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DATA HANDLING TECHNIQUES IN PROJECT MERCURY

By John H. Boynton, Mercury Project, NASA Manned Spacecraft Center

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INTRODUCTION

Project Mercury, the free world's first manned space program, was conceived in 1958 by a small group of dedicated scientists. The initial program objective was to verify that man can exist and function in space by placing an astronaut into orbit and returning him safely to earth. At the outset, it was recognized that, in order to realize maximum mission safety, a worldwide network of telemetry and tracking stations would be required to provide for effective flight control and monitoring. Soon after prime contract was awarded, a method of handling rapidly all real-time flight data was implemented. Since network stations had to be placed discretely along the orbital track, strategically located countries were requested to participate. The response was overwhelming, with most of the countries offering both land and operational support. As in the design of the Mercury spacecraft, the worldwide-network concept embraced a goal of extremely high reliability, with redundancy and the use of proven equipment where practical established as ground rules. A spaceborne telemetry system was developed to transmit data pertinent to the operation of critical spacecraft systems and pilot's status, and the capability was included to record these data onboard for use in postmission analyses. This information is reduced and published in both graphical and tabular form in an amazing brief time period after the flight in order to support most effectively subsequent Mercury missions and advanced projects.

INSTRUMENTATION AND COMMUNICATION SYSTEMS DESCRIPTION

The system complex which is used to provide information relating to the many instrumented flight parameters consists primarily of the spaceborne instrumentation and communication systems, the worldwide telemetry and tracking network, and the Mercury Control Center. Because the astronaut's verbal accounts during the flight facilitate the flight monitoring task, the onboard voice communication systems can be considered as complementing the telemetry system.

Spaceborne System [1]

The spacecraft instrumentation system monitors over 100 parameters throughout the spacecraft, including critical physiological functions of the astronaut and certain aspects regarding the operation of the various spacecraft systems. Specifically, the instrumented items are the occurrence of various mission events which are initiated automatically by the sequential system, the outputs of the attitude and rate gyros and the horizon scanners, control stick position, battery voltages, cabin and suit temperatures and pressures, accelerations imparted to the spacecraft, clock outputs, receiver signal strengths, and the various astronaut physiological parameters[2], such as temperature, blood pressure, electrocardiogram output, and respiration rate. The majority of these data has been commutated through two redundant commutators, each having 90 segments, but a portion of the data is also transmitted without interruption on selected subcarrier frequencies. The noncommutated quantities primarily include the medical data and control system information which have frequencies of occurrence or change that are often greater than the commutator sampling rate. As shown in figure 1, both the commutated and continuous data are processed through oscillators and mixers to form the compound FM signal, which is transmitted to ground stations. It should be noted that the outputs of both commutators and one of the signal mixers were recorded separately on three channels of a seven-track tape recorder. The voice communications conducted during the flight are recorded on an additional track of the recorder. Certain instrumented parameters which have a tendency to drift are calibrated periodically during the flight to maintain the data accuracy.

The spacecraft communication systems consist of the voice transmitter-receivers, the radar beacons, the telemetry transmitters, the command receivers, and the recovery beacons. Redundant UHF and HF transceivers make up the voice system. However, one of the HF transceivers is used during the recovery operation only. The radar beacons are a 400-watt C-band transponder and a 1,000-watt S-band transponder. The telemetry transmitters, of which, until the last flight, there were two nearly identical units, are of the UHF-FM type, operate at a power output of 2 watts, and have transmitted at frequencies of 226.2 mc and 259.7 mc. Since the two redundant telemetry systems have proved to be very reliable during the two unmanned orbital and the first three manned orbital flights, one of these units was deleted for the fourth flight of that series. The command receivers and decoders are used to process command signals which are sent, if required, from ground stations to initiate major flight events. The recovery beacons are used, of course, to facilitate the location and retrieval of the spacecraft after landing.

Ground-Based System[3]

The data acquisition and processing system located on the ground can be thought of as comprising the Mercury Control Center in Florida, the Computing and Communications Center in Maryland, and eighteen range stations located throughout the world along the orbital ground track. Of these range stations, shown in figure 2, all contain telemetry-reception and decommutation equipment, are capable of conducting voice communications with the spacecraft, and are outfitted with an acquisition aid unit. About half of the stations tracks the spacecraft with C-band radar (FPS-16), and the remaining half employs S-band radar (Verlort). Approximately half of the total number of range stations possesses a command capability. Although all range stations used in Project Mercury are shown in figure 2, some of these sites, depending on mission requirements, have not been activated for certain flights. Each radar unit tracks its respective beacon in the spacecraft as it passes over the station, and this observation period lasts for up to about 6 minutes. During these station passes, the flight controllers at each site receive and monitor the telemetry data and conduct voice communications with the astronaut, who reports on his physical status and relays instrument panel readings for comparison with certain telemetered information. Most of the network stations are linked together either by a land line or a submarine cable, although a few remote sites can only be connected conveniently through a radio link. For example, during some missions, specially equipped ships (see fig. 2) were deployed which could only be linked to the network by radio.

The Computing and Communications Center is the focal point for nearly all telemetry data, radio transmissions, and radar information. Here the flight communications are patched, amplified, and relayed to the Mercury Control Center and the stations throughout the range. The radar information acquired during the orbital phase is processed through a redundant pair of high-speed computers for orbital-trajectory and retrograde-time determination and updating. The telemetry data are reduced and sent to the Mercury Control Center, where a portion of these data is displayed on large plotboards and TV screens to provide an up-to-date history of critical flight parameters. These displays are a major tool used in the real-time monitoring by the Operations and Flight Directors and the primary flight control team. Significant flight parameters which are telemetered during a station pass are displayed as direct percentage readouts at most of the network sites. Probably the most dramatic display at the Mercury Control Center is the wall-size world map showing the orbital ground track and all of the network stations. On this dynamic display, which is quite similar to figure 2, the coverage circles of the range stations, a miniature Mercury spacecraft, and a small circle indicating the landing point are illuminated. The coverage circles flash as the spacecraft passes over the respective stations, and the spacecraft and landing-point circle move along the ground trace to indicate instantaneously the point on the earth's surface above which the spacecraft is passing and where it would land if retrofire were commanded.

All telemetry and decommutation equipment is designed to provide high-speed operations and data readout in order to permit rapid response to critical flight situations and possible mission abort conditions. Full data storage capability is provided at the Computing Center, and with this equipment, all significant mission event times are computed and relayed to appropriate network stations. An example of this function is the computation of the retrograde time, which is derived from the computed orbital trajectory and the planned landing point coordinates. One of the most critical phases for the Computing Center and the Mercury Control Center is during the period of powered flight. In this phase, the launch trajectory and the operation of spacecraft and launch vehicle systems are monitored continuously. Should the launch vehicle develop a critical failure, an automatic sensing system immediately shuts down the propulsion system and aborts the flight. If unacceptable conditions, based on a comparison of high-speed computations with a prescribed envelope, are evident at orbital insertion, such that safe orbit cannot be attained, the mission again must be terminated early. These insertion conditions are displayed on a plotboard in the Mercury Control Center which contains the parametric insertion envelope and should the spacecraft telemetry system indicate an uncorrectable system malfunction or an abnormal physiological response by the astronaut, a rapid and justifiable decision must be made and implemented to abort the mission. In each of these instances, the abort trajectory must be rapidly computed to make possible a quick recovery of the spacecraft and astronaut. Once the orbital insertion parameters are known and are used to make the initial orbital trajectory calculations, the fact that they are within acceptable limits must be rapidly verified through computations based upon subsequent tracking data. In summary, the Mercury network, the Computing Center, and the flight monitors located in the Mercury Control Center are capable of receiving and processing rapidly all telemetered flight data, voice communications, and tracking information for real-time control of all mission events.

POSTFLIGHT DATA HANDLING

Data Reduction

After the flight has been terminated, the detailed postmission analysis of the flight data commences. The essence of these data is derived from the onboard tape record and the recordings of telemetry data taken during the flight at the various ground stations. A team of specialists is assembled at the launch site in Florida to conduct the analysis of the reduced data. In areas of particular interest or urgency, a preliminary analysis of any mission anomaly is made using records of the real-time telemetry information. Should the onboard tape recorder fail or the tape record be lost or damaged, the recorded real-time telemetry data become the only source of parametric flight information for analytical purposes. The quality of these data has been exceptionally high for most Mercury missions. The onboard tape record is carried from the landing area to the evaluation site by a special courier, and a master copy of this tape is made and verified immediately. From this master, a number of copies is made for various uses. One copy is transported rapidly to a contracted agency to be reduced from analog to digital data through the use of computers and special equipment, and from these digital data, system parameters and astronaut physiological responses are computed, tabulated, and plotted by machine against flight elapsed time. This process, involving approximately three million data points, has been completed in as little as three days for a $4\frac{1}{2}$-hour orbital flight.

During the formal reduction period, another copy of the recorded data is electrically processed and used to produce oscillograph records. These records represent completely the raw data obtained during the flight and, therefore, a minimum number of processing errors. This form of semi-reduced, but rapidly available, data is utilized primarily for extracting specific data points or closely examining data characteristics for a selected period of the flight, since these lengthy records of direct voltage readouts must be scanned and calibrated essentially by hand. They are, however, important in that they often provide the proper direction for the analysis at an early time, a basic requirement for expeditious reporting of the flight results and analyses.

In addition to flight information yielded by the telemetry system, the flight evaluation team uses many other sources of system and astronaut performance data. The record of the air-ground voice communications is transcribed and time correlated, because it may be the only source of a reported observation and the only means of verifying the occurrence and approximate time of a flight event. The astronaut conducts a self-debriefing immediately following recovery and participates in formal debriefings which are documented and used to complement and support the postflight analysis. Of great importance, however, are the many detailed systems tests which are conducted after the mission by using the actual flight hardware to isolate any specific problem areas which might have been evident during the orbital phase or disclosed during the data analysis period.

All of the raw flight data are referenced to spacecraft elapsed time during the initial reduction operation. After the data in this form are hand-carried to the evaluation site by a special courier, they must be correlated with ground elapsed time. The time-correlation process primarily involves a correction for possible errors which may have existed in the spacecraft clock. Ground elapsed time is the means of chronology which is common to all network operations and begins at the precisely measured time of launch-vehicle lift-off.

Data Reporting

Once the tabulated and plotted parametric data arrive at the evaluation site, the full-scale analysis is begun. A typical schedule of the data handling, preliminary analysis, and initial reporting operation is shown in figure 3 for a three-pass orbital mission (q.v., refs. 1 and 3). The length of this total reporting period is necessarily kept at a minimum in order that pertinent flight results and findings may be applied to subsequent missions. After the tabulated data and time-history analysis plots have been verified for accuracy and completeness of content, these data are further processed and refined for inclusion in the initial postlaunch report. The entire three-volume report has been printed in less than 24 hours by taking advantage of three-shift, overnight service provided by a special contractor at the evaluation site.

In addition to the documented flight data, the postlaunch report contains data resulting from special tests which are conducted by using the flight hardware to support the initial analysis in a specific area. With the exception of the launch escape tower assembly, the retropackage, and certain components associated with the landing system, all of the spacecraft systems are recovered and rapidly returned to the evaluation site to be available for this testing. The initial testing period during the preparation phase of the postlaunch report is planned and monitored on a priority basis by the various systems specialists in order to derive the greatest amount of useful information during the brief time available. This initial report contains all of the detail technical information that pertains to each flight and, for this reason, is most useful to engineers and scientists of the National Aeronautics and Space Administration and its major hardware contractors. After the release of this report, follow-up tests and analyses are conducted to validate the initial conclusions and to complete the investigation of possible unsolved problem areas. Concurrently, the contents of this initial report are closely reviewed for technical accuracy, and test results are noted as they become available.

The technique of assigning and assembling in a central location a large team of specialists for the purpose of analyzing and reporting detailed flight results has proved to be very effective for Project Mercury. A large number of these specialists are temporarily removed from their normal duty station, and their only assignment during this period is that of completing and documenting their particular analysis. The evaluation team is representative of all phases of the mission operations, from preflight checkout and preparation through recovery, and the flight-performance analyses include those for the many spacecraft systems, the astronaut in completing the prescribed flight plan, and all medical aspects of the mission. The initial postlaunch report also includes a detailed description of the changes to the spacecraft and the launch vehicle from the previous mission and personal account of the mission by the pilot.

At the completion of the initial postflight report, the evaluation team is disbanded, but selected authors are instructed to prepare a more formal report (e. g., refs. 1 and 3) for general public distribution. Although this report is widely distributed throughout the world, it is often released in conjunction with an oral presentation of Mercury flight results to selected representatives from the scientific and technical community. Only the significant time-history data are included in this public report.

After the conclusion of the detailed testing and analysis for each flight, the information contained in the initial postflight report is updated, amended, and closely reviewed for technical accuracy and continuity. Much of the flight data contained in the initial postflight report is replotted for various specific purposes. All detailed system performance information, which is updated and verified as a result of continued postflight testing and analysis, is rapidly made available to NASA personnel and its major contractors for use in concurrent analytical studies. For example, the elapsed time between the first and second manned orbital flights was about 3 months. During this period, numerous design changes were incorporated in the spacecraft, which was used for the latter mission, as a result of documented studies conducted after the former flight. These modifications included control system changes and rewiring of sequential circuits for improved reliability. Timely availability of postmission documentation is mandatory to this flight-to-flight procedure of system improvement and development.

In addition to the more or less standard documentation for each flight, many requests for specific information or data in an unusual form are received from outside agencies and answered by the Manned Spacecraft Center.

CONCLUDING REMARKS

The real-time monitoring and control operation during manned orbital missions which are conducted as a phase of Project Mercury is made possible through a telemetry system, a voice radio link, radar tracking, and an elaborate network of telemetry reception equipment, which is operated by trained ground control personnel and located at discrete points around the world. The telemetry system transmits both commutated and uninterrupted instrumentation data to network stations via an FM carrier signal. The voice transmitters provide for communications regarding flight status and instrument readings between the astronaut and ground personnel during the flight. During all flight phases, including reentry, radar tracking stations acquire and track C- and S-band transponders aboard the spacecraft to provide data that are necessary to compute and update the orbital trajectory and to predict the landing point. The Computing and Communications Center receives and processes all real-time flight information for use by the primary flight control team at the Mercury Control Center and by the flight monitors stationed at the various network sites. This vast complex of equipment and personnel is set up to accept flight parameters in a proper form and permit immediate action upon critical mission anomalies, so that the safety of the astronaut and the success of the flight may be given foremost consideration and the greatest chance for realization.

In all manned Mercury flights to date, the Mercury Worldwide Network facilities and the vast flight control team have performed exceptionally well. All data handling and computations were conducted for these flights in a timely fashion, although a decision to terminate the mission prematurely has never been necessary. However, there have been situations during all of the Mercury orbital flights which required a prompt on-the-spot analysis and an immediate decision, and in each case, the necessary corrective action was taken to circumvent or eliminate the problem so that mission success was not jeopardized.

As an example of the effectiveness displayed by the computation facilities in the Mercury network, the spacecraft during the second manned orbital mission landed approximately 250 nautical miles downrange from the planned landing point. This landing error resulted from a misalinement in the spacecraft's yaw heading at retrograde. Within minutes after the thrust was applied at retrograde to bring the spacecraft back to earth, the radar tracking data sent from the California station indicated that the predicted landing point was in error by some 240 nautical miles. Although flight control personnel were reluctant to believe this report at first, subsequent tracking information from sites located across the southern portion of the United States confirmed this prediction. Both the astronaut in the spacecraft and the recovery forces in the Atlantic Ocean were alerted in a timely fashion, making possible an effective location and retrieval operation.

The telemetry and tracking network used for Project Mercury will form the basis of the more complicated and sophisticated system to be used for advanced space missions, involving long-term orbital missions, rendezvous, and ultimately manned flights to the moon. However, of possibly greater importance are the experience and knowledge acquired in the processing and use of real-time telemetry data as a result of Project Mercury which may be applied to these advanced space programs. Nevertheless, the requirements for telemetry system operation and data transmission will become increasingly more demanding as the space frontier is further extended, and the United States, as the primary representative of the free world's effort in space exploration, will continue to apply its resources toward advancing the telemetry technology.

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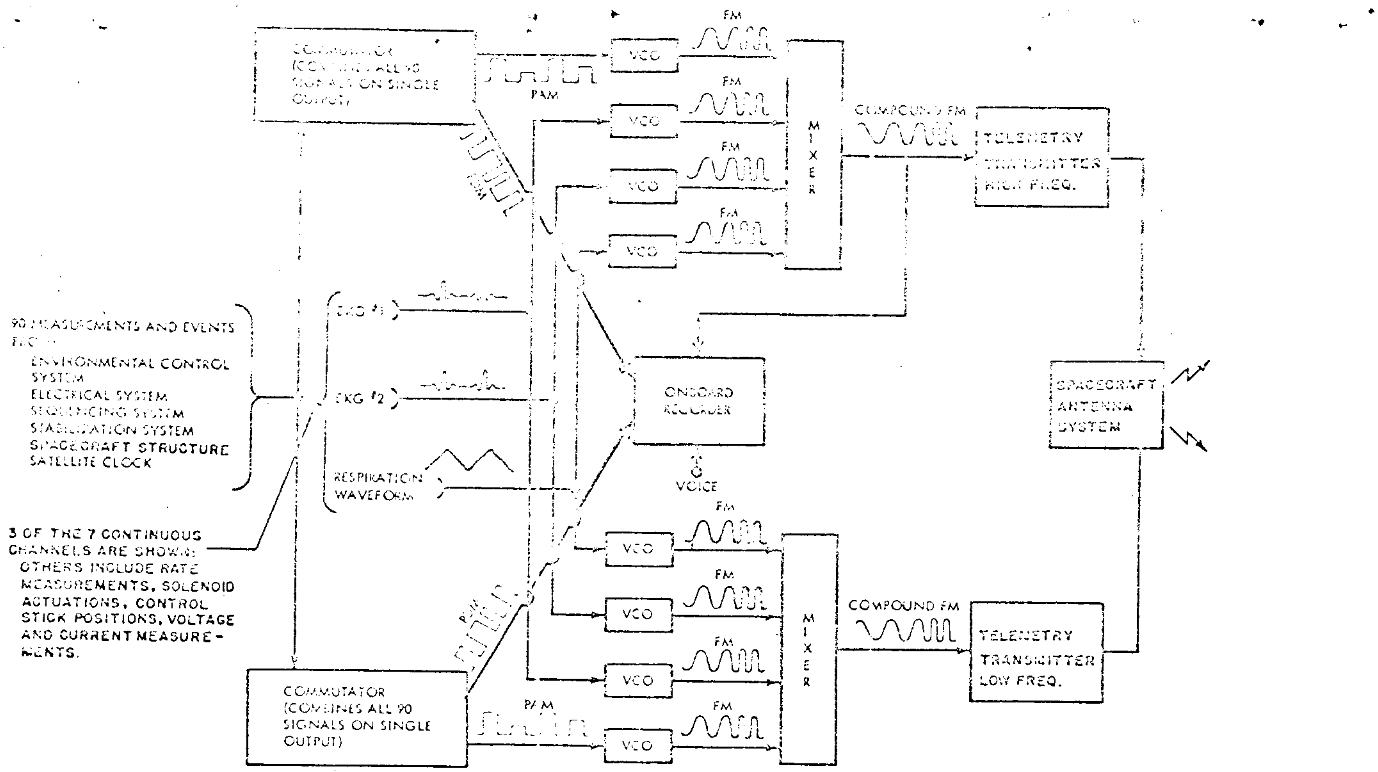

Figure 1. - Spacecraft Instrumentation System

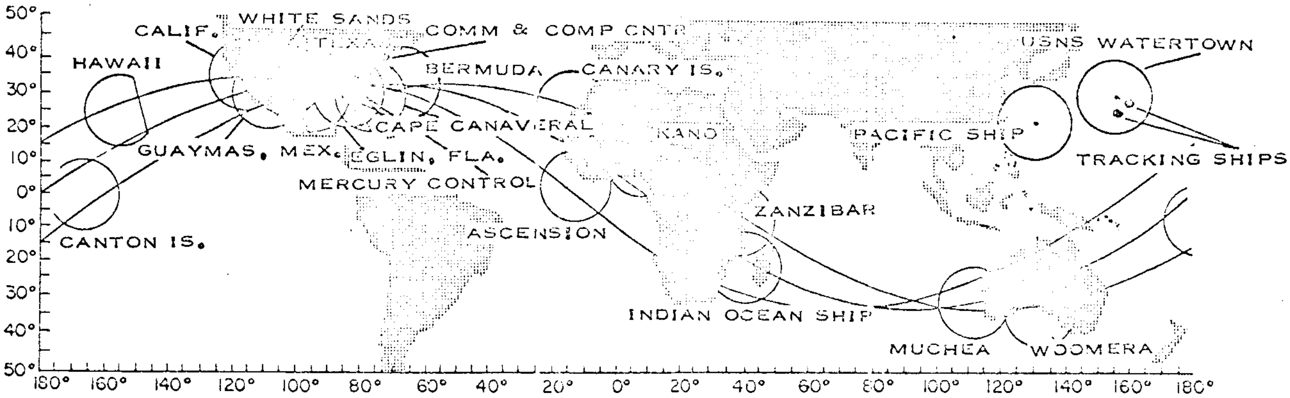

Figure 2. - Mercury Worldwide Network

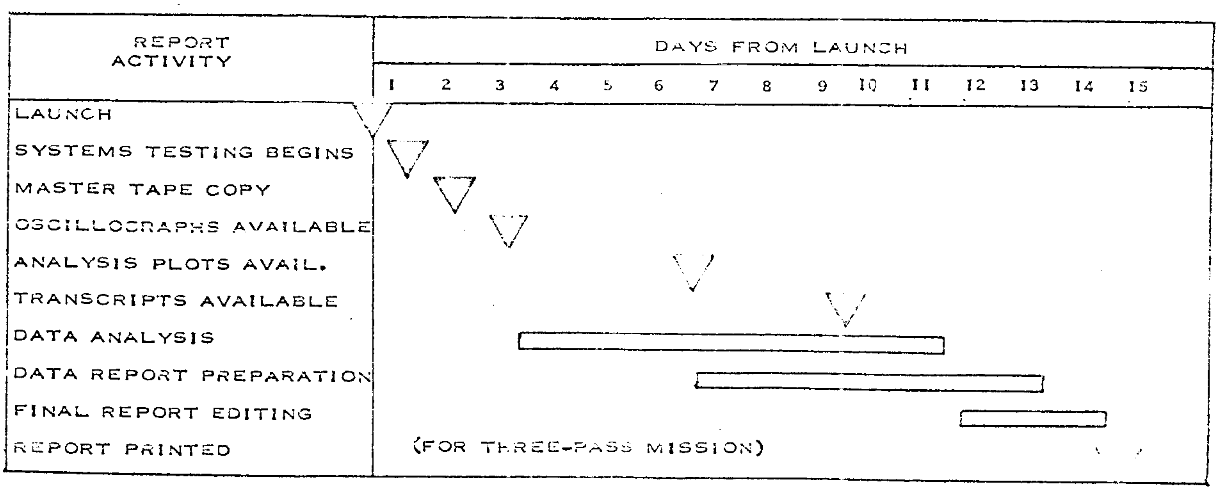

Figure 3. - Report Preparation Schedule