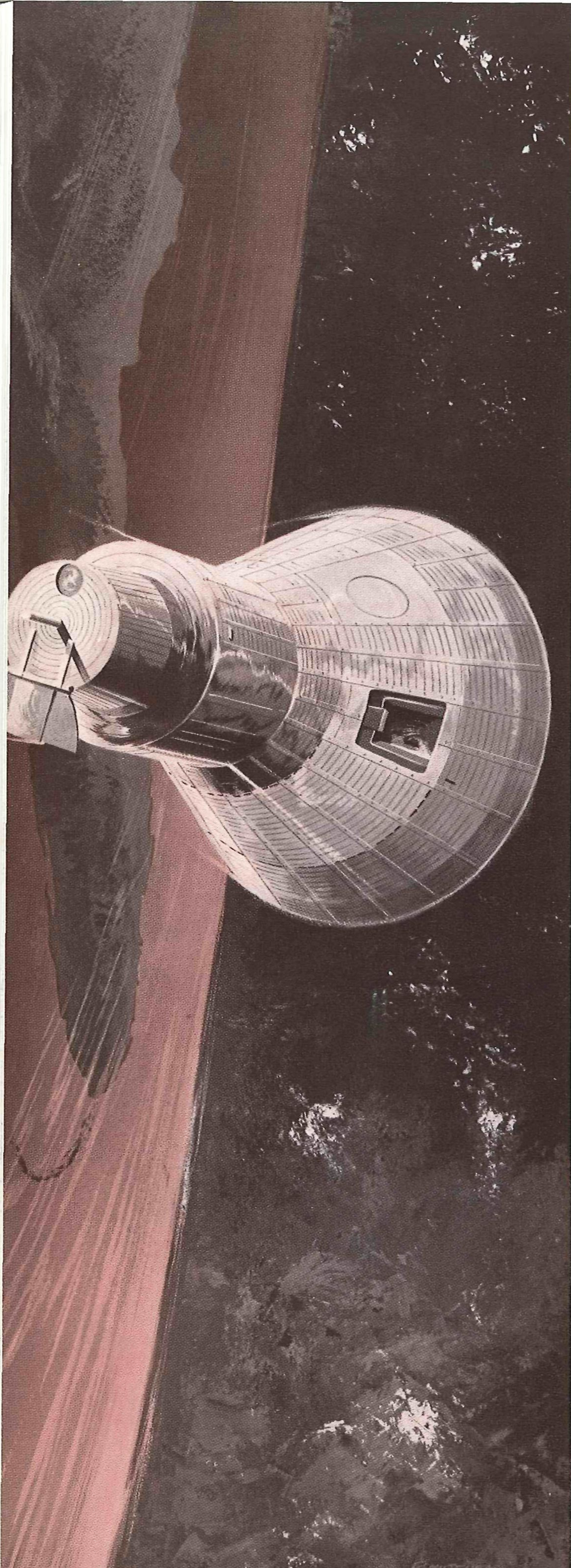
Cover *Slow electron diffraction pattern of a germanium surface is typical of the evidence used in studies of surface properties of solids at the Laboratories.* *(See story on page 282.)*



Bell Laboratories a

In 1903, on the bleak dunes at Kitty Hawk, North Carolina, the world's first airplane rose 15 feet off the ground; that year the telephone industry was just beginning to revolutionize communication facilities. Any relationship between a long-distance voice communication system and Orville Wright's flying machine seemed tenuous or nonexistent. But in the course of less than 60 years, communication facilities pioneered by the Bell System have become indispensable to man's flight.

This relationship is exemplified by the close cooperation between the Bell System and the National Aeronautics and Space Administration (NASA). More than two years before Colonel John H. Glenn's Friendship 7 spacecraft soared around the earth, a team of Bell Laboratories scientists and engineers began work on the design, construction and installation of a worldwide Tracking and Ground Instrumentation System (TAGIS). Such a communication network is essential to placing an astronaut into orbit around the earth and recovering him safely. The industrial team responsible for the entire TAGIS project was led by the Western Electric Company. Other members of this team were the Bendix Corporation, International Business Machines, Burns & Roe and Bell Telephone Laboratories.

The invention of the telephone and its impact on communications is no less vital to space flight than the advance of rocketry itself. This interdependence is exemplified by Project Mercury.

ies and Project Mercury

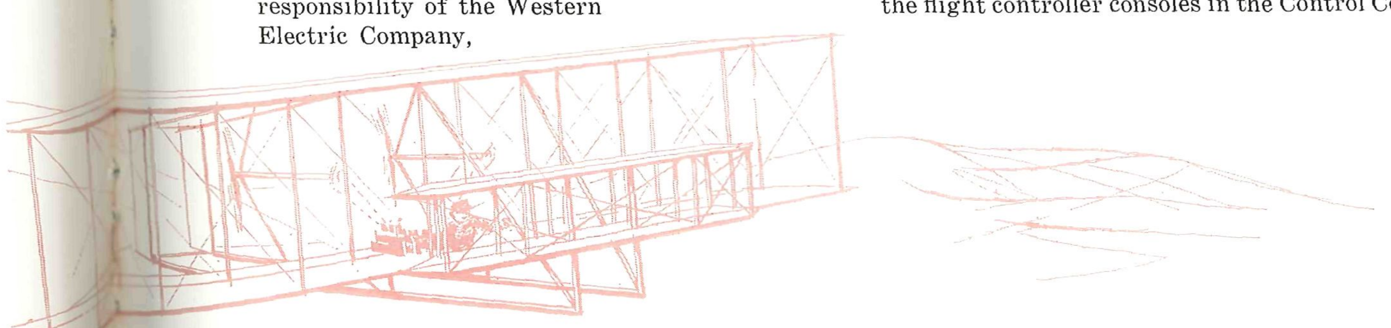
J. J. Hibbert

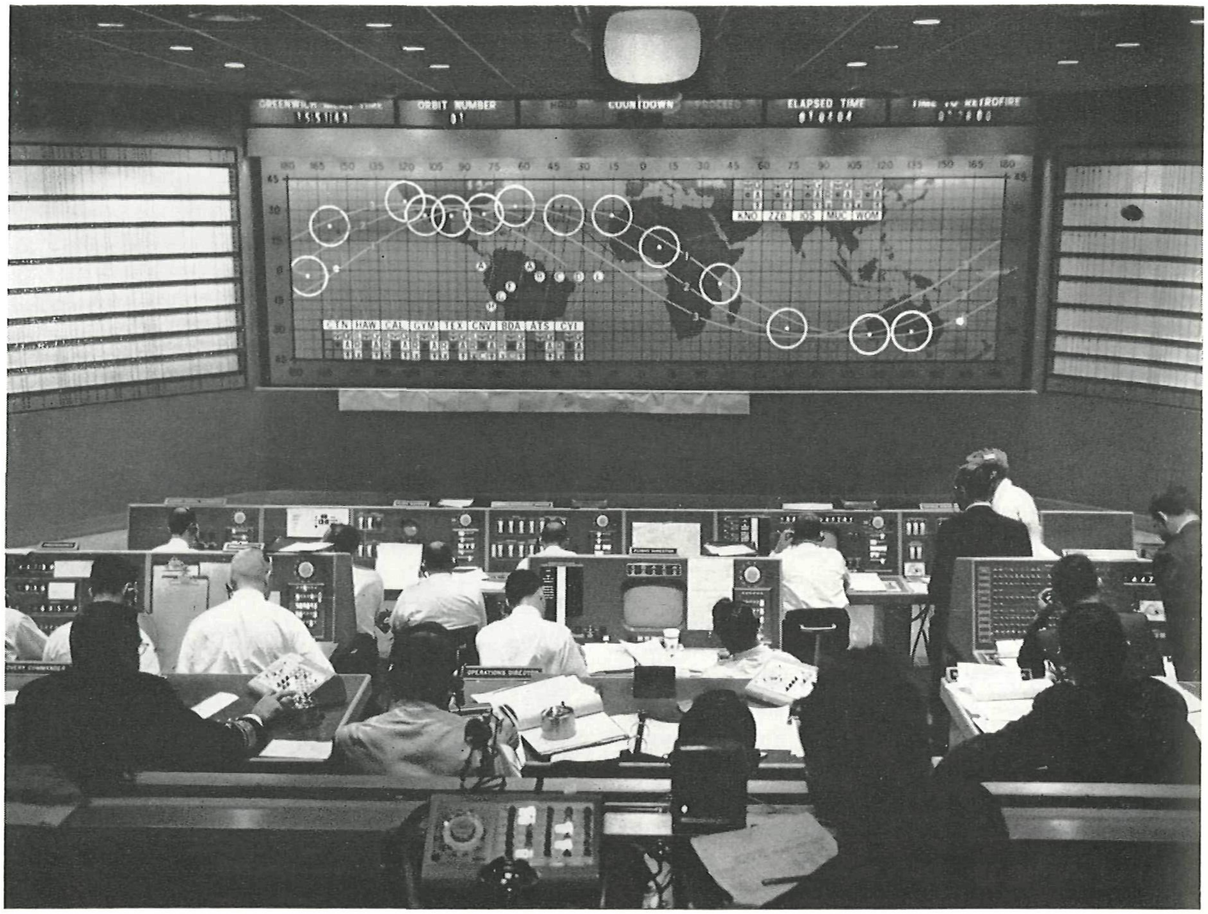
The Mercury Range, as TAGIS is more frequently called, consists of 18 sites at points around the world which (1) track the spacecraft, (2) monitor the status of the spacecraft and its occupant by telemetered signals, (3) provide voice communication with the astronaut and (4) transmit commands to the spacecraft (e.g., to fire retro-rockets). Mercury Control Center at Cape Canaveral monitors the spacecraft during its launch, orbit and re-entry. This primary control center bases its decisions on data obtained from the world-wide network of Mercury tracking sites. These data are transmitted from the Range sites to the Goddard Space Flight Center in Greenbelt, Md., where they are processed by computers and sent to Cape Canaveral.

The TAGIS sites are connected by an extensive communication network. Almost all types of transmission media are used to provide teletypewriter communication between Cape Canaveral and every site and voice communication between Canaveral and all but five sites. In addition to the communication equipment provided by the Bell System, facilities are leased from 20 domestic and foreign common carriers with the cooperation of eight national governments.

While the over-all project management was the responsibility of the Western Electric Company, Bell Laboratories was responsible for system analysis and evaluation, control centers, a training simulator, and consultation on various technical problems. The tasks performed by the Laboratories for Project Mercury can be divided into four categories: equipment design and procurement, equipment engineering, development of operational procedures, and Range evaluation.

The equipment provided for the Project Mercury Range by the Laboratories includes the Operations Rooms at Cape Canaveral and at Bermuda, and the simulator used at Cape Canaveral to train flight controllers (RECORD, *October*, 1961). The Operations Room at Mercury Control Center, Cape Canaveral, is the focal point of the Mercury Range. Here, all information pertinent to the mission is received from all the other Mercury Range sites. The photograph on page 278 shows the Operations Room where 11 flight controllers control the activities of the Range under the direction of the Flight Director. Three of the flight controllers — the Capsule Communicator, the Capsule Systems Monitor and the Flight Surgeon—have their counterparts at 13 other Mercury sites. Whenever the spacecraft is in range of Cape Canaveral, telemetry data transmitted from the capsule actuates the displays on the flight controller consoles in the Control Center.





Mercury Control Center, Cape Canaveral. The position of the spacecraft, the status of its equipment, and the physical condition of the astronaut are continuously monitored and recorded. Such data, obtained from tracking stations around the world, are funneled into this control center.

At other times, while the capsule is orbiting the earth, the information obtained by flight controllers at various TAGIS sites is sent back to the flight controllers at the Mercury Control Center over teletypewriter circuits. Operators at the control center also insert these data on meters on the consoles and plot important quantities (such as temperatures and heart rate) from the capsule and astronaut on the status boards that flank the large map. The position of the capsule is computed at Goddard and transmitted to Mercury Control for automatic display on the map.

The four plot boards on the right side of the Operations Room are driven either by the computer at Cape Canaveral or, during the launch and during orbital flight, by the computers at the Goddard Space Flight Center. These boards display significant data regarding the trajectory of the Atlas launch vehicle and the Mercury spacecraft and aid the Flight Dynamics Officer and the Retrofire Controller in determining the condition of the flight. As the astronaut orbits the earth, flight information is transmitted from outlying sites to Mercury Control Center. Orders from the Flight Director to modify the duration of the mission are sent directly to sites that have command facilities.

A secondary control center in Bermuda determines the validity of the space capsule's orbit. If it is not apparent from data available at the Mercury Control Center whether the orbit is definitely good or definitely bad, the authority to stop or continue the mission is delegated to the Bermuda Control Center which is geographically closer to the capsule at the end of the launch phase.

After several discussions with NASA and Western Electric, Bell Laboratories prepared a specification of requirements for equipment in the Operations Rooms at Cape Canaveral and at Bermuda. The Electronics division of General Dynamics Corporation constructed and installed this equipment. By July, 1960, the Operations Rooms at both Canaveral and Bermuda were equipped and undergoing tests.

Although the major features of the Mercury system had been established by NASA, a systems-analysis group was set up in November, 1959, to review equipment performance and procedures. The group, which consisted of members of NASA, Lincoln Laboratory, and all team members, convened at the Laboratories during November and December, 1959. A formal report of the group's work was issued early in 1960, and it served as a guide for the remainder of the project.

There were continuing problems of making certain that the Range equipment was compatible with capsule equipment. An example of such a problem concerns the Acquisition Aid equipment. (This is automatic telemetry tracking gear which, because of its broad (20°) antenna beam, is usually the first to acquire the spacecraft over a site.) The Acquisition Aid was originally designed to track only the carrier frequency of the telemetry transmitter in the capsule. It was believed that the degree of modulation used in the telemetry system would provide an adequate margin of signal power at the carrier frequency. Unfortunately, it was discovered during tests that the degree of modulation was such that, for certain magnitudes of telemetered data, only a small amount of carrier signal strength was present. In these cases, the Acquisition Aid lost the signal. The problem was quickly resolved by increasing the bandwidth of the Acquisition Aid to accept the sidebands as well as the carrier frequency of the telemetry transmitter.

Another type of equipment engineering undertaken by the Laboratories was the development of diagrams to show all of the equipment used at each site to delineate their interfaces. This task, initiated by the Laboratories, was continued by a systems-engineering group composed of representatives of all members of the Mercury team. In this way, over-all site equipment diagrams obtained early in the program permitted expeditious installation.

The Laboratories also participated in the preparation of test specifications for the equipment used at the range sites. These specifications were used in testing site equipment and verifying its performance. After discussions with NASA, it was decided that three levels of testing should be provided: (1) unit tests (e.g., a radar receiver), (2) subsystem tests (e.g., the radar subsystem), and (3) integrated subsystem tests (e.g., the acquisition system comprising the radars and the Acquisition Aid). Although most of the unit tests were prepared by the team members who supplied the equipment, the Laboratories was primarily responsible for the two higher levels of tests. The 25 specifications for these tests were first tried out with actual equipment at the Mercury Demonstration Site at Wallops Island, Virginia. Several members of the Laboratories, stationed at Wallops Island during this period, checked and verified the test specifications. Subsequently, revised specifications were approved by NASA, issued by Western Electric, and distributed to all range sites. The tests were used to determine whether the equipment would satisfy the requirements of the Mercury Range and served as a basis for NASA's acceptance of the Range equipment.

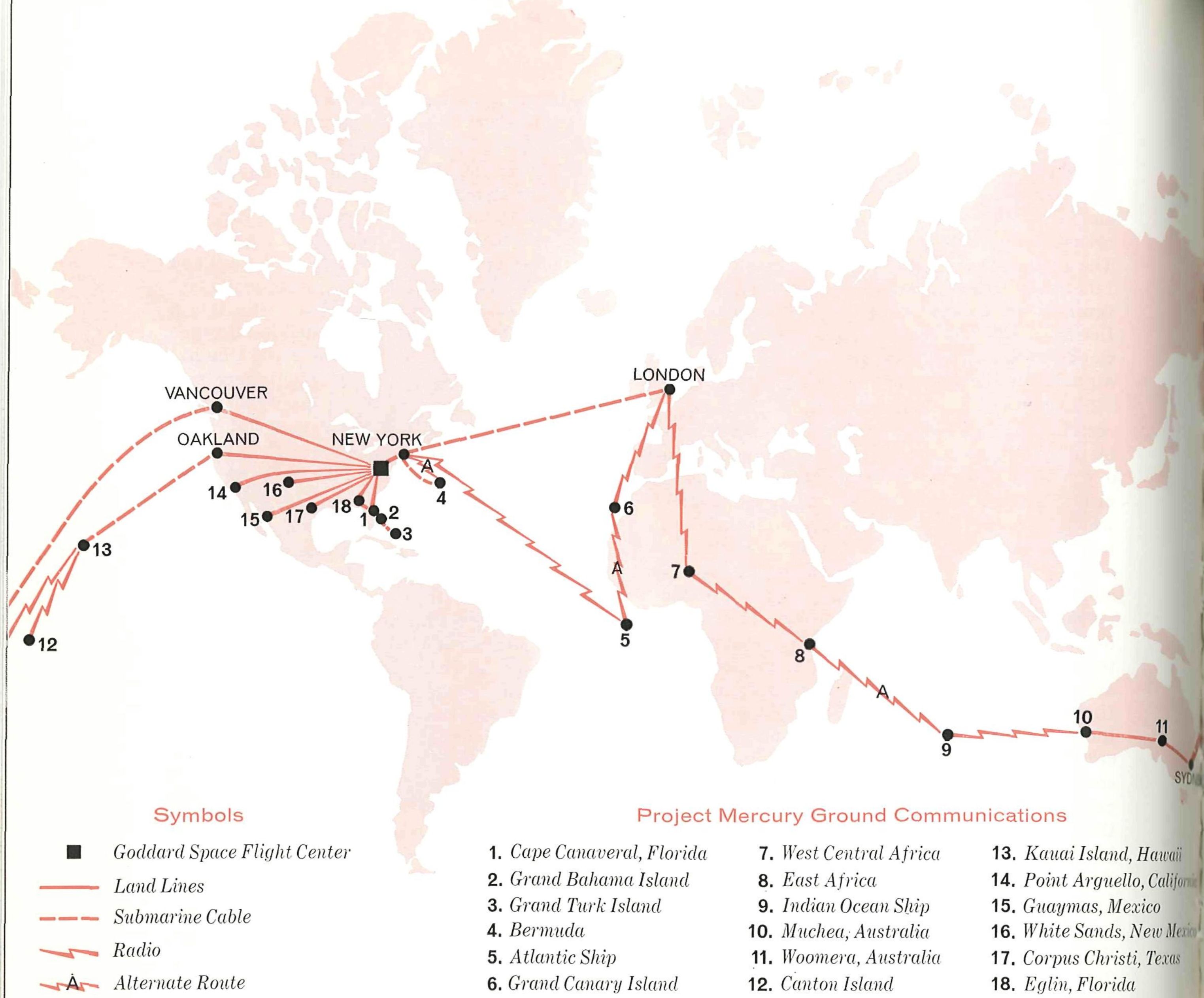
Laboratories Was Technical Consultant

As the technical consultant to the Mercury Project, the Laboratories contributed to the solution of a number of special problems involving Range equipment and operation. These studies included the investigation of interference between various units at each site, the selection of the intercom system to be used for intrasite communications, the choice of an appropriate boresight camera for the tracking antennas, the removal of interference from power supplies, and the redesigning of shipboard equipment to avoid the effects of vibration. Other special problems concerned the testing of the high-speed data lines between Cape Canaveral and the computers at Goddard Space Flight Center.

Throughout the project, the Laboratories monitored the computing and programming developments and served as advisor to Western Electric on such tasks. This work included studies of data processing, computer programming, geophysical effects upon the orbits, and the effects of radar errors on the computation.

One of the major requirements for large systems such as the Mercury Range is the definition of appropriate operational procedures. The generation of such procedures is a challenging and frustrating task. The frustration is the result of the changing character of the problem. The operational procedures were first prepared by the Laboratories, revised by Western Electric's training division, and completed by NASA under operational trials. The Laboratories prepared detailed operational plans in which the activities of the maintenance and operational personnel were prescribed for the sites at Cape Canaveral, Bermuda, Grand Canary Island, and Muchea, Australia. The NASA Space Task Group established the procedures for Flight Controllers at all sites.

One significant characteristic of the Mercury



Range is that it was the first range designed to be operated, if necessary, by teletypewriter messages alone. Previous range operations depended primarily on voice communication. This was not available to five Mercury sites. Thus, a major task was establishing the format and character of the teletypewriter messages that would be used during an operational mission. These formats, with some modifications by Western Electric and by NASA after several trials, were used in the subsequent Mercury missions.

To determine the operational adequacy of the instrumentation and manning of the remote sites of the Mercury range, a series of tests was conducted at Wallops Island during November and December, 1961. These tests, called the Demonstration Site Operational Test Series (DSOTS), simulated the passage of the Mercury spacecraft in real time over the Canary Islands. The preparation and conduct of the DSOTS was a team effort of the Western Electric Company, Lincoln Laboratory, and Bell Laboratories. All equipment, except the radar, was operated according to established procedures, and an observer monitored each operating position and noted the timing of specific events as well as the over-all efficiency of the operations.

In addition to tests with all equipment operating normally, tests were also made with programmed equipment malfunctions. One objective of these tests was to determine whether the equipment and established procedures provided the operators sufficient time to complete their tasks during a capsule pass. The tests showed that the site instrumentation and manning were generally satisfactory. However, some changes in procedures resulted. This was the first time that flight controllers worked as a team with the equipment operators, and the procedures were modified to integrate their operations.

During these tests, the site received simulated teletypewriter messages appropriate to the mission; magnetic tape activated the telemetry displays; one of the operating personnel simulated the voice of the astronaut. Antennas, pointed at the boresight tower, were made to appear to be moving on the operators' displays. This was done by inserting differential synchros between the azimuth and elevation antenna servo and the operators' display. These synchros were adjusted during each simulated pass to make the received signal appear as though it were coming from an object in transit from the western to the eastern horizon. The telemetry signal was in all cases actually radiated from the boresight tower. Attenuators in the voice and telemetry rf circuits were varied during the pass to simulate both the change in range to the spacecraft and the antenna lobe patterns. In this way, the simulated passage of the capsule over the Canary Islands site became quite realistic.

Subsequently, NASA and Western Electric used similar exercises at Wallops Island to refine the operational procedures. The revised procedures were used at each Mercury Range site for training the operating personnel.

In early 1961, after the site equipment was installed and the training program completed, NASA requested that the ability of the entire

Astronaut Walter J. Schirra indicates switch which sends signal to fire retro-rockets in spacecraft to slow it down for its re-entry and recovery.

Range to support the first Mercury mission be established. On behalf of the Western Electric Company, the Laboratories conducted a program to determine the readiness of the Mercury range to support the Mercury Atlas (MA-3) mission, which was scheduled for the Spring of 1961. The original MA-3 mission for an instrumented spacecraft was not planned to go into a complete orbit but to impact in the vicinity of the Canary Islands. Engineers from Bell Laboratories and Western Electric evaluated the condition of each site involved in the mission and monitored the conduct of Range exercises in which these sites operated together in simulated missions in real time. During these simulated missions, three types of exercises were conducted: (1) the nominal MA-3 mission, (2) an aborted mission resulting in a landing near a ship in the Atlantic Ocean and (3) an over-speed mission in which the capsule attained sufficient velocity to continue in orbit beyond the Canary Islands.

Actual Flight Tests Needed

Despite the success of the tests that were conducted, the performance of TAGIS had to be confirmed during an actual orbital flight. This proof came on September 13, 1961, with the successful single-orbit flight of the Mercury Atlas-4, an unmanned instrumented spacecraft. The flight and recovery of this capsule definitely established the over-all adequacy of the range equipment and procedures of the Mercury Range.

Since that time, the participation of the Laboratories in Project Mercury has been in connection with the communication system for the Range. This work began in July, 1961, and is an evaluation of the performance of the world-wide communication network. Computer simulation is used to determine methods of making optimum use of the TAGIS communication paths and to determine the accuracy and timeliness of messages during actual missions. In addition, the performance of the circuits having radio links is given special scrutiny to establish the effects of ionospheric propagation.

Aside from its technical challenge, work on Project Mercury at Bell Laboratories provided contact with the NASA personnel who were given the task of sending an astronaut into orbit and recovering him safely. This association convinced those involved that this task was being handled capably and that when the first astronaut journeyed into orbit around the Earth he would return safely. The performance of the Mercury Range during recent manned orbital missions amply justifies this conviction.