TELEMETRY AND COMMUNICATIONS TO APOLLO FLIGHT CONTROLLERS

ALAN GLINES and JOSEPH A. LAZZARO
Flight Control Division
NASA Manned Spacecraft Center
Houston, Texas

I. Summary The focus of this paper is on the use of telemetry and communications as essential tools in Apollo flight operations. The operational capabilities of the spacecraft and ground systems are described briefly to provide a background for detailing the management of the Apollo data system. The Mission Control Center is the central point of the operations and the recipient of all real-time Apollo data. Therefore, the operational structure within the mission operations control room is outlined briefly, with emphasis on the flight controllers who are the prime users and manipulators of telemetry data. The Instrumentation and Communications Officer (INCO) and the Operations and Procedures Officer (PROCEDURES) in the mission operations control room are responsible for the compatibility control of both the spacecraft and ground telemetry and communications systems. Their mission duties in four areas are detailed: (1) space-vehicle/ground communications compatibility, (2) telemetry subcarrier and bit-rate control, (3) spacecraft antenna management, and (4) data retrieval. The INCO and the PROCEDURES, through effective management of the many communications-systems modes of operation, maximize the amount of preferred real-time and playback data being transmitted to the Mission Control Center. The importance of the data is illustrated by specific mission events f rom the Apollo 11, 12, and 13 missions.

II. Introduction The NASA experience gained throughout Project Mercury and the Gemini and Apollo Programs has demonstrated the effectiveness of conducting manned space-flight operations from a centralized flight-control facility staffed by highly qualified flight-control personnel. With this approach, a strategically placed worldwide network of highly instrumented tracking and communications sites provides the data paths between the inflight space vehicles and the Mission Control Center. These data paths handle telemetry, voice, TV, tracking information, and digital commands. The uplink and downlink of these data are in real time. The term real time, as used in flight operations, means that the data are being transmitted, processed, and presented in usable form at essentially the same time that the data events occur. The time delay is small enough (within a few seconds) to allow corrective action to be taken or recommended, if required.

Real-time telemetry and communications are the primary tools used in Apollo flight operations. Three areas are emphasized in this paper:

1) A description of the Right-control operation with emphasis on the flight controllers who are prime telemetry users.

2) A brief functional description of the Apollo data system for transmitting data between the space vehicle and the flight-controller consoles.

3) A detailed description of space-vehicle/ground-data-system management from the Mission Control Center.

III. Acronyms and Callsigns

AFD	Assistant Flight Director callsign
ARIA	Apollo range instrumentation aircraft
BOOSTER	Saturn Launch-Vehicle Systems Engineer callsign
CAPCOM	Capsule Communicator or Spacecraft Communicator callsign
CCTV	Closed-circuit TV system
cm	Command module
CONTROL	LM Guidance, Navigation, and Control Systems Engineer callsign
CSM	Command and service module
DOD	Department of Defense
DSC	Dynamic standby computer
DSE	Data storage equipment on board the CSM
D/TV	Digital-to-TV display system
EECOM	Electrical and Environmental Officer callsign
EMU	Extravehicular mobility unit
EVA	Extravehicular activity
FAO	Flight Activities Officer callsign
FDO	Flight Dynamics Officer callsign
FLIGHT	Flight Director callsign
GNC	CSM Guidance, Navigation, and Control Systems Engineer callsign
GSFC	Goddard Space Flight Center
GUIDO	Guidance Officer callsign
INCO	Instrumentation and Communications Officer callsign
IU	Instrumentation unit
LBR	Low bit rate
LGC	LM guidance computer
LM	Lunar module
MCC	Mission Control Center
MOC	Mission operations computer

MOCR	Mission operations control room
MSFN	Manned Space Flight Network
NETWORK	Network Controller callsign
OMNI	CSM or LM omnidirectional S-band antenna
PROCEDURES	Operations and Procedures Officer callsign
PTC	Passive thermal control
RETRO	Retrofire Officer callsign
RTCC	Real-time computer complex
SSR	Staff support room
SURGEON	Flight Surgeon callsign
TELMU	LM Electrical, LM Environmental, and PLSS Systems Engineer callsign
USB	Unified S-band

IV. Mission Control Center Operations The centralized flight control facility is called the Mission Control Center (MCC) and is located at the NASA Manned Spacecraft Center near Houston. During a mission, the MCC contains those flight-control personnel necessary to accomplish the operations and management responsibilities from lift-off to splashdown. The focal point of the building is the mission operations control room (MOCR), where the prime control positions are located in four rows of consoles (fig. 1). Three operations groups are located in these four rows. The Mission Command and Control Group occupies most of the positions in the third and fourth rows. Management of MCC operations, Manned Space Flight Network (MSFN) equipment and personnel, the astronauts' flight plan, and Department of Defense (DOD) personnel is the function of most of this group. The Systems Operations Group (located mostly in the second row) is responsible for monitoring the operation of all onboard spacecraft and launch-vehicle systems ' The Flight Dynamics Group in the first row assures that the space vehicle maintains the desired trajectory during all mission phases. All course corrections also are determined by this group.

Adjoining the MOCR are staff support rooms (SSR) that contain consoles manned by systems specialists who assist specific MOCR positions. From the real-time data available on their consoles, SSR personnel perform data analyses, analyze long-term performance trends, compare these trends with base-line data, and relay this information with recommendations to their respective MOCR leader.

Communications systems, including telemetry, on the command and service module (CSM), lunar module (LM), and extravehicular mobility unit (EMU) are the responsibility of the INCO. The PROCEDURES and the INCO share a console in the third row and are responsible for MCC/MSFN interface procedures and configuration control. They are both part of the Systems Operations Group. More detail on the duties of the PROCEDURES and the INCO is given in the section on Apollo Data System Management.

The operational structure shown in figure 1 – with the Systems Operations Group monitoring the real-time telemetry from space-vehicle systems, the Flight Dynamics Group tracking and perfecting the space-vehicle trajectories, and the Mission Command and Cbntrol Group managing the many facets of the operation – assures the optimum use of the primary ground-support tool: real-time telemetered data.

V. Apollo Data Flow In order for the many types of Apollo information to be exchanged between the MCC and the inflight spacecraft, a complex system exists that consists of (1) onboard transceivers and antennas; (2) MSFN antennas and communications equipment; and (3) MCC data processing, control, and display equipment. This system transmits telemetry, voice, TV signals, tracking data, and commands. Biomedical data monitored by the SURGEON are included in the general category of telemetry in subsequent discussions. Although communications with the launch vehicle are maintained until impact of the Saturn IVB (S-IVB) stage on the lunar surface, communications with the two spacecraft are of prime importance during Apollo missions and are the emphasis of the remainder of this paper.

A. Spacecraft-to-MCC Data Flow: The complete downlink of each spacecraft can be received by any MSFN ground station (fig. 2). From the operational standpoint, there are two types of full uplink- and downlinkcapability stations: the ten 30-ft sites and the three 85-ft sites. The “30 ft” and “85 ft” refer to the diameter of the unified S-band (USB) antenna at that site. The 30-ft sites are used primarily for the earth-orbital phases of the lunar missions, and the 85-ft sites (with redundant 85-ft dishes) support the lunar phases. The locations[1] of the 85-ft sites allow continuous spacecraft communications beyond a distance of 4000 n. mi., except during periods of lunar occultation. Two of the three 85-ft sites have the additional use of 210-ft antennas for improving the downlink composite transmissions. These antennas normally are scheduled to be used only during critical lunar phases of the mission when the additional 9-db gain is of the greatest importance in maintaining a solid lock on the highbit- rate telemetry.

Some additional capability is gained from the ships and aircraft that act as tracking and communications sites. The U. S. N. S. Vanguard, a highly instrumented seagoing vessel, has the greatest advantage as a tracking site because of its far-reaching geographic mobility. The Vanguard is used for support primarily during the earth-orbital phases of each mission. The ship is a 30-ft site with full uplink and downlink capability and

---

[1] The 85-ft sites are located at Goldstone, Calif.; Madrid, Spain; and Honeysuckle Creek, Australia (near Canberra).

transmits high-speed mission data to the MCC through a communications satellite to the Goddard Space Flight Center (GSFC).

During the translunar-injection and reentry phases, Apollo range instrumentation aircraft (ARIA) are used to relay voice communications between the spacecraft and the ground. They also record spacecraft telemetry data for subsequent playback to MCC. The ARIA supplement ships and land-based stations by tracking in selected areas of the earth not covered by MSFN.

The prime responsibility for the uplink and downlink of one spacecraft is assigned to one site. The telemetry data path from each site to the MCC consoles is similar to that for the other types of information and serves as the best example for tracing the data.

At a site, the telemetry is received at 51.2 kbps from the spacecraft, decommutated, and routed to a Univac 642B telemetry computer for reformatting the frames into tables. The tables then are transmitted over two high-speed lines at 2.4 kbps to Univac 494 communications processors at GSFC (fig. 3). The GSFC is the central control point for MSFN and, as such, receives all MSFN data. The Univac 494 at GSFC receives the 2.4-kbps streams from each of the two actives sites (one tracking the CSM and one the LM) and reformats and combines the four data streams for real-time transmission to one of three similar Univac 494 processors at the MCC. The transmission between the Univac 494 processors at GSFC and MCC uses a prime and an alternate 50.0-kbps wide-band data line (fig. 3).

B. MCC Data Flow and Display Devices: Receipt of the telemetry by the MCC Univac 494 communications processor is the first step in the internal MCC flow of data. The Univac 494 takes the wide-band data and decommutates, repacks, converts certain analogs to percent-full-scale, performs some truncation, and routes the data to the real-time computer complex (RTCC). The RTCC consists of five IBM System 360/75 data processors, any two of which are used for mission support. One is termed the mission operations computer (MOC) and accomplishes all telemetry, trajectory, and command processing and routing. The second is a dynamic standby computer (DSC) and parallels all processing functions of the MOC. In the event of a failure of the MOC, the DSC becomes the MOC and another IBM System 360/75 is activated as a DSC. The MOC performs all necessary calculations and conversions on the telemetry for final display, in various forms, to the flight controllers. These computers comprise the basic data receiving, processing, and routing elements in the MCC (fig. 3). The total time required for a telemetered parameter to get from the spacecraft transmitter to a flight-controller console is approximately 3 sec.

After processing, the telemetry data are converted and limit-sensed for real-time display, in various forms, to the flight controllers. The most used and most important display device in the MCC is the closed-circuit TV system (CCTV). The CCTV consists of TV monitors on all consoles in the MOCR and in each SSR; each console can accommodate as many as three monitors. The 80-channel system has two general sources. The first source is the digital-to-television (D/TV) subsystem, which converts all real-time telemetry, tracking, and command data outputted from the MOC to TV display formats. The MOC updates these displays once per second, regardless of the spacecraft bit rate. Although 80 TV channels are available, a maximum of 40 channels is available for the D/TV system; and, of these 40, only 28 can contain telemetered information. The versatility of the system is illustrated by the fact that approximately 400 telemetry display formats are available for the 28 channels. Other display devices in the MCC are digital timers, event lights, X-Y plot-boards, projection plotters, meters, and chart recorders.

VI. Apollo Data System Management The management and configuration control of the Apollo data transmissions between the spacecraft and the MSFN site are the responsibility of the INCO. Included in this responsibility are the configuration and proper functioning of the CSM, LM, and EMU communications equipment and the configuration of all MSFN sites. The PROCEDURES and two communications-systems engineers in an SSR assist the INCO in this function. Specific real-time tasks that fulfill this responsibility are (1) MSFN configuration planning and control, (2) spacecraft antenna management and telemetry bit-rate control, and (3) digital-command control of onboard-recorded CSM and LM telemetry.

A. Spacecraft/MSFN Communications Modes: One of the more important responsibilities of the INCO concerns the compatibility of the communications systems between the MSFN and the space vehicles. The INCO maintains overall cognizance and control of both the total spacecraft downlink and the ground configuration required to support that downlink. The elements of the communications systems requiring control are voice, live PCM telemetry, playback PCM telemetry and voice, tracking data, commands, and TV. Radar tracking data[2] do not require spacecraft/MSFN compatibility control because these data are passive from a spacecraft standpoint. On board the spacecraft, switches control the absence or presence of all the previously listed communications channels. The INCO has additional command control of the onboard voice, live PCM telemetry, playback PCM telemetry and voice, and tracking data as well as the S-band power amplifier.

The large number of possible ground-system configurations with all the normal, first backup, and second backup methods of uplinking and downlinking any combination of

---

[2] The radar data originate at each MSFN site and reach the MCC the same way as telemetry data (i.e., 2.4 kbps to GSFC, 50 kbps to MCC). The Flight Dynamics Officer (FDO) selects the radar data as required for his trajectory analysis.

the previously listed communications channels for either spacecraft has led to the creation of a mode-number identification system for the most used S-band ground and spacecraft configurations. Extensive premission planning determines most onboard and MSFN configurations; however, the INCO frequently must change modes to maintain adequate communications performance. If possible, all commands executed by INCO are relayed by voice to the active MSFN site through the Network Controller (NETWORK) in advance of a change requirement. Also, before each MSFN site acquires the spacecraft, NETWORK transmits (via teletype) the updated site configuration to that site. In some contingency situations, such as a MSFN equipment failure or an initial failure to switch antennas during the passive thermal control (PTC) mode,[3] the INCO may verbally request new configurations by speaking directly to the active MSFN site. In this way, the INCO, during both planned and nonnominal parts of the mission, maintains efficient spacecraft/ ground compatibility and, therefore, optimum communications with the spacecraft throughout the flight.

(PTC) mode,[3] the INCO may verbally request new configurations by speaking directly to the active MSFN site. In this way, the INCO, during both planned and nonnominal parts of the mission, maintains efficient spacecraft/ground compatibility and, therefore, optimum communications with the spacecraft throughout the flight.

B. Spacecraft Communications Systems Control: Management of the communications systems onboard the CSM requires constant attention. To relieve the flightcrew of this routine time-consuming task, the capability to control the S-band system by digital command from the INCOI s console has been implemented.

The telemetry portion of the CSM downlink is controlled with PCM high- and low-bit-rate commands and a PCM subcarrier on/off command. In the LM, all communications functions, including PCM bit rate and subcarrier control, are controlled by onboard switches. However, most LM telemetry bit-rate changes are planned premission and are listed in the crew’s onboard checklist.

Spacecraft antenna management consumes a large percentage of the INCO’s time during mission phases. During most of the translunar-coast and transearth-coast phases, the spacecraft is in a PTC mode in which the X-axis (nose-to-tail axis of the CSM) is perpendicular to the earth-sun plane. The reaction control jets, with an initial burst, cause a slow roll of the spacecraft to evenly distribute the heat of the sun over the spacecraft surface. Hence, PTC is maintained with a roll rate of one revolution every 20 min.

---

[3] A change of the uplink mode to command-only increases the circuit margins and modulation index to enhance the probability that the slowly rotating spacecraft will receive a second or third omnidirectional-antenna (OMNI) switch-command.

Maintaining continual communications with the vehicle in PTC requires frequent changing of antennas. Although the flightcrew has the switching capability, the INCO controls the routine task of antenna switching for two reasons: (1) when the crew is awake, they have little time to perform the many required tasks, and (2) astronaut sleep is not compromised by antenna switching.

Two of the four S-band OMNI antennas (mounted 180° apart) are the antennas used for PTC. As the active OMNI rolls out of view of the earth, the INCO commands a switch to the soon-to-appear OMNI through the disappearing active OMNI. To minimize the loss of telemetry data, low bit rate is commanded before the OMNI switch when the signal strength descends below the high-bit-rate threshold and communications systems circuit margins become marginal. The percentage of high-bit-rate telemetry for each PTC revolution decreases as the spacecraft distance from earth increases. Because of low signal strength and negative circuit margins at lunar distance, flight controllers experience complete communication losses for as long as 1 or 2 min during the switching between the two PTC OMNI antennas.

During PTC, the INCO takes his cue for each command execution from several sources. The command from high to low bit rate is prompted by a drop in the signal strength to below the high-bit-rate threshold. The uplink signal strength is displayed digitally on his spacecraft telemetry TV display. Downlink and uplink signal strengths from the active 85-ft site are available on calibrated percent-full-scale meters on his console. As the signal strength drops below threshold, data dropouts also will appear on the telemetry display. The INCO’s primary cue to switch the antennas is the uplink signal strength; the point just before the uplink signal strength drops below the command uplink threshold (or loss of the command capability) is the optimum time. An additional, very subjective cue is the presence of noise from the voice subcarrier. The INCO’s spacecraft-antenna look-angle D/TV display also provides assistance. Telemetered spacecraft attitude drives this display, which depicts (both digitally and graphically) the spacecraft antenna look angle to the active MSFN site. Continual MCC computer calculations update the look angle every 12 sec in additional coordinate systems.

The remainder of the real-time antenna-management task deals with the CSM high-gain antennas and the LM steerable antenna. Only the flight-crew can control these antennas with their selectable antenna pitch and antenna yaw dials. When the earth signal is being tracked automatically from ground transmitters, these controls are inactive. Initial lockup of these antennas is made by the crew manually dialing in predetermined pitch and yaw angles. The astronaut has two sources for the correct antenna pitch and yaw angles for locking the antenna onto the earth signal: (1) the MCC can relay the angles directly from the INCO’s look-angle display, or (2) a short subroutine entry into the onboard guidance computer can give the astronaut the same angle read-out. To minimize loss of communications, the crew locks the antenna onto the earth signal before the switch from the OMNI to the high-gain antenna. Except for the Apollo 13 mission, the two LM OMNI antennas normally are not required for PTC; therefore, no INCO command capability exists for these antennas.

In short, the INCO is able to optimize the task of spacecraft anterma management through the use of such telemetry-dependent devices as digital uplink signal strength, uplink and downlink signal-strength meters, and digital and graphic spacecraft-antenna look-angle displays.

C. Data Retrieval: To prevent voice and telemetry dat a losses from occurring during periods of lunar occultation, negative station contact, and critical mission maneuvers, the command module (CM) is equipped with a data-storage-equipment (DSE) tape recorder. The DSE can record scientific data, digital clock data, and CM/LM voice and PCM digital data on its 14 parallel tracks. A VHF RF link allows recording of LM data on the CM DSE. The recorded information subsequently is transmitted down (dumped) to selected S-band stations by INCO-executed commands. As the voice and telemetry data are received at a MSFN site, they are routed to multichannel magnetic tape recorders where the information is retained. In this way, a permanent record of the mission is provided.

In addition to the dumped DSE information, all real-time spacecraft voice and telemetry data also are received and stored on the multichannel magnetic tape recorders. The MCC flight controllers, therefore, can accomplish a detailed analysis of past mission events by requesting tape playbacks from the MSFN site to the MCC. These requests are made to the PROCEDURES, who, after giving consideration to the location of the data, the type of data requested (CM PM, LM PM, LM FM, CM DUMP, etc.), the desired high-speed data format, and other pertinent items, coordinates the data-flow effort from the MSFN sites to the MCC console displays. The. MCC has the capability of simultaneously monitoring both real-time and playback data by processing the playback information through a special set of RTCC buffers and displays.

VII Telemetry Support of Mission Events Through management of the communications modes, onboard communications systems, and playback data, the PROCEDURES and the INCO maximize the amount of preferred data being telemetered to the MCC. The importance of these data and of this system can best be appreciated by examining the following specific mission events that occurred during the Apollo 11, 12, and 13 missions.

A. Apollo 11 Descent: During Neil Armstrong' s and Edwin "Buzz" Aldrin's descent to the lunar surface on the Apollo II mission, telemetry proved to be invaluable. The Guidance Officer (GUIDO) was monitoring all his displays concerning the operation of the critical LM Guidance Computer (LGC) when a total data loss occurred just before the LM powered descent began. As data returned and the powered descent continued, the GUIDO noted an overspeed of 20 ft/sec that the LGC had not yet noted. Extraneous onboard rendezvous-radar data fed to the LGC caused the first computer program alarm. The complexity of the descent operation in the computer and the extraneous radar data caused continuous overload alarms in the computer. The third alarm prompted the concern of a very busy Neil Armstrong, who called down “for a reading on these program alarms. 11 Because telemetry provides the GUIDO a better picture of the overall LGC operation than is available to the astronauts, the GUIDO was able to give an immediate”... go on that alarm, 11 thereby averting a possible abort of the Apollo 11 lunar landing.

B. Apollo 12 Lift-Off: The Apollo 12 space vehicle lifted off the pad at Kennedy-Space Center at 11: 22 a. m. e.s.t. on November 14, 1969. Thirty-six and one-half seconds into the mission, lightning struck the CSM, causing a total loss of the downlink. Seconds later when voice capability returned, Charles “Pete” Conrad reported numerous caution and warning lights on board. At 52 sec, the crew reported loss of the inertial guidance platform reference. At 60 sec, the ground locked onto the telemetry signal again but few data were available. The failure of the primary signal-conditioning equipment prevented diagnosis of the power problem. The Electrical and Environmental Officer (EECOW) requested that the crew switch to the secondary signal-conditioning equipment and, at 98 sec, all telemetry was restored. From the telemetry displays, the EECOM immediately saw the problem: all three fuel cells had disconnected from the main buses. The main electrical loads of the spacecraft were drawing power from two of the three batteries used for reentry power. The EECOM requested that the crew reset all three fuel cells. Fuel cells one and two went back on the line at 144 sec; fuel cell three at 171 sec. The main bus voltages rose to approximately 30 v, and all electrical parameters returned to normal. Later, a new guidance reference was transmitted to restore the spacecraft to normal. The flight controllers’ trained reactions to the restored telemetry allowed a quick recovery from a serious situation.

C. Apollo 13 CSM Oxygen-Tank Failure: At approximately 56 hr into the somewhat uneventful flight of Apollo 13, the crew had just finished a TV broadcast and a checkout of the LM and were preparing to take some lunar photographs when James Lovell interrupted a conversation between John Swigert and the ground with the report “Houston, we have a problem.” A rupture had just occurred in the service module of one of two oxygen tanks that fed the fuel cells. The pressure was soon zero in that tank and descending in the only other tank. Efforts by the flight controllers to isolate or in some way to salvage the electrical power system were to no avail. The telemetry displays on all consoles showed that the CM electrical power was being slowly depleted. Activation of the LM as a lifeboat for the remainder of the mission was the next action. Analysis of the telemetry from the LM showed that conservation of all consumables would be required to return the astronauts safely to earth; therefore, all systems not required for life support or communications were turned off. The telemetry data rate was reduced to low bit rate. The S-band power amplifier was turned off, causing noisy but readable voice. Additional 210-ft antenna support was secured from the Australian government. The normal use of the Goldstone, Calif., 210-ft antenna was diverted to support the disabled Apollo 13 spacecraft. Late in the return voyage, an activation of the CM showed (via telemetry) that the CM was capable of reentry under its own battery power. The postmission analysis of telemetry was one of the primary means of determining the cause of the tank rupture. The successful return of the Apollo 13 crew was the climax in the most rigorous and critical use of telemetry and ground-support equipment and personnel in the Apollo Program to date.

D. Apollo 13 LM OMNI Switching: The significance placed on telemetered data is illustrated by an Apollo 13 incident that occurred approximatelylO9hrintothemission. The three-man crew was 34 hr from splashdown in a two-man LM attached to a powerless CSM. Passive thermal control was revolving the LM/CSM combination at the rate of one revolution every 20 min. The low-bit- rate data were, for the most part, uninterrupted. The flightcrew was switching between the LM forward and aft OMNI antennas every 10 min to maintain communications. At 109 hr, the burst disk in the supercritical helium tank ruptured as expected, venting the remaining 27 lb in the tank. The supercritical helium was used for its intended purpose of pressurizing the descent-stage propellants only during a short return-to-earth burn. The venting imparted an unexpected propulsive force to the spacecraft such that the PTC rate was stopped and reversed to a rate of one revolution every 2 min. The problem that resulted from this expected rupture was that the crew’s frequency of antenna switching now increased to a switch every minute. When the crew was told that half as much low-bit-rate data would satisfy the flight controllers if they tired of switching the OMNI antennas every minute, James Lovell, who was the only crewman awake at the time, replied, “That’s okay. It’s not very much trouble. That’s all we’re doing anyway. We’ll try to keep up with it.” Although tired, cold, and cramped, James Lovell, John Swigert, and Fred Haise realized the importance of the telemetered data and were willing to control the antenna system to provide as much data as possible.

VIII. Concluding Remarks Although voice communications with the flightcrew are essential, telemetered information from inflight space vehicles is the most important tool in the accomplishment of Apollo flight operations. Redundant spacecraft transmitters and a complex high-speed ground data system provide large quantities of real-time information to a specialized team of flight controllers who are trained to respond to all flight situations. In the MCC Systems Operations Group, the PROCEDURES and the INCO devote all their time to managing the onboard and ground communications systems to provide the maximum amount of data to the flight-control team. The remainder of this group monitors and evaluates the 1200 parameters that are updated once each second. The Apollo hardware and manpower commitments described in this paper emphasize the fact that telemetry and communications are tools that are centrally important to the success of the Apollo Program.

IX. Bibliography

E. F. Kranz and J. O. Covington, “Flight Control in the Apollo Program,” Astronaut. Aeron., vol. 8, no. 3, pp. 64-71; March, 1970.

M. P. Frank, “ Flight Control of the Apollo Lunar- Landing Mission,” NASA TM X-58036; December, 1969.

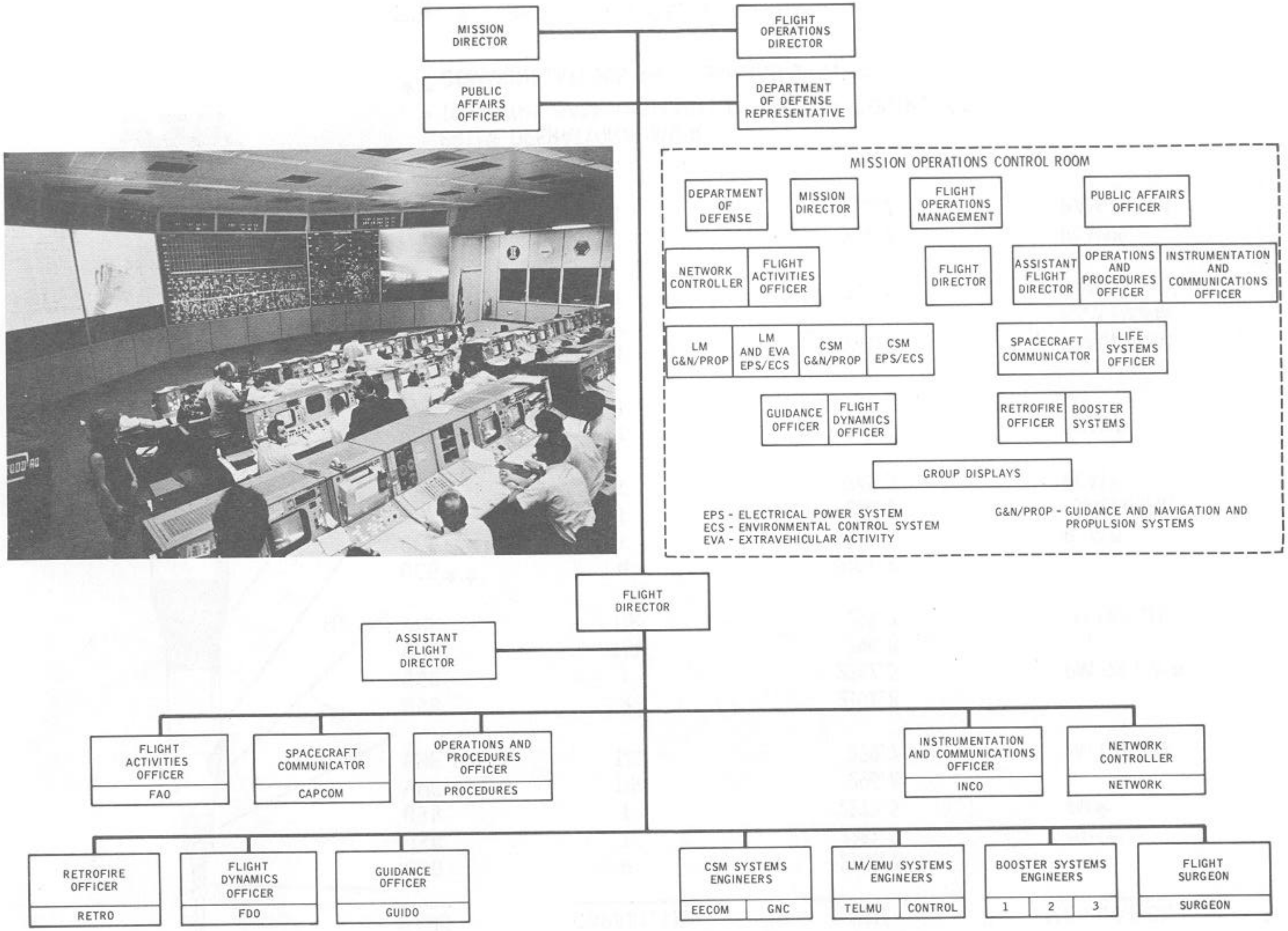
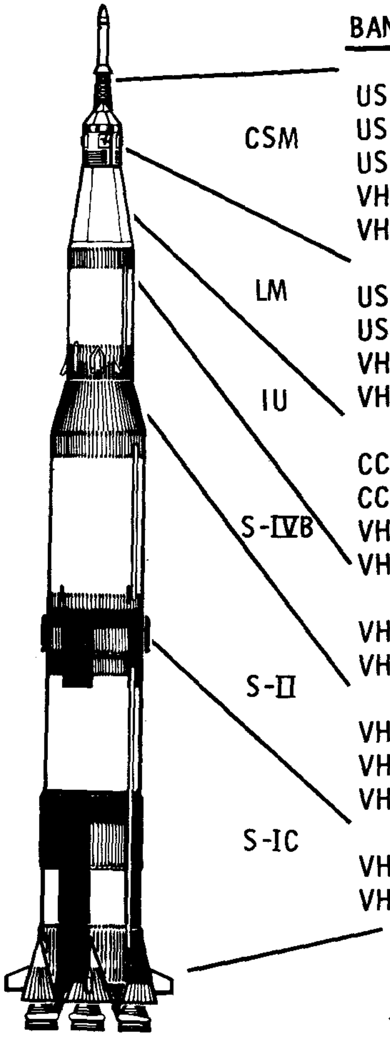


Fig. 1 - Layout and operational structure of the MOCR.



	BAND	TRANSMIT/ RECEIVE CAPABILITY	FREQUENCY, MHz	MODULATION
CSM	USB	R	2106.4	
	USB	T	2287.5	PM*★
	USB	T	2272.5	FM★
	VHF	T/R	296.8	
	VHF	T/R	259.7	LM LBR (R)
LM	USB	R	2101.8	
	USB	T	2282.5	PM OR FM*★
	VHF	T/R	296.8	
	VHF	T/R	259.7	LM LBR (T)
IU	CCS★★	R	2101.8	
	CCS★★	T	2282.5	PCM★
	VHF	T	250.7	PAM/FM/FM
	VHF	T	245.3	PCM*
S-IVB	VHF	T	258.5	PCM*★
	VHF	T	253.8	FM
S-II	VHF	T	241.5	PAM/FM/FM
	VHF	T	234.0	PAM/FM/FM
	VHF	T	248.6	PCM*★
S-IC	VHF	T	244.3	PCM*★
	VHF	T	256.2	PAM/FM/FM

* PRIME OPERATIONAL MODE
★ TELEMETRY DATA AVAILABLE IN MISSION CONTROL CENTER
★★ COMMUNICATIONS AND COMMAND SYSTEMS

Fig. 2 - Saturn V/CSM/LM telemtery.

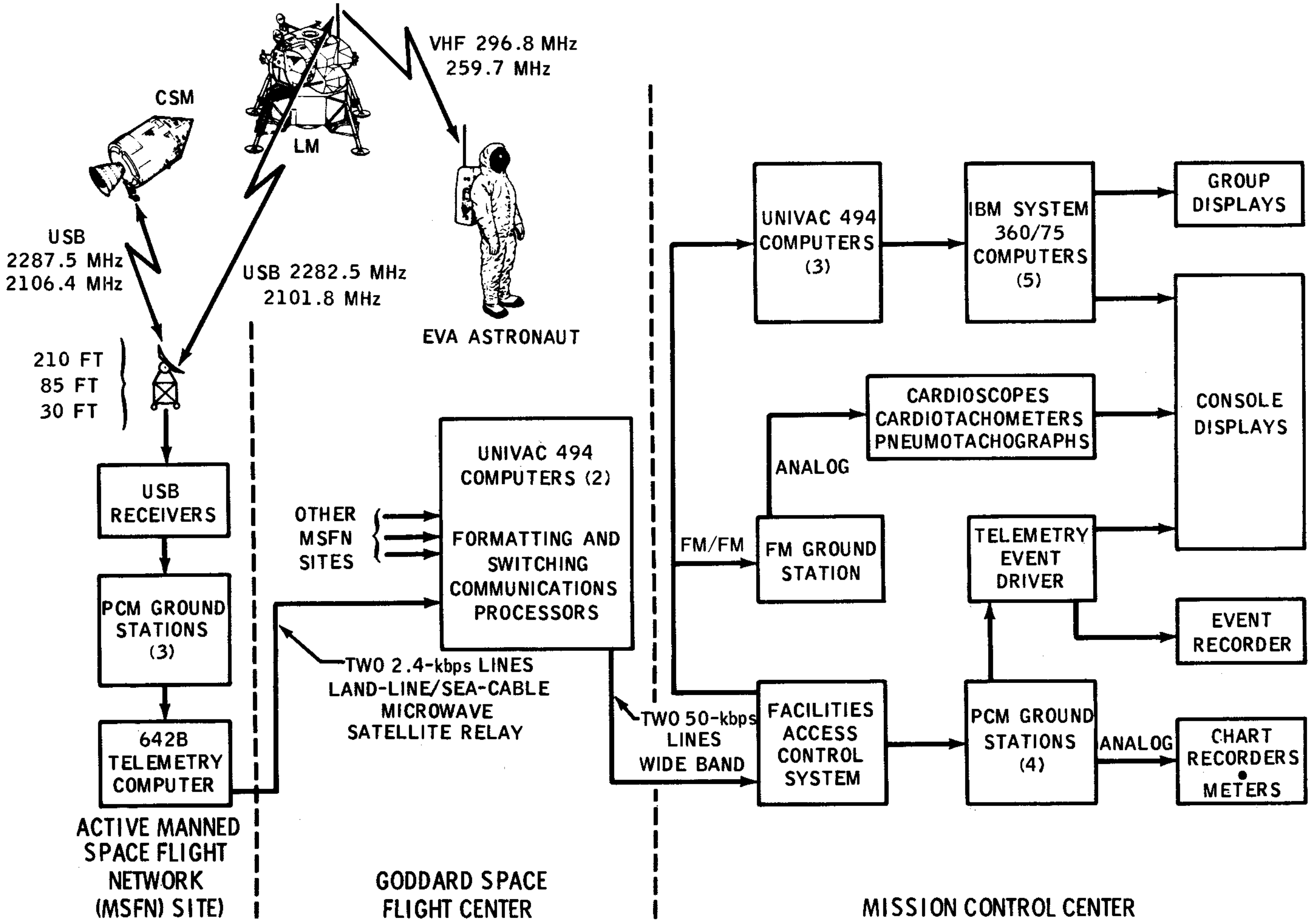


Fig. 3 - Simplified Apollo telemetry data flow.