19. MISSION CONTROL CENTER AND NETWORK

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Summary

As planning for the Gemini Program began, the capabilities of both the Mercury Control Center at Cape Kennedy, Fla., and the Manned Space Flight Network were reviewed and found inadequate to support the Gemini rendezvous missions. A new control center with expanded facilities was required to support the Gemini missions and the advanced flight programs of the future. Major modifications to the Manned Space Flight Network were also required. Equipment used in both systems was generally off the shelf, with proven reliability. Mission results have proved both support systems to be satisfactory.

Introduction

Project Mercury established the requirement for an effective ground-control capability for unmanned and manned space flights. During the Mercury flights, a control center remotely connected to a worldwide network of tracking stations repeatedly demonstrated its speed and efficiency in reacting to the anomalies encountered.

Mercury space flights, however, involved controlling only a single vehicle with no maneuvering capability. The Gemini Program, with its multiple-vehicle rendezvous and docking maneuvers and long-duration flights, required a ground control capable of processing and reacting to a vast amount of complex data on a real-time basis. Therefore, a new control facility was established that would support the Gemini Program and the future space flight programs.

The Manned Spacecraft Center at Houston, Tex., was chosen as the site for a new mission control center to be designated "MCC–H" (fig. 19–1). However, this control center could not be placed into operation in time to support the early nonrendezvous Gemini flights. To support this phase of the Gemini Program, the facilities of the Mission Control Center (MCC–K) at Cape Kennedy, Fla., were evaluated, and it was found that, with minor modifications, they would give sufficient support.

The new mission control center was designed to effect direction and control of the Gemini flights through the Manned Space Flight Network, which is a worldwide communications, tracking, and telemetry network. This network of stations had proved its operational capabilities through the Mercury flight program but, for the more complex missions of the Gemini Program, the network would require major modifications to all of its systems. The network had to have the capability to track two vehicles simultaneously and to provide dual command data based on orbital ephemeris, orbital plane changes, rendezvous maneuvers, and reentry control to the vehicles' computers. The amount of information generated during a Gemini flight was over 40 times the amount generated and transmitted to the control center during the most complex of the Mercury flights. The primary consideration in design efforts was reliability; the ground systems would have to support long-duration flights.

Existing schedules, reliability requirements, and monetary limits required that equipment going into the new control center be of a fully developed nature, and resulted in the control center being a consolidation of off-the-shelf equipment.

The Mission Control Center at Houston was designed to perform all known control and

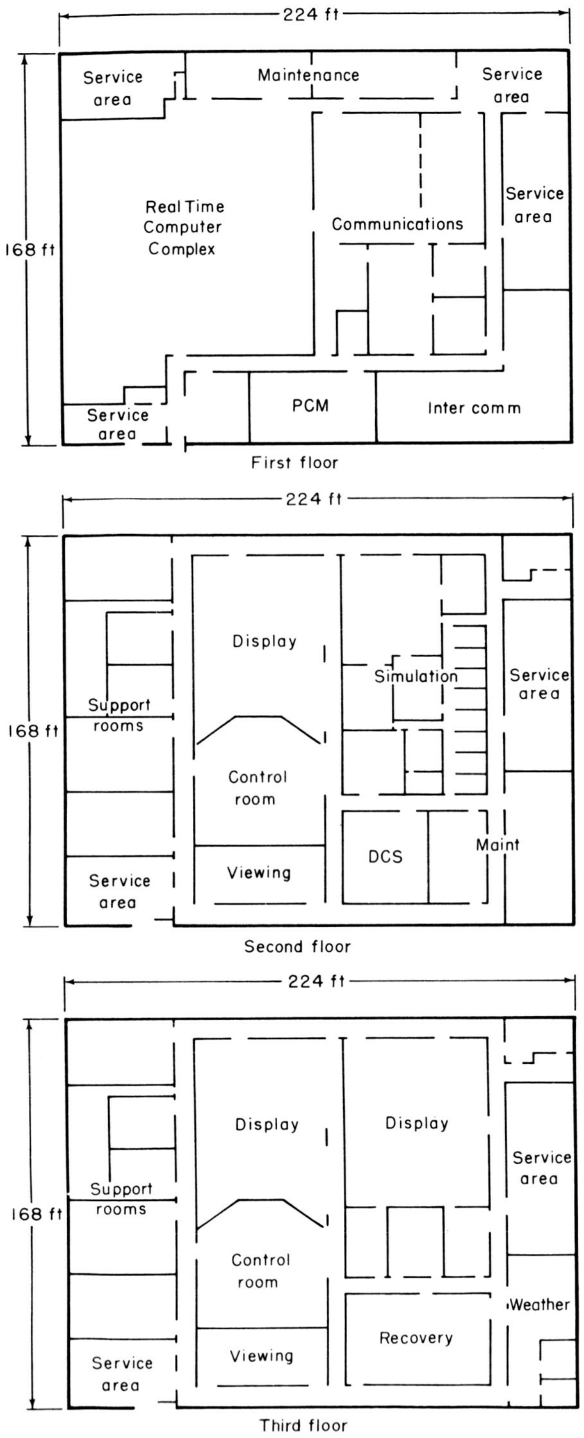

FIGURE 19-1.—Floor plan of Mission Control Center, Houston, Tex.

monitoring functions associated with manned space flight. The major requirements were—

(1) To direct overall mission conduct.

(2) To issue guidance parameters and to monitor guidance computations and propulsion capability.

(3) To evaluate the performance and capabilities of the space-vehicle equipment systems.

(4) To evaluate the capabilities and status of the spacecraft crew and life-support system.

(5) To direct and supervise activities of the ground-support systems.

(6) To direct recovery activities.

(7) To conduct simulation and training exercises.

(8) To schedule and regulate transmission of recorded data from sites.

(9) To support postmission analyses.

Development of Mission Control Center Equipment Systems

Real Time Computer Complex

The first three Gemini flights were controlled at the Mission Control Center at Cape Kennedy, but, as had been done during Project Mercury, the majority of real time computations were processed at the Goddard Space Flight Center (GSFC), Greenbelt, Md. The design of the Mission Control Center at Houston included a large increase in computer capacity to support actual and simulated missions. This increase was made necessary by the mounting number of mathematical computations required by the complex flight plans of the Gemini rendezvous missions.

The Real Time Computer Complex (fig. 19-2) was designed for data and display processing for actual and simulated flights. This computer complex consists of five large-capacity digital computers. These computers may be functionally assigned as a mission operations

FIGURE 19-2.—Real Time Computer Complex, Houston, Tex.

computer, a dynamic standby computer, a simulation operations computer, a ground support simulation computer, and a dynamic checkout computer; or they may be taken off-line and electrically isolated from the rest of the Real Time Computer Complex.

During a mission, the flight program is loaded into both a mission operations computer and a dynamic standby computer. This system allows the outputs of the computers to be switched, thus providing continued operation if the mission operations computer should fail. As the flight progresses, the vast amount of data received in the Real Time Computer Complex from the Manned Space Flight Network is translated into recognizable data displays that enable mission controllers to evaluate current mission situations and make real-time decisions.

During a mission, the remaining computers can be utilized for a follow-on mission simulation and development of a follow-on mission program.

Communications

The design of the Mission Control Center at Houston enables communications to enter and leave over commercial common-carrier lines, which are divided into five categories:

(1) Wideband data (40.8 kbps) lines handle only the transmission of telemetry data.

(2) High-speed data (2 kbps) lines carry command, tracking, and telemetry data.

(3) Teletype (100 words a minute) lines carry command, tracking, acquisition, telemetry, and textual message traffic.

(4) Video lines carry only television signals.

(5) Audio lines primarily handle voice communication between the Mission Control Center, the Manned Space Flight Network, and the spacecraft.

The Mission Control Center communications system (fig. 19–3) monitors all incoming or outgoing voice and data signals for quality; records and processes the signals as necessary; and routes them to their assigned destinations. The system is the terminus for all incoming voice communications, facsimile messages, and teletype textual messages, and it provides for voice communications within the control center. Telemetry data, routed through telemetry ground stations, are sent to the Real Time Computer Complex for data display and telemetry summary message generation. Some of the processed data, such as biomedical data, are routed directly to the display and control system for direct monitoring by flight controllers and specialists. Incoming tracking data are sent to the Real Time Computer Complex for generation of dynamic display data. Most command data and all outgoing voice communications, facsimile messages, and teletype textual messages originate within the system.

Display

The Mercury Control Center display capability required modification to support the Gemini flights. Additional flight controller consoles were installed with the existing Mercury consoles and resulted in increased video, analog, and digital display capability. The world map was updated, both in Gemini network-station position and instrumentation capability. A large rear-projection screen was installed for display of summary message data. A second large screen was provided for display

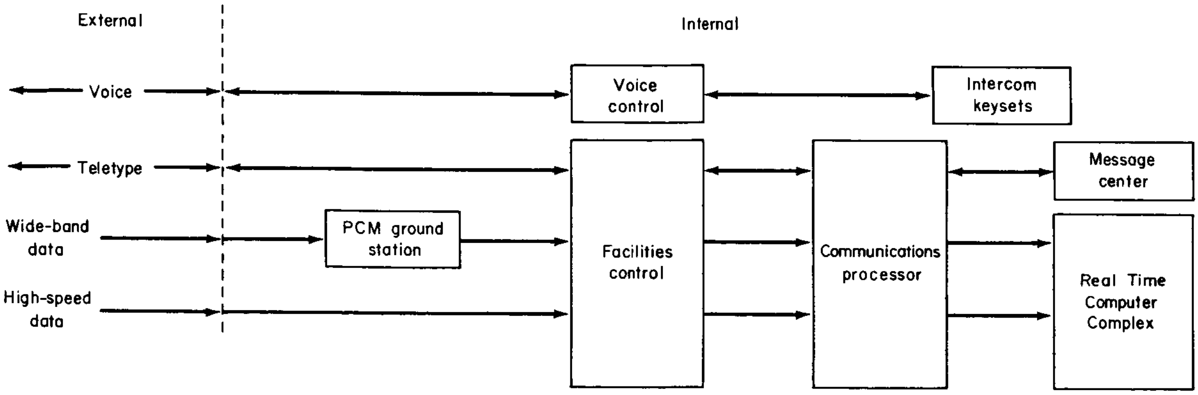

FIGURE 19–3.—MCC–H communications flow.

of flight rules, checklists, time sequences, or other group displays.

The implementation of the Mission Control Center at Houston provided major improvements in the amount and type of data displayed for real-time use by flight controllers. The display system utilizes various display devices, such as plotting, television, and digital, to present dynamic and reference information. Dynamic displays present real-time or near real-time information, such as biomedical, tracking, and vehicle systems data, that permits flight controllers to make decisions based on the most current information.

The display control system (fig. 19-4) is divided into five subsystems.

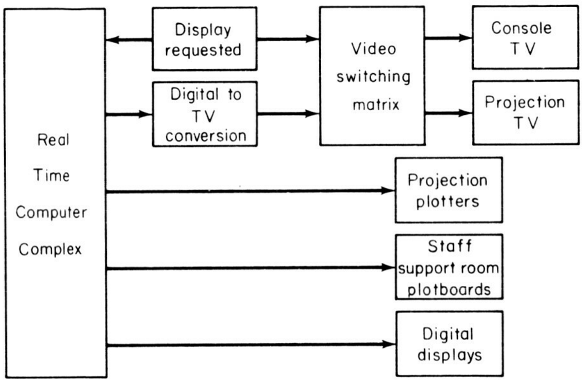

FIGURE 19-4.—MCC-H display/control subsystem.

Computer interface subsystem.—The computer interface subsystem and the real-time computer complex function together to provide the displays requested by flight controllers during actual or simulated missions. The interface subsystem detects, encodes, and transmits these requests to the real-time computer complex and, in turn, generates the requested displays, utilizing the output information from the computer complex.

Timing subsystem.—The timing subsystem generates the basic time standards and time displays used throughout the control center. The master instrumentation timing equipment utilizes an ultrastable oscillator and associated timing generators referenced to Station WWV and generates decimal, binary-coded decimal, and specially formatted Greenwich mean time for various individual and group displays. Standby battery power is provided for emergencies.

Television subsystem.—The television subsystem generates, distributes, displays, and records standard and high-resolution video information, using both digital and analog computer-derived data. A video switching matrix enables any console operator to select video from any of 70 input channels for display on his console TV monitor. The matrix accepts inputs from the 28 digital-to-TV converter channels, 11 opaque television channels, and other closed-circuit TV cameras positioned throughout the control center. Each console operator can also obtain hardcopy prints of selected television displays.

Group display subsystem.—The group display subsystem is made up of wall display screens in the Mission Operations Control Room (fig. 19-5). This system provides flight dynamics, mission status information, and reference data displayed in easily recognizable form. The system consists of seven projectors which project light through glass slides onto the large 10- by 20-foot screens. By selection of appropriate filters, the composite picture can be shown in any combination of seven colors.

Console subsystem.—The console subsystem is made up of consoles with assorted modules added to provide each operational position in the Mission Control Center with the required control and data display. The subsystem also provides interconnection and distribution facilities for the inputs and outputs of all these components, except those required for video and audio signals.

FIGURE 19-5.—Mission Operations Control Room, MCC-H.

Command

In the Gemini spacecraft, the amount of onboard equipment requiring ground control activation and termination has increased many times over that in the Mercury spacecraft. Project Mercury used radio tones for the transmission of command data; however, the number of available radio tones is limited by bandwidth and was found inadequate to support Gemini flights. Therefore, a digital system was subbit encoding is used to meet the Gemini command requirements.

At the Mission Control Center, the digital command system (fig. 19–6) can accept, vali-

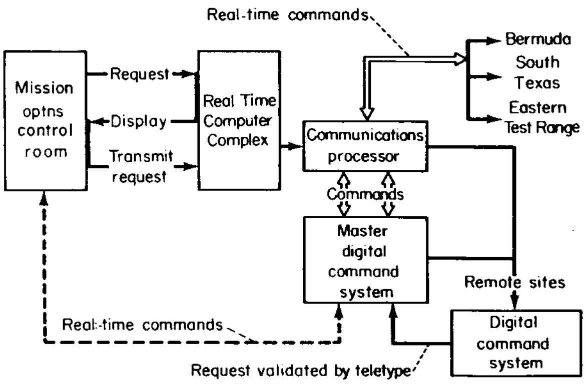

FIGURE 19–6.—Digital command system.

date, store (if required), and transmit digital command data through the real-time sites of the Manned Space Flight Network and to the remote sites equipped with digital command capabilities. The command data are transmitted to inflight vehicles or, at Cape Kennedy only, to a vehicle waiting to be launched. The system can also perform a simulated mode of operation similar to the operational modes.

Commands can be introduced into the digital-command control logic from the Real Time Computer Complex, from teletypewriter punched paper tape, or by manual insertion from the digital-command control consoles as remote control modules (located on the flight controller consoles).

Gemini Launch Data System

The Gemini launch data system was designed to provide the two Mission Control Centers with continuous command, radar, voice, and telemetry contact with the spacecraft from lift-off through orbital insertion. Inputs from three telemetry ground stations at Cape Kennedy are multiplexed with the downrange telemetry from the Eastern Test Range and are transmitted over wideband communciation lines to the Mission Control Center at Houston. In addition, real-time trajectory data can be sent to the Mission Control Center at Houston on high-speed communications lines.

Simulation Checkout and Training System

The simulation checkout and training system at the Mission Control Center in Houston allows the mission control team to perform either partial or total mission exercises. It provides for the development of mission operational procedures, the training of all personnel involved in controlling the mission, practicing the required interfaces between flight crew and mission control teams, and validation of support systems and control teams necessary during a mission.

Development of the Manned Space-Flight Network

If the requirements of the Gemini orbital and rendezvous missions were to be supported by the Manned Space Flight Network, major modifications of the network were necessary. Gemini missions required increased capability from all network systems, with exacting parameters and an exceedingly high reliability factor. To guarantee this reliability, the network was modified with proved systems that were constructed with off-the-shelf items of equipment. (See figs. 19–7 and 19–8.)

The network was required to provide the following functions necessary for effective ground control and monitoring of a Gemini flight from lift-off to landing:

(1) Communications between the network stations and the control center.

(2) Tracking and control of two vehicles simultaneously.

(3) Voice and telemetry communications with the spacecraft.

(4) Dual command data to two orbiting vehicles simultaneously.

(5) Reliability of all onsite systems for extended periods of time.

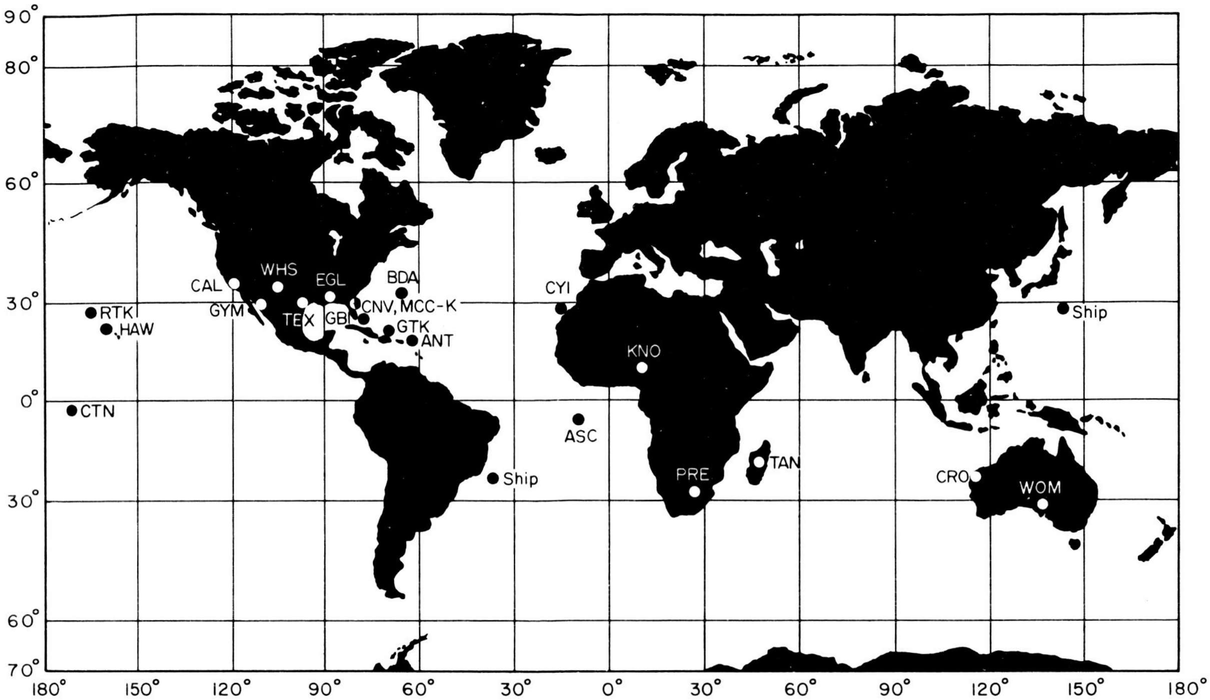

FIGURE 19-7.—Gemini network stations.

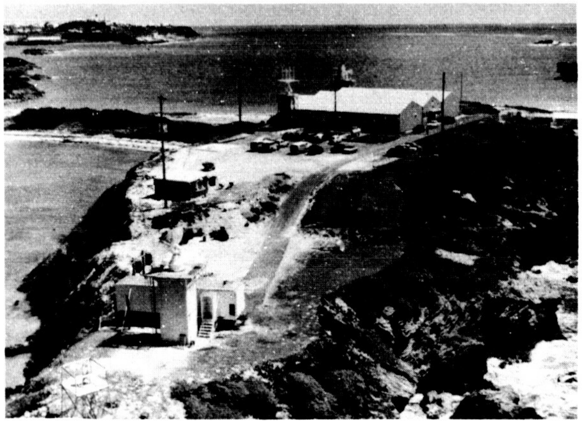

FIGURE 19-8.—Tracking station on Cooper's Island, Bermuda, West Indies.

Development of Network Equipment Systems

Radar

The network radar capability consists of the acquisition aid system and the radar tracking system.

Acquisition aid system.—For the rendezvous missions, the acquisition system must have the capability to acquire and accurately track two space vehicles simultaneously, as azimuth and elevation data from this system are used to aid the narrow-beam radars in rapidly acquiring their targets. Once the target is acquired, automatic tracking is possible, and no further acquisition assistance is required unless tracking is interrupted.

The spacecraft transmits telemetry signals in the 225- to 260-megacycle band. The signal is also used for target acquisition. The acquisition aid is a broad-beam-width antenna and does not require precise pointing to locate a target. It does, however, track with sufficient accuracy to provide pointing information to the narrow-beam radar.

The acquisition aid antenna provides not only a tracking and telemetry function but receives very-high-frequency voice communications from the orbiting spacecraft.

Although the target is normally first "seen" by the acquisition aid systems, the radar (C-band and S-band) search independently. At contact, all antennas can immediately be slaved to the system which makes acquisition first. This capability is provided by the acquisition bus system, which permits the operator of each individual system to know the status of all other antenna positions so that he can slave his equipment in azimuth and elevation to any other antenna.

Radar tracking system.—The radar tracking system provides the network and the control center with real-time information; that is, as soon as the radar has acquired the spacecraft, the operator enables a circuit and transmits the range, angle, and time data directly to the computers at the control center. These data are transmitted via teletype and high-speed data circuits.

The network radars consist of long-range, standard tracking radars that have been modified to meet manned space flight requirements. The network radar stations are equipped with

TABLE 19–I.—*Capabilities of Network Stations*

Station	Station symbol	Real-time telemetry to MCC–H	Acquisition aid	Radar	PCM telemetry ground station	Telemetry record	PAM telemetry (FM/FM) ground station	Flight controller display consoles	Digital command modulation	Radiofrequency command	Spacecraft communications (air-to-ground)	Voice	Teletype
Cape Kennedy	CNV												
Mission Control Center	MCC–K	X	X	X	X	X	X	X	X	X	X	X	X
Grand Bahama Island	GBI	X	X	X	X	X	X			X	X	(a)	X
Grand Turk Island	GTK	X	X	X	X	X				X	X	(a)	X
Bermuda	BDA	X	X	X	X	X	X			X	X	X	X
Antigua	ANT	X	X	X	X	X	X				X	(a)	X
Grand Canary Island	CYI		X	X	X	X	X	X	X	X	X	X	X
Ascension Island	ASC			X		X	X				X	(a)	X
Kano, Africa	KNO		X			X	X				X	X	X
Pretoria, Africa	PRE			X		X	X						X
Tananarive, Malagasy	TAN		X			X	X				X	X	X
Carnarvon, Australia	CRO		X	X	X	X	X	X	X	X	X	X	X
Woomera, Australia	WOM		X	X								X	X
Canton Island	CTN		X			X	X				X	X	X
Kauai Island, Hawaii	HAW		X	X	X	X	X	X	X	X	X	X	X
Point Arguello, Calif	CAL		X	X		X	X				X	X	X
Guaymas, Mexico	GYM		X	X	X	X	X	X			X	X	X
White Sands, N. Mex	WHS		X	X								X	X
Corpus Christi, Tex	TEX	X	X	X	X	X	X	X	X	X	X	X	X
Eglin, Fla	EGL		X	X		X	X					X	X
Wallops Island, Va	WLP		X	X	X	X	X	X	X	X	X	X	X
Coastal Sentry Quebec (ship)	CSQ		X		X	X	X	X	X	X	X	X	X
Rose Knot Victor (ship)	RKV		X		X	X	X	X	X	X	X	X	X
Goddard Space Flight Center	GSFC											X	X
Range Tracker (ship)	RTK			X		X					X	X	X

[a] Through Cape Kennedy Superintendent of Range Operations.

either S-band or C-band radars, or both. C-band radars operate on higher frequencies and afford greater target resolution or accuracy, while the S-band radars, operating at lower frequencies, provide excellent skin track capability.

The three principal types of radars used by the network stations (table 19–I) are the very long-range tracking (VERLORT), the FPQ–6 (the TPQ–18 is the mobile version), and the FPS–16. The S-band VERLORT has greater range capability (2344 nautical miles) than the C-band FPS–16; however, the FPS–16 has greater accuracy (±5 yards at 500 nautical miles). The C-band FPQ–6 has greater range and accuracy than the other two (±2 yards at 32 366 nautical miles).

Telemetry

Telemetry provides the flight controllers with the capability for monitoring the condition of the flight crew and of the spacecraft and its various systems.

To handle the tremendous flow of telemetry data required by Gemini rendezvous missions, eight of the network stations use pulse-code-modulated wideband telemetry instead of the frequency-modulated telemetry that was used during Project Mercury. The pulse-code-modulation data-transmission technique is used for exchanging all data, including biomedical data, between the spacecraft and the network tracking stations. Each station then selects and routes the biomedical data to the Mission Control Center in frequency-modulated form over specially assigned audio lines. Data are routed from the real-time sites in pulse-code-modulated form over wideband data and high-speed data lines to the Mission Control Center and in teletype summary form from the remote sites.

Remote-Site Data Processors

Associated with the telemetry systems are the remote-site data processors which help flight controllers keep up with the tremendous flow of information transmitted from the spacecraft. The controllers can select and examine specific types of data information on a real-time basis. The system automatically summarizes and prepares telemetry data for final processing at the Mission Control Center.

Command

The flight controllers must have some method of remote control of the onboard electronic apparatus as a backup to the flight crew. But, before the clocks, computers, and other spacecraft equipment can be reset or actuated from the ground, the commands must be encoded into digital language that the equipment will accept. This requirement led to development of the digital command system. Over 1000 digital commands can be inserted and stored in this system for automatic transmission to the space vehicles as required. Correctly coded commands can be inserted into the remote-site computers manually or by the control center via teletype data links. In addition, real-time commands can be transmitted through the command system from the control center.

Before the orbiting vehicles accept the ground commands, the correctness of the digital format must be verified. The information is then decoded for storage or for immediate use. Both the ground and spacecraft command systems have built-in checking devices to provide extremely high reliability. The space vehicles are able to accept and process over 360 different types of commands from the ground, as opposed to the 9 commands available with Mercury systems.

Communications

The Goddard Space Flight Center operates the overall NASA Communications Network (NASCOM) located around the world, and provides high-speed ground communications support for the agency's space flight missions. The Manned Space Flight Network uses a portion of the NASA Communications Network to tie together all network sites and the Mission Control Center with 173 000 miles of circuits, including 102 000 miles of teletype facilities, 51 000 miles of telephone circuits and more than 8000 miles of high-speed data circuits. Transmission rates over the network vary from 60 to 100 words per minute for teletype language to 2000 bits per second for radar data. The radio voice communications system at most stations consists of two ultrahigh frequency (UHF) receiving and transmitting systems and two high frequency (HF) transmitters and receivers for communications between the sites and the spacecraft.

Consoles

Five types of remote station consoles are included in the control rooms.

Maintenance and operations console.—The maintenance and operations console is used by the maintenance and operations supervisor. He is responsible for the performance of the personnel who maintain and operate the electronic systems at the station.

By scanning the panels, the maintenance and operations supervisor knows immediately the Greenwich mean time and the Gemini ground elapsed time since lift-off. Also available on the panel are pulse-code-modulated input/output displays, as well as controls with which the supervisor can select any preprogramed format that the pulse-code-modulation telemetry can receive.

On the right side of the maintenance and operations panel are status displays for the various electronic systems at the station. Through use of the internal voice loop, the supervisor can verify the RED or GREEN status of the systems.

Gemini and Agena systems monitor consoles.—Two consoles monitor Gemini and Agena systems. One console is the Agena systems monitor (to be used for rendezvous missions), and the other is the Gemini systems monitor. Identical in design, the two consoles display telemetered information and permit command of the vehicle events. Forty-five indicators on each console show vehicle parameters such as spacecraft attitude, fuel consumption, temperature, pressures, radar range, and battery current or supply. Meter alarm circuits generate audible signals whenever an indication exceeds the predetermined limits. To provide distinct signals for each console, the audible tones can be varied by adjustment of the oscillators.

Command communicator console.—The command communicator console is operated by the director of the flight control team and provides command control of certain spacecraft functions. In addition to having the displays and switches that the system consoles have, this console has nine digital clocks, including indicators for Greenwich mean time, ground elapsed time, and spacecraft elapsed time. Greenwich-mean-time concidence circuitry in the console allows presetting a time at which the time-to-retrofire (T_R) and the time-to-fix (T_F) clocks of the space vehicles will be automatically updated by the digital command system.

To convert telemetry information into teletype format, a pushbutton device is provided on the console. With this device, the Flight Director instructs the computer on which summary messages are to be punched on paper for teletype transmission.

Aeromedical monitor console.—The aeromedical console is monitored by one or two physicians. Displayed on this console are the physiological condition of the two orbiting astronauts and the operational condition of the onboard life-support systems.

As the Gemini spacecraft circles the earth, the console operators closely watch the fluctuations of four electronically multiplexed electrocardiogram (EKG) signals on the cardioscope. This display provides information concerning the heart functions of both astronauts.

As long as the spacecraft remains within tracking range of a station, the observers follow the electrocardiograms and blood pressures of the astronauts as charted on the aeromedical recorder. They also check the cabin pressure and oxygen consumption indicated on the dc meters, and they monitor the respiration and pulse rates of the astronauts.

Concluding Remarks

The performance of the Mission Control Centers at Houston and Cape Kennedy and the Manned Space Flight Network in supporting the Gemini Program has been completely adequate. In particular, the phase-over from the Mission Control Center at Cape Kennedy to the one at Houston during the early Gemini flights did not present any major problems. Operational failures did occur, particularly during long-duration missions. In all cases the redundancy and flexibility of the equipment have prevented any serious degradation of operational support.