quired which may be applied to future programs. Details of the operational procedures and findings are documented in the several reports of the Mercury missions (refs. 1 to 12).

The nature of the challenge called for the development of some ground rules applicable to the medical aspects. It was determined that:

(1) The simplest and most reliable approach should be used.

(2) Off-the-shelf items and existing technology should be used wherever possible.

(3) Man was being thrust into a truly unknown environment, and his reactions to this environment were relatively unknown.

(4) A direct approach would be taken to the problem areas, and attempts would be made to provide the best protection and monitoring capable within the operational constraints of the mission.

Many lessons have been learned from this first experience of the free world with manned space-flight operations. The responsible medical community had honestly attempted to evaluate potential problems based upon knowledge at that time. In doing this, several possible problems were raised which, it appears, this program has answered to some degree. Weightlessness is a good example of the many barriers to man's entry into space which were raised prior to this program. Some of the dire physiological effects predicted as a result from exposure to this condition and therefore to be limiting to space flight were anorexia, nausea, disorientation, sleepiness, sleeplessness, fatigue, restlessness, euphoria, hallucinations, decreased g-tolerance, gastrointestinal disturbance, urinary retention, diuresis, muscular incoordination, muscle atrophy, and demineralization of bones. It will be seen that few of these remain of concern. Another area in which there were predictions of undesirable effects is in the psychological response to the isolation of space. The astronauts to date have not been isolated in space and have generally complained of too much earth contact. There has been no evidence of any breakoff phenomenon or aberrent psychological reaction of any sort. Thus, while no serious problems have developed, more information is needed on increased time periods in space and the conclusions of the present paper can only be based upon the duration of flights thus far flown. Each mission has been used as a means of evaluating the next step into space, and it is believed that the six manned missions in this program have laid the groundwork for future programs. Project Mercury gave the opportunity to define more closely the medical problem areas, and the future is anticipated with great expectations and confidence in man's ability to adapt to and conquer this new frontier.

Crew Selection and Training

The medical portion of the selection program had as its objectives the provision of crew members who (1) would be free of intrinsic medical defects at the time of selection, (2) would have a reasonable assurance of freedom from such defects for the predicted duration of the flight program, (3) would be capable of accepting the predictable psycho-physiologic stress of the missions, and (4) would be able to perform those tasks critical to the safety of the mission and the crew. The selection board found themselves viewing already trained test pilots somewhat in the same manner as cadets entering a training program are viewed. Small numbers were selected, leaving little excess for attrition. In view of these objectives, the group was culled by records review, interview, and testing until a final group was given a rigorous medical examination at the Lovelace Clinic in Albuquerque, New Mexico. This examination was followed by a stress-testing program at Wright-Patterson Air Force Base, Ohio. The results of these examinations were reviewed by the participating physicians, and the candidates were given a medical rank order. This rank order was then presented to a board which selected the original seven astronauts. In retrospect, it can be said that the results of this program were adequate in view of the fact that the assigned astronauts have successfully completed their flight missions. This early program has been of assistance in the development of current selection program. The stress-testing in the initial selection efforts has been deleted since it was found to be of little value in a group who had already been very thoroughly stress-tested by virtue of their test-pilot background. Stress-testing has become a part of the training program with a selection in depth carried on during the training. Thus, each exposure is mission-oriented and further is an additional selection test as well as providing baseline medical information. In the current programs, this technique is being used; and the astronauts understand that they are continually undergoing selection and that there may be attrition.

The premise that detailed physical examinations given to groups as select as test pilots will show up many physical defects which would interfere with a reasonable prediction of career length in the manned space-flight program has been confirmed in this program.

The training program has included a series of lectures on the anatomy and function of the human body, and the series has proven to be of great value during inflight monitoring and discussion of potential medical problems. Every attempt has been made to use engineering analogies where possible and to impress the flight crews with the fact that the human organism and its many systems must be monitored as thoroughly as many of the engineering systems if mission success is to be assured. There has been no formal physical training program but each astronaut has been charged with maintaining his fitness through programed exercise of his choice. A wide variety has been used by the group. Medical advice was offered and the importance of regular training periods was stressed during the preflight preparation period. A plateau should be reached and, although no specific level is specified, it is believed the astronaut is better prepared to withstand the flight stresses if he maintains a state of physical fitness.

Medical Maintenance and Preflight Preparation

The medical maintenance during this program consisted of the routine medical care similar to that provided specialized groups of aircraft pilots, annual physical examinations, and special physical examinations performed before procedures such as altitude-chamber runs, pressure-suit indoctrinations, and centrifuge runs. The flight schedule with its necessary preflight spacecraft checkout procedures, simulated flights, and launches, frequently exposed each flight crew member to several physical examinations within a given year. An attempt was made to make these physical examinations serve several purposes such as qualifying the individual for his annual physical, being ready to participate in a given procedure, and collecting baseline data. A close and frequent contact between flight crews and flight surgeons, with the flight surgeons monitoring participation in all stress exposures and training exercises, proved to be extremely valuable preparation for the flight mission. This close association also provided excellent preventive medicine practice among the flight crews. It is thought that the flight crews have certainly had no more illness than what would be expected in a routine pilot population; and the general feeling is that there was probably much less.

The preflight physical examinations were to serve two basic purposes. First, they should allow the flight surgeon to state that the astronaut was qualified and ready for flight. Second, they should provide a baseline for any possible changes resulting from exposure to the space-flight environment. The flight crew surgeon appears best qualified to determine whether the astronaut is medically ready for flight. Early in the program, the search for unexpected changes in body systems as a result of exposure to space flight dictated specialty examinations of various body systems. A team was assembled from the Department of Defense and included specialists in internal medicine, ophthalmology, neurology, psychiatry, and laboratory medicine. The same specialties have continued to be represented, but certain items of the examinations have been modified as knowledge of the lack of serious effects of flight on the astronaut was gained. Prior to the selection of a flight astronaut for a given mission, the medical records of those being considered are reviewed in detail and a medical recommendation given to the operation director. Following experience on the early missions, it was determined that a thorough evaluation of the flight astronaut would be made 10 days prior to the scheduled mission to assure management and the flight director that the astronaut was indeed ready for the mission. This examination included a medical evaluation of both the flight astronaut and his backup. Three days prior to the mission, the detailed physical examination was completed by the various medical specialists and the necessary laboratory work was accomplished. On flight morning, following a brief medical examination, a final determination was

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made as to the readiness of the astronaut for flight. This examination was principally concerned with noting any recent contraindications to flight which may have developed. While early in the program other specialists participated in this examination, on the last two missions, the participation was reduced to that by the flight crew surgeon.

The postflight medical examinations were initially made by the Department of Defense recovery physicians stationed aboard the recovery vessel. On the early mission, the astronaut was then flown to Grand Turk Island and was joined there by the team of medical specialists who had made the preflight examination and by the flight crew surgeon. As the flights became longer and recovery was accomplished in the Pacific Ocean, the plan was changed and one of the NASA flight surgeons was predeployed aboard the recovery carrier to do the initial postflight examination and debriefing. On the MA–8 mission, the Director of Medical Operations and the medical evaluation team deployed to the Pacific recovery site several hours after recovery, and this was not only a tiring experience, but necessitated that a great deal of the examination and debriefing be done prior to their arrival. The detailed postflight specialty examination was then conducted at Cape Canaveral when the astronaut returned from the recovery site. In some instances, this practice required the teaching of special techniques to the flight surgeon in order that early information could be obtained. Project Mercury has been most fortunate in having rapid postflight recovery and examination of the flight astronauts, allowing excellent comparison of postflight with preflight data. It would seem from our experience that the retention of any specialty examination team at a mainland launching or debriefing site would be the preferable plan of action.

Early in the preflight preparations, it was determined that there was a need for many practice runs of various procedures. These runs were accomplished by doing the actual flight-type preparation for centrifuge runs, spacecraft checkout runs in the chamber at Hanger S, simulated flights and launches, and procedures trainer exercises. The Mercury-Redstone suborbital flights were also extremely helpful in preparation for orbital flight. A medical countdown was developed with specific timing of the various events and coordination with the blockhouse and range countdown. In order to have no delay in the scheduled launch, a great deal of practice in this countdown was necessary. It has continued to pay dividends in the later missions. Backup personnel in the various medical areas are needed just as backups are needed for the various pieces of equipment. Experience has allowed the number of backup personnel to be kept to an absolute minimum.

Prior to the first launch, consideration was given to the necessity for isolating the flight crew in order to prevent the development of some communicable disease immediately prior to or during flight. It soon became evident, however, that such isolation was impractical in view of the numerous requirements upon the flight crew during the 2 weeks prior to launch. Many activities required the presence and participation of the astronaut, and the isolation was reduced to attempts to curtail the number of contacts with strangers. As the missions get longer and longer, the situation may have to be re-evaluated since the mission could last longer than the incubation period of some diseases. No difficulty was encountered during the Mercury program with the use of only a very modified isolation plan.

One of the basic concepts developed stated that there would be no drugs used as routine measures, but that drugs would be made available for emergency use. Injectors were made available which could deliver their contents through the pressure suit into the astronaut's thigh. During the first four missions, the drugs available in the injectors included an anodyne, an antimotion sickness drug, a stimulant, and a vasoconstrictor for treatment of shock. In the later missions, this was reduced to the antimotion sickness drug and an anodyne, available both on the suit and in the survival kit. An evaluation of the longer mission programed for MA–9 led to the decision to make available tablets of dextro-amphetamine sulfate, both in the suit and in the survival kit. Antimotion sickness and antihistamine tablets were also made available. The astronaut's mental and physical integrity were never in doubt during the mission. As the time for retrofire approached, a review of the mission tasks made it evident that the astronaut had undergone a long and rigorous work schedule from which he might be expected to experience considerable fatigue, even assuming ideal environmental conditions and full benefit from restful sleep. As has been reported, medication was used for the first time during flight when the dextro-amphetamine sulfate was taken prior to the initiation of retrosequence. Such drugs should be available and plans must be made for their availability both during flight and postflight in the survival kit. The astronaut must always be pretested for effect of the drugs which will be used.

Experience has shown that care must be taken to prevent astronaut fatigue during the final preflight preparations as well as postflight. Many individuals have matters of importance which must be decided by the astronaut during the final week of preparation; and as launch day grows closer, the demands on the astronaut's time increase. Careful scheduling of rest, activities, and exercise periods are needed; and much more attention must be paid to this scheduling in future missions. Since the effects of these variables were unknown, it was the flight surgeon's decision to administer 5 mg of dextro-amphetamine sulfate to the astronaut in order to increase the probability of peak performance during reentry. Experience has shown that 48 to 72 hours is a minimum time for a postflight rest and relaxation following a 34-hour mission. Seventy-two hours should be a minimum for future missions.

Early missions required only simple provisions for the collection of urine and blood samples. The short-mission durations made it entirely feasible to collect all the voided urine in a single container within the suit and to recover it after astronaut recovery. As mission duration increased, this became an unworkable procedure; and further, there was a desire to obtain separate urine samples for analysis. The last mission utilized a system for collecting five separate and complete urine samples for later evaluation. This system worked properly but will require modification for future missions. No blood samples have been obtained during flight. Every attempt has been made to combine the various blood requirements in order to require as few vena punctures as possible both preflight and postflight.

Early in the preparation period, a medical flight plan is developed and integrated with the overall mission flight plan. A good deal has been learned about realistic sampling in light of flight plan and in utilizing normal operational activities and reports as means of medical evaluation.

Dietary control has been utilized for approximately 1 week prior to each mission. The first several days were used to assure a normal balanced diet during the rather hectic preflight preparations. In order to prevent defecation during the mission, the low-residue diet was programed for 3 days prior to launch, and the time extended if the launch was delayed. This diet performed its task very satisfactorily during the entire Mercury program; still, indications are that any more prolonged period would seem unwise. The inflight food has consisted of the bite-size and semi-liquid tube food on the early missions. On the last mission, the freeze-dehydrated food was added. Problems with crumbling have been encountered with the bite-size food, and difficulty in hydrating the freeze-dehydrated food was encountered on the last mission. The assurance of palatable food is necessary, and proper containers and practice in their use appear indicated. It also appears necessary to schedule food and water intake on the flight plan and to check to see that it has been properly accomplished.

Medical Monitoring

The Mercury program provided the free world with the first opoprtunity for full-time monitoring of man in the space-flight environment. At the start of this program, the continuous monitoring of physiological data from a pilot conducting a mission was a very recent concept. At the time, there were no off-the-shelf items available to allow continuous and reliable physiological monitoring. It was decided to attempt to monitor body temperature, chest movement, and heart action (ECG). Standards required that the sensors and equipment be comfortable, reliable, compatible with other spacecraft systems, and would not interfere with the pilot's primary mission.

It should be realized that the biomedical sensors are used as a means of flight-safety monitoring. The primary purpose is to assist the monitoring flight surgeon in determining whether the astronaut is capable of continuing the mission from a physiological point of view. The information is used as a basis for making go-no-go decisions in the control center. No attempt has been made under the current operational conditions to perform detailed system evaluation or analysis.

A great deal of experience in medical flight control of an orbiting astronaut was obtained through the use of the many range simulations and the several actual flights. The participation in simulations and in flights prior to those which were manned proved to be extremely valuable training exercises for the actual missions. The medical flight controller has indeed shown himself to be a valuable member of the flight-control team. The development of mission rules to aid in flight control was necessary in the medical area just as in the many engineering areas. It is difficult to establish definite number-value cut-offs for various medical parameters, but this was done early in the program. Gradually, these rules were made less specific so that the evaluation and judgment of the medical flight controller were the prime determinants in making a decision. The condition of the astronaut as determined by voice and interrogation rather than physical parameters alone became a key factor in the aeromedical advice to continue or terminate the mission. This is as it should be and follows the lessons which were learned in general medicine wherein numerical laboratory values are not necessarily the final answer. Trend information as shown by at least three stations was shown more reliable than single values. In developing the flight-control philosophy prior to the first manned flight, it was thought that it would be necessary for the flight surgeon to talk directly to the astronaut very frequently in order to evaluate his physiological state. As operational experience was gained, it became obvious that this was not the case. Information inquiries were passed easily and smoothly through the spacecraft communicator with the flight surgeon retaining the privilege of talking directly should the need arise. It was also thought early in the program that the occurrence of most any medical emergency in flight would require an early or even a contingency landing. Again, as operational experience was gained with the range and with the planned recovery operation, it was determined that the best philosophy was one which held that the astronaut was in a very fast, air-conditioned ambulance on 100-percent oxygen and in most instances it would be better to return him in the spacecraft to a planned recovery area rather than to abort the flight in a contingency area where it might take hours or days to recover him.

The physiological parameters monitored and the sensor changes and problems may be summarized in the following manner. Body temperature was monitored in all missions through MA–9 with a rectal thermistor. Rectal temperature was found to be the most reliable measurement. The long duration of the last flight and a desire for more comfort resulted in this thermistor being modified for oral use. The range of the thermistor was also changed, so that when it was in the stowed position on the right ear muff it would record suit-outlet temperature. It worked very satisfactorily in this manner.

Respiration was at first measured by an indirect method by using a linear potentiometer and carbon-impregnated rubber. This method was changed early in the program to a thermistor kept at 200° F and placed on the microphone pedestal in the helmet. Neither of these methods gave reliable respiration traces during flight, and a change was made to the impedance pneumograph for the last two missions. This device gave very accurate respiration information during most of the flight.

Electrocardiographic electrodes were of a low impedance to match the spacecraft amplifier. They were required to record during body movements and to stay effective during flight durations of over 30 hours. These electrodes functioned well and gave very good information on cardiac rate and rhythm. The value of having two leads of electrocardiograph, even though they differed from the standard clinical leads, was repeatedly shown. This allowed easier determination of artifacts and was most helpful in determining the valid sounds on the blood-pressure trace by comparison with the remaining ECG lead. The electrode paste was changed from 30-percent calcium chloride in water mixed with bentonite to a combination of carboxy polymethylene in Ringer's solution.

The ten times isotonic Ringer solution not only retained the necessary conductivity and low impedance required, but also afforded decreased skin irritation after prolonged contact.

In 1958, the obtaining of blood pressures in flight was considered and then delayed as no satisfactory system was available. Definitive work began about the time of the Mercury-Redstone 3 (MR–3) flight, and the automatic system which used the unidirectional microphone and cuff was developed for use in the orbital flights. This system without the automatic feature was used on the MA–6 mission of Astronaut Glenn. During the MA–7 mission, all of the inflight blood pressures obtained were elevated, and an extensive postflight evaluation program was undertaken. It was determined that the cause of these elevations was most likely instrumentation error resulting from the necessity for very careful gain settings matched to the individual astronaut along with the cuff and microphone. A great deal of preflight calibration and matching of these settings was done prior to the MA–8 flight; and on both MA–8 and the last mission, MA–9, very excellent blood-pressure tracings were obtained.

Voice transmissions have been a very valuable source of monitoring information. The normal flight reports and answers to queries have been used for evaluation of the pilot. In order to insure that the monitors were familiar with the astronaut's voice, tapes of mission simulations with the flight astronaut as a pilot were dispatched to all of the range stations for use in preflight simulations. In addition to normal reports, verification of actual comfort level was very valuable in determining the importance of temperature readings obtained by way of telemetry. Inflight photography and, on the last mission, television views of the astronaut have been planned as additional data sources. In Mercury experience, both of these sources have proven to be of very little value in the medical monitoring of the astronaut because of poor positioning of cameras and varying lighting conditions resulting from the operational situation. A full face view of the astronaut in color on a real-time basis would be a good monitoring tool for it would approximate the clinical face-to-face confrontation of the patient.

The value of the comparison of multiple physiological parameters and their correlation with environmental data has been repeatedly proven. Abnormal or lost values attributed to instrumentation difficulty have frequently been obtained, but it has been found that interpretation of the astronaut's physiological condition could be made by the use of the parameters remaining or the correlation of those remaining with environmental data.

It has been interesting to note that a satisfactory amount of information on current astronaut status can be obtained with the use of such basic vital signs or viability measures. It is realized that the monitoring methods may be far from ideal. They did not provide the ultimate in the measure of man's physiological status. It would have been desirable to have a single parameter which would tell the ground monitor whether the nervous system of the pilot was capable of the peak mission performance necessary. To date, however, there is no such single or even multiple measures; and an attack must be made upon this problem from the periphery. It is believed that at present the raw physiological data cannot be replaced by computer evaluation. The basic idea of computer reduction has merit, and help is certainly needed in relieving ground medical monitors of long periods of observation. At present, however, there appears to be no useful system to meet this demand.

In the postflight report on the MR–3 mission (ref. 3), it was stated that "the remote monitoring on a noninterference basis of parameters such as temperature, respiration, the electrocardiogram, and blood pressure in active men fully engaged in prolonged and exacting tasks, is a new field. Hitherto, flight medicine has accepted the information concerning the well-being that could be derived from the pilot's introspection and conveyed by the invaluable voice link. For the rest it has relied on performance to tell how close the man was to collapse. It is to be hoped that some of the developments in automation necessitated by Project Mercury will find application in clinical medicine."

This hope is rapidly coming to fruition in the light of the wide activities in medical monitoring now being carried on in everyday medicine.

Physiological Responses to Space Flight

One of the basic objectives of the Mercury flights was the evaluation of man's physiological responses to exposure to this space-flight environment. These responses also had implications as to his performance capability in this environment. The stresses of this environment to which physiological responses are elicited include the wearing of the full-pressure suit although not pressurized in flight, confinement and restraint in the Mercury spacecraft with the legs at a 90° elevated position, the 100-percent oxygen 5-psi atmosphere, the changing cabin pressure through powered flight and reentry, variation in cabin and suit temperature, the acceleration force (g force) of launch and reentry, varying periods of weightless flight, vibration, dehydration, the performance required by the flight plan, the need for sleep and for alertness, changes in illumination inside the spacecraft, and diminished food intake.

Sources of data used in evaluating these responses have included the control baseline data previously referred to, data from the biomedical sensors received at both the Mercury Control Center and the range stations, voice responses at these stations and the detailed onboard tape, the film record of the onboard tape, answers to debriefing questions, and the detailed postflight examination.

In considering these physiological responses, it was found necessary to have a detailed inflight event history since the peak physiological responses are closely related to critical inflight events. This meaningful relationship is very well demonstrated in considering the pulse responses to the Mercury flights. The peak pulse rates during the launch phase has usually occurred at sustainer engine cut-off. This peak value has ranged from 96 to 162 beats per minute. The peak rates obtained on reentry have ranged from 104 to 184 beats per minute. This peak usually occurred immediately after obtaining peak reentry acceleration, or on drogue parachute deployment. Pulse rates obtained during weightless flight have varied from 50 to 60 beats per minute during the sleep periods to 80 to 100 beats per minute during the normal wakeful periods. (See table 11–I.) Elevated rates during weightless flight can usually be related to flight-plan activity. The respiratory rates have ranged from 30 to 40 breaths per minute at sustainer engine cut-off, from 8 to 20 breaths per minute during weightless flight, and from 20 to 32 breaths per minute at reentry. Changes noted in the electrocardiograms have included alterations in the pacemaker activity with wandering pacemakers and aberrant rhythm including atrio-ventricular nodal beats and rhythm, premature atrial and ventricular contractions, sinus bradycardia, atrial rhythm, and atrio-ventricular contraction. All of these "abnormalities" are considered normal physiological responses when related to the dynamic situation in which they were encountered. Inflight blood-pressure values and body-temperature readings have all been within the physiologically normal range.

Table 11–I.—Pulse Rates

Mission	SECO (Peak)	Weightlessness (Range)	Reentry (Peak)
MR–3	138	108 to 125	132
MR–4	162	150 to 160	171
MA–6	114	88 to 114	134
MA–7	96	60 to 94	104
MA–8	112	56 to 121	104
MA–9	144	50 to 60 (sleep) 80 to 100 (awake)	184

The six astronauts who have flown have shown themselves capable of normal physiological function and performance during the acceleration of launch and reentry. The launch accelerations are those imposed by the Redstone and the Atlas launch vehicles. These impose a peak transverse acceleration load of 11g in the case of the Redstone and 7g to 8g in the case of the Atlas.

The vibration produced by launch or reentry has been well tolerated in all cases.

There has been no conclusive evidence of disorientation during flight; and while the astronaut may not have been oriented with respect to the earth, he has always remained so with respect to his spacecraft. The lack of earth orientation has posed no problem whatsoever. There has been no evidence of motion sickness in any of the flight astronauts.

The heat loads imposed by the environmental control system have on occasion caused discomfort but have not been limiting factors in the missions to date. The heat loads and decreased water intake have resulted in postflight dehydration. It has been learned that thermal control in the environmental system is of critical importance.

The Mercury missions were originally planned for altitudes which would not involve contact with the Van Allen Belt of radiation. It was therefore believed that radiation posed no problem in the conduct of these missions, and this was the case until the man-made radiation belt was noted just prior to the MA–8 mission. Personal dosimeters were added within the astronaut's suit and inside the spacecraft at this time in addition to the film packs which had originally been carried. The results obtained from this dosimetry on the last two flights revealed that the astronauts have received no more radiation dose than they would have received had they been here on earth and certainly less than that received during a chest X-ray.

The Mercury program has provided incremental exposures to weightless flight in order to obtain information on which to base predictions of reactions to more prolonged exposures. The crews have uniformly reported that the condition is extremely pleasant and restful. In fact, most of the crews think that it is the only time they have been comfortable in a pressure suit. They have conducted complex visual motor coordination tasks proficiently in the weightless environment. No evidence of body system disfunction has been noted during the period of weightless flight through any of the means of monitoring at our disposal. Food, in cube, liquid, and reconstituted freeze-dried forms, has been eaten normally. Urination has occurred quite normally in timing and amount, and there is no evidence of difficulty in intestinal absorption in the weightless state. Our one experience with sleep periods has raised the question as to whether brief periods of sleep in the weightless condition are more restful than the same periods in a 1g atmosphere. The MA–9 astronaut feels that they are. There is also some question concerning the effect of such a relaxing condition as weightlessness because a number of unscheduled naps occurred. This question will require further investigation on other flights. In the missions to date, there has been no evidence of the mobilization of calcium.

On the last two missions, some postflight orthostatic hypotension, or changes in blood pressure and pulse rate with change in body position, has been noted. This postflight condition has been investigated by the use of the tilt table during the last mission and these results confirm what was only a suspicion on the previous mission. Symptoms of faintness occurred following egress from the spacecraft, and the changes in blood pressure and pulse rate were present for some 7 to 19 hours after landing. In both instances, these changes have been present up until the astronaut retired for the night, a time period of approximately 7 hours; and they have always disappeared by the time of the first check after the astronaut has awaken. Thus, the orthostatic changes have lasted no longer following the more prolonged flight in the MA–9 mission than for the shorter flight; and in both instances, blood pressure and pulse rate have returned to normal while the astronaut was at bed rest. These findings do cause concern about prolonged exposure without some interim steps for further evaluation of this condition.

Recovery

The medical support of the overall Project Mercury recovery operation had to meet two basic requirements:

(1) The capability of providing prompt, optimum medical care for the astronaut, if necessary, upon his retrieval from the spacecraft.

(2) The provision for early medical evaluation to be made of the astronaut's postflight condition.

It was considered essential to establish a medical capability for any circumstance under which recovery could occur. The general concept was to provide the best care in the fastest manner possible. Details of the medical recovery requirements may be found in the appropriate NASA documents (refs. 1, 4, 7, 10, and 12). The original plans were necessarily based on anticipating the direst situation expected, and very correctly so. The extent of medical care which could be effectively administered to the astronaut during the recovery operation is governed to a large degree by the physical circumstances under which recovery occurs. Consequently, the level of medical support necessary at the different recovery areas varies according to the potential extent to which competent medical treatment can be administered in that area, and the most extensive medical support is properly concentrated in those areas where descent to earth by the astronaut is most probable. Access times for the various recovery areas were determined to be medically acceptable time periods to allow reasonable protection of the astronaut based upon accumulated knowledge of human survival, need for medical attention, and reaction to physiologic stress. Since the recovery forces are routine operational units diverted to this operation by the Department of Defense, it also became obvious that the medical support must be obtained through the cooperation of the Department of Defense. Civilian physicians are not available for deployment for the necessary time periods. It will be noted that one of the basic philosophy changes during the program involved a change in emphasis from taking medical care to the astronaut in the early missions to provisions for returning the astronaut to definitive medical care in the later missions. The medical support was provided for three basic categories:

(1) Rapid crew egress and launch-complex rescue capability during the late countdown and early phases of powered flight.

(2) Positive short-time recovery capability throughout all phases of powered flight and landing at the end of each orbital pass.

(3) Reduced capability in support of an unplanned landing along the orbital track.

In the launch-site area, this support included a medical-specialty team consisting of a general surgeon, an anesthesiologist, surgical technicians and nurses, a thoracic surgeon, an orthopedic surgeon, a neurosurgeon, an internist, a radiologist, a pathologist, a urologist, a plastic surgeon, and supporting technicians. In the early missions, these individuals were deployed to Cape Canaveral and were available should the need arise for their use either at Cape Canaveral or, in the event of a requirement for their services in the recovery area, they could be dispatched by aircraft. On the last two missions, it became necessary to develop a team at Tripler Army Hospital, Hawaii, to cover the Pacific area as well as a team deployed to Cape Canaveral to cover the Atlantic area. It became obvious that there were large numbers of highly trained physicians who were merely waiting out the mission in a deployed state with an unlikely probability that they would be utilized. Careful evaluation of the experience and of sound medical principles involving emergency medical care led to the conclusion that the specialty team could be maintained on standby at a stateside hospital and easily flown either to Cape Canaveral or a recovery site if their services were needed. There were surgical resuscitatives teams available at these sites. Other launch-site support was provided by a point team consisting of a flight surgeon and scuba-equipped pararescue personnel airborne in a helicopter. Medical technicians capable of rendering first-aid care were also available in LARC vehicles and in a small water jet boat stationed on the Banana River. A surgeon and an anesthesiologist with their supporting personnel were stationed in a blockhouse at Cape Canaveral to serve as the first echelon of resuscitative medical care in the event of an emergency. Physicians were stationed throughout the recovery areas aboard destroyers and aboard one aircraft carrier in the Atlantic and one in the Pacific. In the early missions each vessel was assigned a surgeon, anesthesiologist, and a medical technician team with the supporting medical equipment chest necessary for evaluation and medical or surgical care. As confidence was gained in the operations, this distribution was modified to assigning only a single physician, either surgeon or anesthesiologist, to the destroyer. Attempts were made to place a surgeon on one and an anesthesiologist on another vessel nearby. This would allow their teaming up if necessary. The general concept was, however, that they would provide resuscitative care only and then evacuate the astronaut to the carrier in their particular area. The carrier was provided a full surgeon, anesthesiologist, technician team. Hospitals along the orbital track were alerted for their possible use, and some near planned landing areas were briefed by NASA-DOD teams. These briefing are thought to be extremely valuable aids in assuring adequate medical support. Early in the missions, blood was drawn from donors and made available for transfusion at Cape Canaveral and in the recovery area. As the operation grew wider in scope involving the Pacific, and as more confidence was gained, dependence was placed upon walking blood bank donors who were typed, and drawn blood was available only in the launch site area.

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III

FLIGHT OPERATIONS

12. SPECIAL INFLIGHT EXPERIMENTS

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Summary

The Mercury spacecraft, although not designed as a vehicle for performing experiments, was used to accomplish a program of special inflight experiments not directly related to mission objectives. The major constraints imposed on the experiment program by the spacecraft were the weight and volume requirements, and the consumables required such as attitude-control system fuel and electrical power. The program evolved from an early period when no planned experimental endeavor existed through the development and implementation of an inflight experiments panel specifically chartered to evaluate the growing number of proposed inflight experiments. The inflight experimental program carried out during the Mercury manned orbital flights is outlined in this paper and the results of these experiments are briefly presented. An analysis of the results of those experiments performed in the area of the physical sciences is presented in paper 19.

Introduction

A major objective of the Mercury manned space-flight program was the determination of man's ability to function in the space environment. The Mercury spacecraft was designed to sustain a man in space for a given period of time and to protect him against the accelerations and temperatures to be encountered during exit from and reentry into the earth's atmosphere. Because of the emphasis on the sustentation and protection of man in space in the design stages, practically no consideration was given to the employment of the spacecraft as a platform for specific inflight experiments. Astronaut safety was the prime design consideration; and, even in the latter stages of the Mercury Project, this concept was not compromised by the desire to perform experiments.

However, an inflight experiment program was evolved in the latter stages of the Mercury Project within the constraints imposed by the spacecraft and operational requirements. The experiments, in general, fall into three categories—biomedical, physical sciences, and engineering. The biomedical experiment program is described in paper 11 and is not covered herein.

This paper discusses the constraints placed on the Mercury experiment program by the spacecraft and the operational limitations, describes the procedures which evolved for the evaluation and implementation of experiments, and summarizes the Mercury inflight experiment program. An analysis of those experiments in the area of space sciences is made in paper 19.

Spacecraft Constraints

Weight

The maximum allowable weight of the Mercury spacecraft was dictated by the capability of the Atlas launch vehicle and by the requirement to achieve an extremely high probability of satisfactory orbital insertion. The entire 5-year history of the Mercury Project has been marked by a constant struggle to maintain the weight of the spacecraft within the weight constraints. Even without the addition of inflight experiments, the spacecraft weight was still increasing approximately 1 pound per week at the close of the program.

After the first manned orbital mission, when it was shown that man can function reliably in the space environment and is a competent technical observer, an increasing amount of spacecraft weight was devoted to the accomplishment of experiments. The battle to reduce the weight of the Mercury spacecraft had not been won by any means; but weight devoted to the performance of experiments was considered to be justified by the fact that Mercury became a part of a growing national program of scientific space exploration for peaceful purposes.

The weight associated with experimental equipment carried on each of the Mercury manned orbital missions is tabulated as follows:

Mission	Weight, lb
MA–6	11
MA–7	18
MA–8	22
MA–9	62

Volume

An observation of the Mercury spacecraft interior, particularly with the astronaut in place and wearing his pressure suit, impresses one with the compactness of the spacecraft and the lack of available volume. Several worthy suggestions for experiments were rejected simply because there was no space available to store the equipment required for the experiment. A relatively small hand-held camera, for example, became a major problem because of no suitable place to stow it for launch and reentry. Although the astronauts have had available to them a personal-effects container, this storage space was rapidly filled with food, flight plans, star charts, and other paraphernalia required for the flight. Astronaut Cooper on the MA–9 mission managed to squeeze into this bag two cameras together with associated film magazines and lenses, but he experienced a great deal of difficulty in extracting and storing his camera equipment. One planned experiment could not be completed because a piece of equipment could not be taken from the container.

Operational Limitations

On the two, three–orbital–pass missions, the short duration of these flights allowed little time for experimental observations. In general, on such a mission, the astronaut used the first orbital pass to acclimate himself to the space environment and verify proper systems operation. The major portion of the third orbital pass was devoted to preparations for retrofire and reentry. Thus, only part of a continuous 90-minute period was available for the performance of experiments. On both the manned three–pass missions, control–system difficulties forced the astronauts to devote their attention to flying the spacecraft. Although the time available was limited, both Astronauts Glenn and Carpenter were able to make observations of scientific interest. Even on the 34–hour manned 1–day mission (MA–9), the requirements for engineering and operational data, astronaut rest periods, communications, and other duties resulted in only a limited time available for experiments.

A major constraint on the selection of experiments for the Mercury spacecraft was the small amount of control-system fuel available for experiments. At least some degree of attitude control of the spacecraft was required for practically all of the experiments. After reserves were first established for operational requirements, in particular the retrofire and reentry maneuvers, the fuel available for experiments was allocated according to priorities established for the experiments.

Other limitations imposed by the spacecraft consumables were requirements for electrical power and for data–recording channels. While these limitations were not severe, they were additional considerations in the selection of experiments.

Some types of experiments require an extremely accurate control of spacecraft attitude. Such fine control was not designed into the Mercury spacecraft because of weight limitations and the necessity for conserving control-system fuel. The automatic-control system, for example, had a deadband of up to 11°. The manual-control system and the attitude and rate indications to the astronaut were such that the astronaut could control the spacecraft attitude within a deadband of approximately only 2°. These tolerances made the spacecraft unsuitable for certain types of experiments.

The optical qualities of the Mercury spacecraft window were limited to begin with, and even these qualities were considerably degraded by residue from the escape rocket which was normally ignited when the escape tower was jettisoned just after launch-vehicle staging. Future spacecraft will require some type of high-quality optical port if precision photographic experiments are to be conducted.

Evalution and Selection of Experiments

Prior to the MA–6 manned orbital flight, no formal procedures existed for the acceptance, evaluation, and incorporation of proposed experiments in the Mercury missions. Suggestions were made informally by organizations both within and outside of the Manned Spacecraft Center for certain types of observations or photography to be accomplished on the MA–6 mission. These suggestions were made directly to the office responsible for astronaut training activities; and, where possible, certain of the suggested experiments were incorporated into the MA–6 flight plan.

With the successful accomplishment of the MA–6 mission, the original objective of the Mercury Project was fulfilled. It had been proven that man could function effectively in space and be safely recovered. With the realization that the Mercury Project was now in a position to perform certain types of experiments of scientific value from an orbiting spacecraft, the Mercury Project Office became the recipient of a large number of proposals for such experiments. These proposals originated from divisions within the Manned Spacecraft Center, other organizations and centers within the NASA, industry, and educational institutions. It was soon evident that a special organization was needed to serve as the focal point of the effort devoted to inflight experiments.

In April 1962, the Manned Spacecraft Center officially established the Mercury Scientific Experiment Panel (MSEP). This panel was made up of representatives of the Mercury Project Office and all technical, operational, aeromedical, and scientifically oriented divisions of MSC. The MSEP was specifically charged with the following responsibilities:

(1) To evaluate inflight experiments proposed for inclusion in Project Mercury missions.

(2) To propose to the manager of the Mercury Project the order of priority in which acceptable experiments should be incorporated into the program.

(3) To seek out and foster the generation of suitable experiments from all available sources.

In carrying out these responsibilities, the MSEP formed a close working relationship with scientists in the NASA Office of Space Sciences and the NASA Goddard Space Flight Center.

The major considerations in the evaluation of proposals for experiments by the MSEP were: scientific, technical, and biomedical merit; weight of equipment; volume and location of equipment; attitude-control-system fuel required; electrical power requirement; instrumentation requirement; effect on safety of flight; state of readiness and qualification of equipment and effect on spacecraft schedule; and extent of changes required to the spacecraft.

The MSEP functioned effectively for the MA–7 and MA–8 missions. With the approach of the MA–9 manned one-day mission, however, it became increasingly evident that the scope of the MSEP should be enlarged to include consideration of scientific experiments for MSC's advanced programs and to encompass a broader background of scientific interest.

To accomplish this broadening of responsibilities, the MSEP was supplanted in October 1962 by the Manned Spacecraft Center In-Flight Experiments Panel (IFEP). The IFEP difers from the MSEP in that its membership was enlarged to include representatives of the other two spacecraft project offices and an ex–officio member from the NASA Office of Space Sciences. Its recommendations for the implementation of experiments are made to the Director of the Manned Spacecraft Center for approval. The chairman of the IFEP is the MSC Assistant Director for Engineering and Development.

It is the policy of the MSC to make maximum use, for scientific and research purposes, of the flights scheduled under approved spacecraft programs. In keeping with this policy, the Center encourages the development of worthwhile investigations which can be implemented on manned flights within the limitations of operational requirements and flight safety. To promote this policy, the IFEP has established formal procedures for the submission, evaluation, and acceptance of proposals for inflight experiments.

Implementation of Experiments

The IFEP recommends to the MSC Office of the Director the experiments for a given spacecraft mission. With the approval of the Director, these experiments become the official experiments for the mission. An experiment coordinator was appointed from within MSC for each of the approved experiments. His responsibility was the timely development and flight qualification of hardware required for the experiment. In general, the equipment required for an experiment was furnished by the organization which had proposed the experiment.

The Mercury Project Office was responsible for the integration of experimental equipment into the Mercury spacecraft. The experiment coordinator submitted the following documentation for an approved experiment:

(1) A firm schedule showing all significant milestones for the delivery of equipment

(2) A qualification plan in accordance with specified requirements

(3) A weekly status report

To prevent the spacecraft schedule from being affected by the integration of experiments, it was necessary to set the delivery date of experimental equipment well in advance of the scheduled launch date. In a normal prelaunch schedule for a Mercury spacecraft, the final checkouts of the spacecraft and its systems are made 8 weeks prior to the scheduled launch date. Once these tests were complete, absolutely no changes were made to the spacecraft except those dictated by flight–safety considerations. Therefore, the experimental equipment was required to be at the launch site 3 months prior to the scheduled launch in order to allow sufficient time for the installation and checkout of this equipment before the final spacecraft tests were begun. It was also imperative that the flight astronaut be thoroughly familiar with the equipment and trained in its use. It becomes apparent, then, that the selection and evaluation procedure for experiments must be completed many months before the scheduled launch of a spacecraft to allow time for the design, construction, and qualification of equipment before the required delivery date.

It was specified that the qualification environments and the levels of these qualification tests for experimental equipment be no less stringent than the qualification testing that was required of all Mercury spacecraft systems. The possibility of the compromise of a Mercury mission because of the failure of a piece of experimental apparatus could not be tolerated. Failure modes of the experimental apparatus were examined very closely to assure that such failures could have no degrading effect on the mission or on pilot safety.

The responsibility for integrating experiments into the mission flight plan and into the astronaut training activities was that of the MSC Flight Crew Operations Division. This division worked closely with other elements of MSC to develop a flight plan for each mission which would accomplish the mission objectives and would, at the same time, provide for the performance of experiments. It was necessary that the flight plan be completed in final form many weeks prior to a mission so that the training of the flight astronauts in the procedure trainers would conform with the flight plan. Once the final phases of astronaut training in preparation for the mission had begun, the flight plan could not be changed except for compelling reasons because late changes could seriously disrupt the astronauts' training status to the point where mission safety could have been affected. This, then, was the second reason why experiments must have been approved for a given mission many months in advance.

Mercury Inflight Experiment Program

With this brief background on how the experimental program in manned space flight has evolved, a review of the results of the Mercury experimental program will now be presented. These experiments generally can be divided into two major categories. The first category, that of special inflight experiments, is the topic of this paper. The second category, that of analysis of observations and comments on the space environment and astronomical phenomena, is discussed in paper 19.

Planned Inflight Experiments

The inflight experiments planned for and carried out during the Mercury Project can be grouped generally into several areas of study. These areas are: (1) visual acquisition and perception experiments, (2) general photographic experiments, (3) radiation experiments, (4) tethered balloon experiment, and (5) several miscellaneous studies which include investigations of fluid behavior under zero gravity and of the characteristics of various ablative materials under reentry conditions.

Visual Acquisition and Perception Studies

In future space flights it may be necessary for astronauts to acquire and track lighted targets either on the ground or in space to provide a backup capability for rendezvous and navigation. Visual acquisition of a target in space may also be used to back up the primary method of rendezvous with other space vehicles. Experiments were, therefore, undertaken on Mercury flights to evaluate the operational problems associated with visual acquisition from space of both earth-based lights and lighted targets ejected from the spacecraft.

Ground-light experiments.—Attempts were made on each of the manned orbital Mercury flights to sight known earth-based lights at night. These studies were expected to provide information on man's ability to acquire a fixed light source against an earth background and determine to what extent targets of this type would prove useful as navigational aids in space. An attempt was made by Astronaut Glenn to sight flares launched by mortars from the Indian Ocean Ship on the first and second orbital passes of the Mercury–Atlas 6 (MA–6) flight. The astronaut was unsuccessful in his attempts to see these flares, however, because of heavy cloud coverage in the area. Attempts were again made to acquire ground flares of 1,000,000 candle-power intensity over the Woomera missile range in Australia on both the Mercury–Atlas 7 (MA–7) and Mercury–Atlas 8 (MA–8) missions. These experiments were also unsuccessful on both flights because heavy cloud cover and poor visibility prevented the pilots from sighting these targets. A ground-based xenon light located at Durban, South Africa, was also used on the MA–8 mission to increase the probability of having favorable weather at one site. Unfortunately, rain and clouds obscured the light in South Africa as well as the ground flares in Australia. Another attempt to sight the xenon light was planned for the Mercury–Atlas 9 (MA–9) mission. By using statistics furnished by the U.S. Weather Bureau to determine a favorable location, the light was positioned at Bloemfontein, South Africa. Sightings were scheduled for the sixth orbital pass and in this case Astronaut Cooper was successful in acquiring the light.

The light assembly used for this experiment, shown in figure 12–1, was a pulsed xenon arc light consisting of three sections of six lamps each. The lamps were mounted in a shallow open–top box above a polished reflector and were operated by using a 50–cycle, 220–volt, three–phase a–c circuit. Each section operated independently from a single phase and flashed once every cycle. Thus, the three sections produced a total of 150 flashes per second, well above the response of the eye, and appeared as a steady burning light. The measured average intensity of the light was found to be between 30,000 and 35,000 candle power and required between 13 and 15 kilowatts of power for operation. The light could first be viewed at a slant range of 320 nautical miles from the spacecraft and was calculated to be as bright as a 3.5 magnitude star. Astronaut Cooper estimated the light to be third magnitude in brightness when first acquired, and he was able to retain it in sight for 30 to 40 seconds before it faded out. Thus, the experiment produced sighting results approximately as predicted and the light was considered of sufficient brightness to be used as a navigational landmark. A flashing light or some distinctive light pattern, however, was believed essential for identification of a target light for any future use. The rapid angular passage of the spacecraft over the ground will also pose a problem for use of

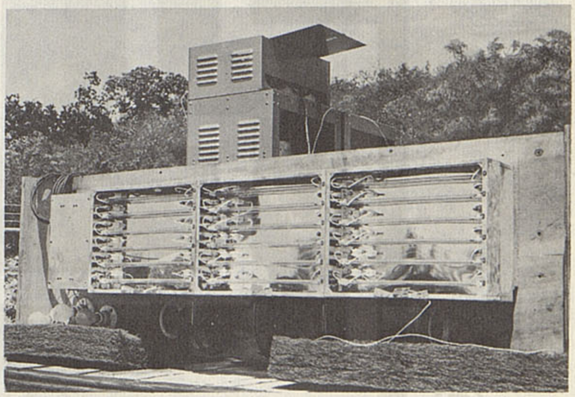

FIGURE 12–1.—Ground-light installation.

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ground targets of this sort as navigational fixes. Weather conditions on the ground also proved to be an important factor in using ground lights, and perhaps airborne lights carried above the weather region of the atmosphere would prove more dependable. More testing is needed to prove the operational feasibility of using airborne lights and to determine flash frequencies most desirable for acquisition and tracking.

Flashing-light experiment.—The problem of visual acquisition of other space vehicles directly relates to the rendezvous of two spacecraft. For visual sighting of another vehicle at ranges up to 100 miles, the problems of visual acquisition and tracking need to be identified and studied. Therefore, a study to investigate some of the problems of visual acquisition of a target vehicle in the space environment was carried out on the Mercury-Atlas 9 (MA–9) flight.

On this flight a flashing light was ejected from the spacecraft and viewed by the astronaut at varying distances in orbit. The light, its container, and the ejection mechanism were built by the NASA Langley Research Center, and the details of this assembly are shown in figure 12–2. The flashing–light unit was a 5.75–inch–diameter spherical assembly weighing about 10 pounds and equipped with two xenon–gas–discharge lamps located at opposite poles. The two lamps flashed simultaneously at a rate of approximately one signal per second. The beacon was designed to appear about as conspicuous as a second magnitude star when viewed at a distance of 8 nautical miles. As shown in the figure, the sphere was ejected from the container at a speed of 10 ft/sec by means of

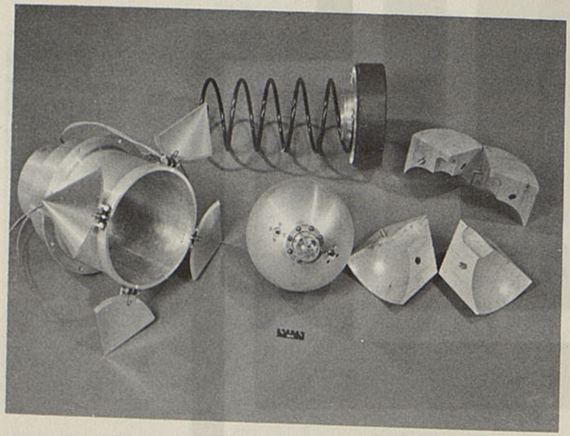

FIGURE 12–2.—Assembly for flashing-light beacon.

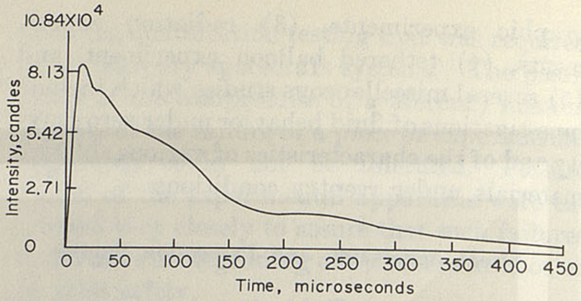

FIGURE 12–3.—Time history of a typical flash of the beacon.

a compressed spring acting against a piston when the canister covers were released. The light was powered by mercury-cell batteries, which were connected in series, and it delivered approximately 8 watt-seconds of power per flash.

A typical time history of one of the flashes is shown in figure 12–3. This figure shows that the light reached a peak intensity output of about 8.0×10^4 candles and that the light has a flash duration of about 100 microseconds at or above one–half peak intensity.

Extensive measurements were made by the National Bureau of Standards to determine the integrated light intensity and to establish that the distribution of the light was reasonably uniform in all directions and reasonably constant throughout its designed lifetime of 5 hours. Figure 12–4 is an example of this directional survey and shows the variation of integrated light output in candle–seconds per flash with light orientation. Distributional measurements of this type for varying viewing angles showed that the light output was reasonably uniform and produced a flash intensity of approximately 12 candle–seconds per flash. As shown by figure 12–4, regions near the 0° and 180° orientation showed some degradation in light intensity, with intensity falling as low as 8 to 9 candle–seconds in these regions. By using a value of 0.2 for the Blondel–Rey constant for threshold viewing of flashing lights, this light can be converted to an equivalent effective steady–light intensity of from 40 to 60 candles. This intensity corresponds to a light of second magnitude in brightness when viewed at a distance of between 7 and 8 nautical miles by using the commonly accepted value of 8.3×10^{-7} lumens per square meter for a first magnitude light. Visual air–to–air and ground–

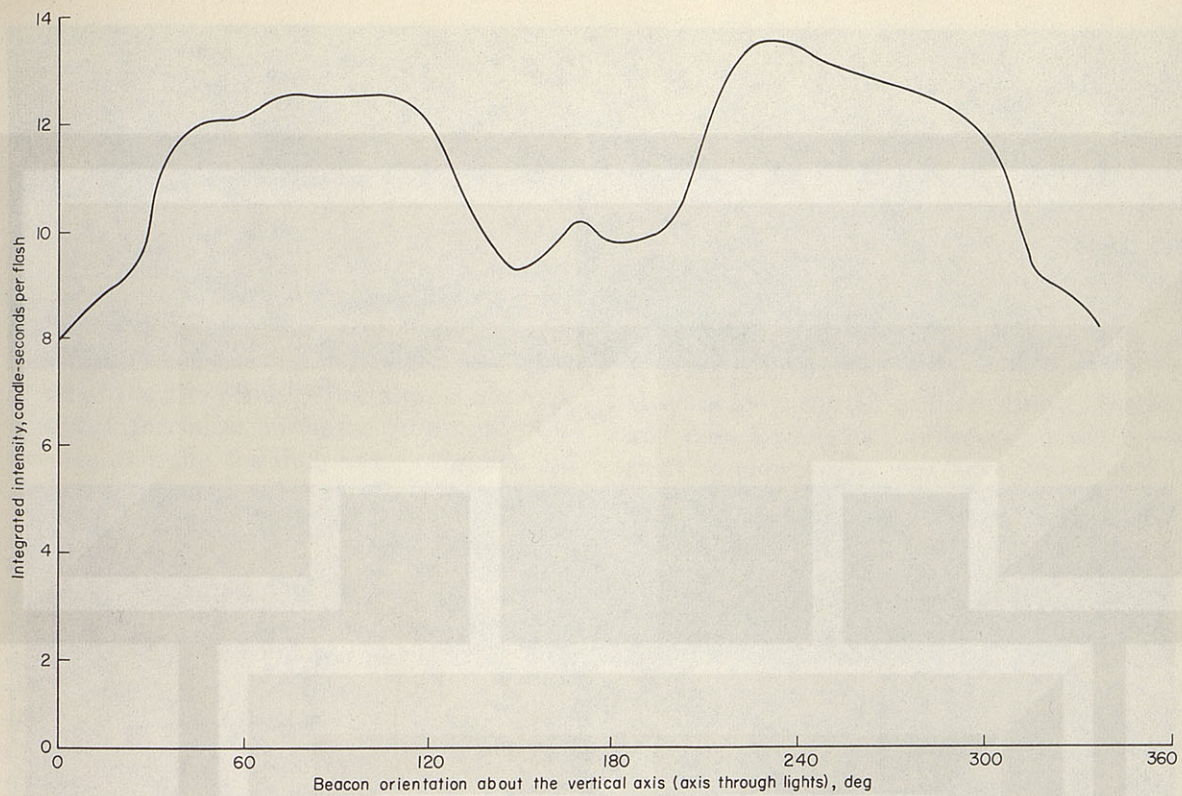

Figure 12-4.—Integrated intensity of the flashing beacon about an axis passing through the lights and inclined at 30° from the vertical.

sighting tests, with Astronaut Cooper as one of the test subjects, indicated that the light intensity was approximately the same as had been measured in the laboratory.

Trajectory studies of ballistic number, ejection angle, ejection velocity, and orbital position at ejection were made to determine the proper orbital conditions for deployment of the light. These studies showed that if the beacon were ejected 88° below the pitch horizon of the spacecraft at a velocity of 10 ft/sec, the desired trajectory would be obtained. Figure 12-5 shows the spacecraft attitude and canister location used to provide the desired ejection angle. The pilot controlled the spacecraft attitude to

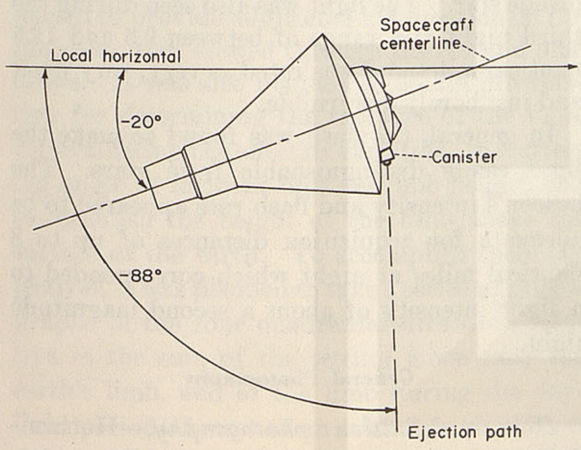

Figure 12-5.—Spacecraft orientation at beacon deployment.

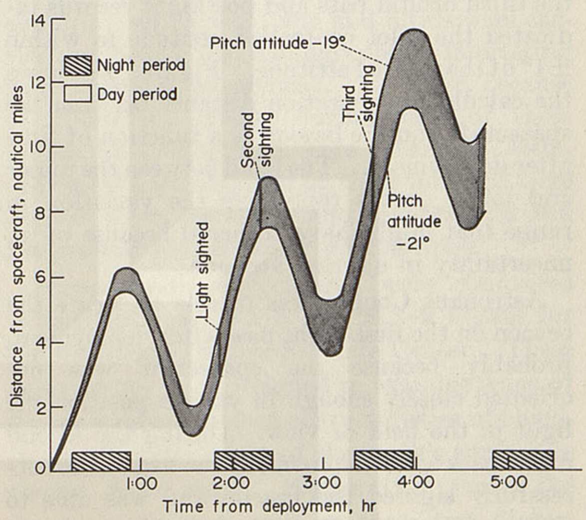

Figure 12-6.—Variation in separation distance between the spacecraft and the flashing beacon after deployment.

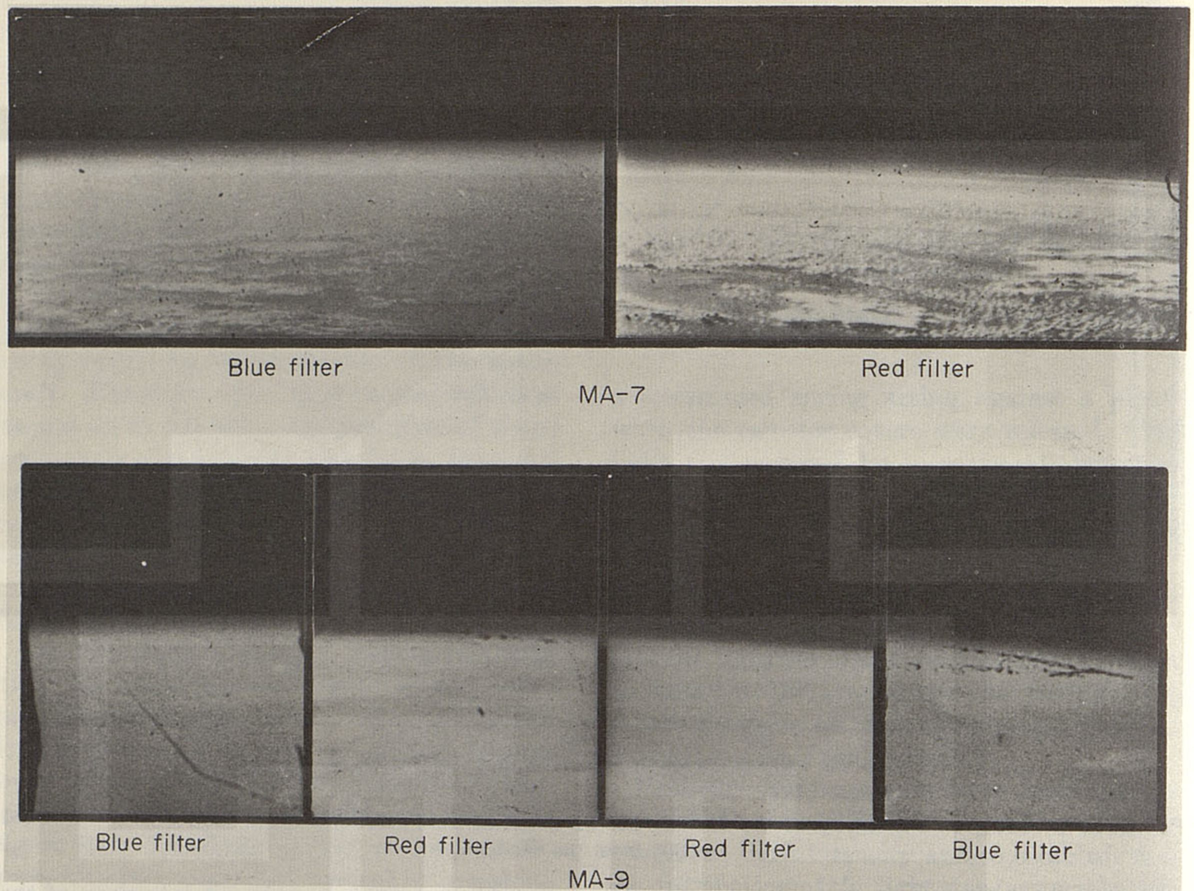

FIGURE 12-7.—Typical horizon definition photographs.

the desired position by using horizon-sighting markings on the window for aiming. The beacon was ejected 15 minutes prior to sunset on the third orbital pass and postflight records indicated the pilot controlled attitude to within ±1° of the desired attitude. Figure 12-6 shows the calculated separation distance between the spacecraft and the beacon as a function of time after deployment. The band between the upper and lower curves represents the variation in range that might have occurred because of an uncertainty in ejection attitude.

Astronaut Cooper was unable to locate the beacon on the first night pass after deployment, probably because the spacecraft was not oriented closely enough in yaw to position the light in the field of view. During the second night pass after deployment the astronaut successfully sighted the beacon and was able to change the spacecraft attitude and then return to reacquire the light. During these sightings, noted on figure 12-6, the astronaut rated the light as about one star magnitude dimmer than had been expected. For example, when the beacon was between 7.5 and 9 nautical miles away at 2 hours and 14 minutes after deployment, the light was described as not very bright but discernible, about the order of a third magnitude star. The light was also seen during the third night at a range of between 9.5 and 11.5 nautical miles and was rated as very, very weak and just barely discernible.

In general, the flash was found to make the light easily distinguishable from stars. The beacon's intensity and flash rate appeared to be adequate for acquisition distances of up to 8 nautical miles at night which corresponded to a light intensity of about a second magnitude light.

General Photography

Horozin-definition photography.—Horizon-definition photography was conducted on two Mercury space flights to assist the Instrumentation Laboratory of the Massachusetts Institute of Technology (MIT) in determining the effectiveness with which the earth's sunlit limb could be used for navigational sighting during the terminal phase of advanced space missions. Photographic studies were carried out on both the MA–7 and MA–9 flights. A 35-mm Robot camera was flown in MA–7 and a 70-mm Hasselblad was used as the photographic device for MA–9. For both flights, a special red and blue split filter was inserted in the field of view just ahead of the film plane. This filter was used to provide information on the resolution and effectiveness of using the limb as a navigation aid at the two extremes of the visible spectrum.

Data obtained from these photographic studies are presently being analyzed by Instrumentation Laboratory scientists under the direction of Dr. Max Peterson. Limited results of the MA–7 flight have shown, as expected, that the earth's limb viewed through a blue filter has a somewhat higher elevation than when viewed through a red filter. This distinction is clearly evident in figure 12–7 which shows typical photographs obtained on both the MA–7 and MA–9 flights. The MA–7 flight results have shown that contrast and definition are improved when viewed in the longer wavelengths of the visible spectrum (see fig. 12–7). The limb viewed through a blue filter is expected, however, to provide a better navigational reference because the blue limb appears more stable and is not as subject to interference effects from clouds and other atmospheric conditions as is the red limb.

The MA–9 photographic study was conducted to provide additional information on the limb elevation viewed through the red and blue filters. It was also planned to obtain information for determining the radiance of the limb, for evaluating the effect of variations in scattering angle of incident light on limb height, and to establish the height of the limb above the surface of the earth. To accomplish these objectives, it was planned to take a series of photographs in the four quadrantal directions relative to the sun, of the setting moon near the earth's limb, and of the limb during the daylight period of most of an orbital pass. It was not possible to obtain the daylight–period photographs on the MA–9 flight because of operational difficulties during the period in which this photography was planned.

A preliminary analysis of the MA–9 photographs taken substantiates the initial results of the MA–7 flight. Although the analysis is not yet complete, it is expected that the limb radiance in both the red and blue portions of the spectrum can be fairly accurately established. An accurate determination of the height of the limb cannot be made by using data from the MA–9 flight, however, because the image of the moon is too distorted and indistinct. The film and dust layer which collected on the spacecraft window might well have contributed to this indistinct image. Although no significant difference in limb height was noted when the four quadrantal photographs were compared, much more data covering a wide variation in the angle of incidence of sunlight striking the atmosphere are needed to determine the effect of variation in scattering angle on limb height. In order, therefore, to establish the value of the earth's limb as a navigational reference, additional studies are needed to determine limb height and the variation in this height at different scattering angles of incident light.

Weather photography.—Weather observations and photography were carried out during the Mercury flight program to augment other meteorological information and to provide specific information that would be useful in designing advanced weather satellite systems. On both the MA–6 and MA–7 missions, cameras equipped with special film and filters were carried on board for photographing interesting meteorological phenomena. However, because of difficulties arising during each of these flights, no photographs were obtained. Meteorological data obtained on these missions were derived from the astronauts' observations and the general-purpose color photography.

Photographic experiments were conducted during both the MA–8 and MA–9 flights for the National Weather Satellite Center. These experiments were designed to examine some of the spectral reflectance characteristics of cloud, land, and water areas of the earth's surface as viewed from space. Figure 12–8 shows the camera and filters used on these two flights. The 70-mm Hasselblad camera shown in the figure was used for both missions. For the

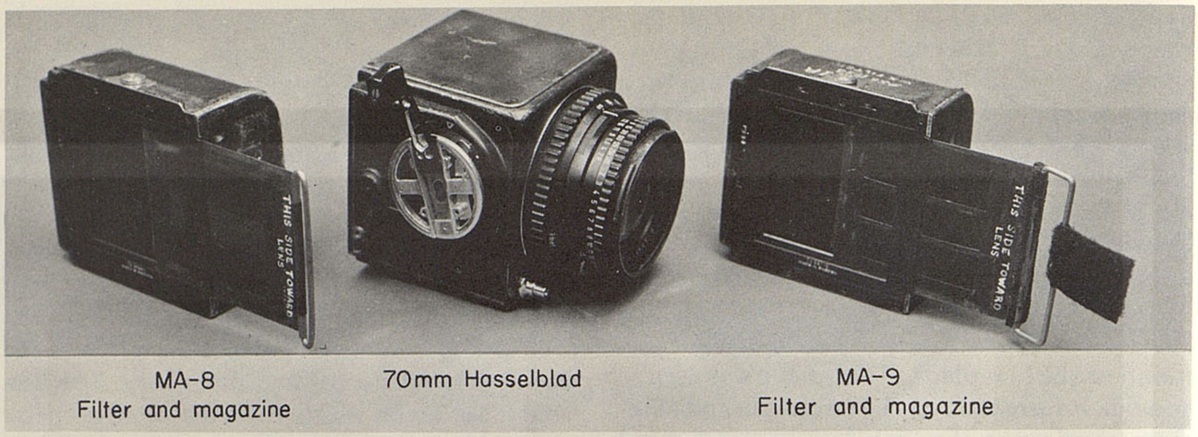

FIGURE 12–8.—Photographic equipment used for Weather Bureau experiment.

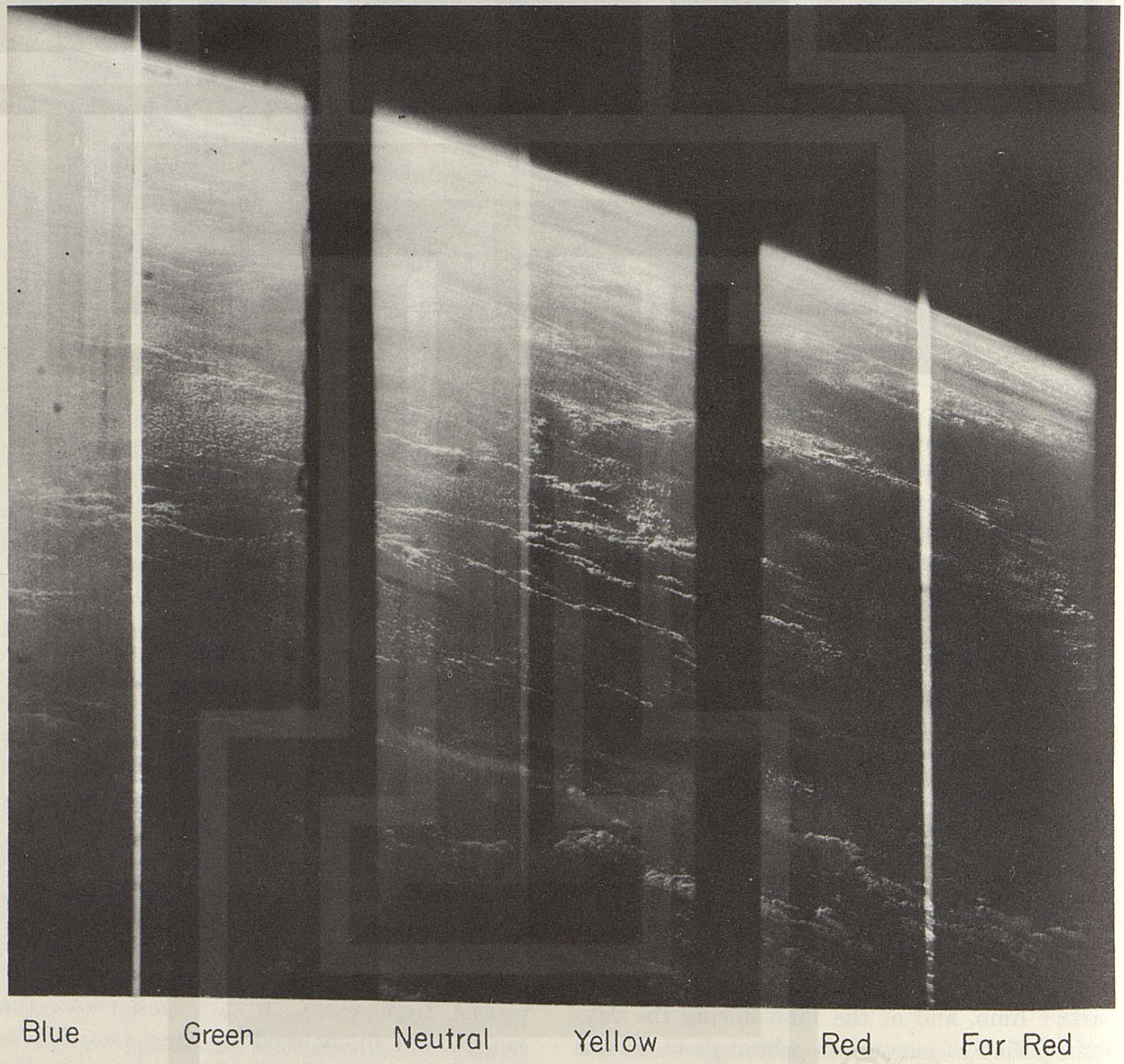

FIGURE 12–9.—Weather photograph of a region of the South Atlantic, southeast of Brazil taken by Astronaut Schirra on the MA–8 flight.

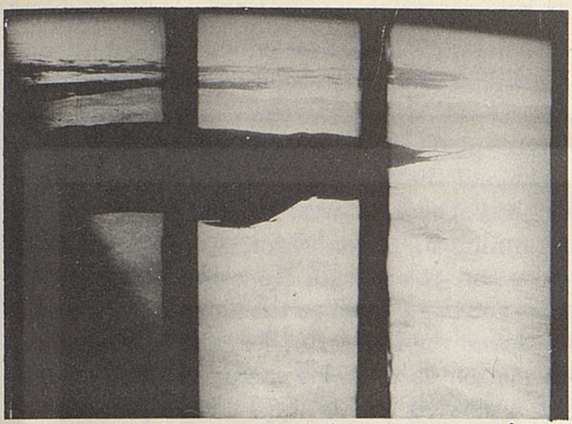

FIGURE 12–10.—Weather photograph of the Baja California area taken by Astronaut Cooper on MA–9.

MA–8 mission a wide bandpass Wratten filter consisting of six elements varied in range of spectral transmission from blue to far red. Neutral density was added to each of the color filters to produce a nearly uniform neutral density over the entire spectrum examined. Film sensitivity extended from 3,700 Å to 7,200 Å thus limiting the wavelength response to 7,200 Å.

Figure 12–9 is a photograph from the series obtained during the MA–8 flight and was taken over the South Atlantic on the fifth orbital pass. It was exposed at an altitude of 140 nautical miles viewing northwest toward the southeast coast of Brazil approximately 1,000 miles away. Analyses of this and other photographs of this series were carried out by Mr. Stanley Soules of the National Weather Satellite Center to provide design inputs to future weather satellites. Results from the MA–8 flight indicated that contrast increased with wavelength in the visible spectrum as shown by figure 12–9. These results indicate that the optimum wavelength for viewing the earth might be the near infra-red spectrum where scattering by atmospheric particles is relatively low.

The MA–9 weather photography was conducted to investigate this hypothesis by using infra-red film and a special filter shown in figure 12–10. This filter divided the infra-red spectrum from 6,600 Å to 9,000 Å into three parts. To accomplish this division of the spectrum, the filter was divided into three sections each having the bandpass width shown in figure 12–10, which is a typical photograph and was taken over southern Arizona looking westward. As pointed out by Mr. Soules in his analysis of these results, water has a very low reflectance in the near infra-red as shown by the dark portion on the left of the photograph covering the Pacific Ocean. Clouds and land have a very high reflectance; hence, coastlines and cloud patterns over water are easily discernible. However, as illustrated by the figure, clouds are more difficult to detect over land area because both the clouds and land areas covered with green vegetation have a high reflectance.

Terrain photographs.—Terrain photographs have constituted a portion of the general purpose photographs on each of the four manned orbital flights. However, they were specifically scheduled as a part of the flight plan on only the MA–8 mission. On the other three flights, terrestrial photographs were taken when the opportunity arose rather than as specifically planned activities. These photographs were taken to aid in building up a catalog of space photographs of various geological features such as folded mountains, fault zones, and volcanic fields, and to provide topographical information over a major portion of the earth's surface. They were taken on each flight by using high-speed color film in the general-purpose camera carried aboard for the flight. The following table lists the camera and exposure settings used on each flight.

Generally, the terrain photographs of the first three manned orbital flights were of poorer

Flight	Camera	Film	Exposure
MA–6	35–mm Ansco Autoset	Eastman color negative stock no. 5250	Automatic
MA–7	35–mm Robot Recorder	Eastman color negative stock no. 5250	1/125 at f/16
MA–8	70–mm Hasselblad	Super Anscochrome color ASA no. 160	1/125 at f/11
MA–9	70–mm Hasselblad	Ultraspeed Anscochrome color FPC 289	1/250 at f/16

quality than those obtained on the MA–9 mission, although some useful photographs were obtained on each of these flights. The reduced quality of the photographs on these first missions resulted primarily from the much poorer weather conditions that existed over the land areas of the earth and by the limited land area covered during the flights. It was quite fortunate that worldwide weather conditions during the MA–9 mission were much better than on previous flights; and because of the favorable weather and the fact that the flight covered many land areas of the world, excellent photographic coverage, particularly regions of the African and Asian deserts and the Himalaya mountains, was possible.

Preliminary analysis of these photographs has been made by Mr. Paul D. Lowman of the NASA Goddard Space Flight Center and is presented in paper 19. As a result of the analysis of these photographs, Mr. Lowman concluded that potentially useful geological and topographical information could be obtained from all terrain photographs taken during orbital flight. The quality and resolution of these photographs approached or equaled that of the black and white exposures from the best rocket flights.

Dim–light photography.—A dim–light photographic experiment sponsored by the School of Physics, University of Minnesota, was carried out for the MA–9 mission to obtain photographic data on two dim–light phenomena best observed outside the earth's atmosphere. These phenomena are the so–called zodiacal light and the night airglow. Photographs of the zodiacal light were needed to assist in determining its exact origin, geometric distribution, and relationship to solar radiation and flare activity. Data on the airglow were needed to define the layer further and to provide information on the solar energy conversion process occurring in the upper atmosphere.

Figure 12–11 shows a photograph of the 35–mm Robot camera as it was modified for this experiment. The camera was equipped with an automatic film advance and had a fixed lens with an equivalent speed of f/0.95. Exposures were timed manually, and the camera controls were simplified to improve operation by the astronaut in a pressure suit. Three small supports or "feet" (see fig. 12–11) were provided to aid the pilot in positioning the camera against the window for aiming.

Photographs, varying in exposure time from 1 to 30 seconds, of the zodiacal light were to begin immediately after sunset and were to cover the ecliptic region from sunset to about 30° of arc past sunset. Photographs of the airglow layer were to be taken periodically over an entire night orbital pass with exposures varying in duration from 10 to 120 seconds.

Unfortunately, the zodiacal–light sequence yielded very little useful data since all of these photographs were underexposed. A small de-

FIGURE 12–11.—Modified Robot camera used for MA–9 dim-light photography.

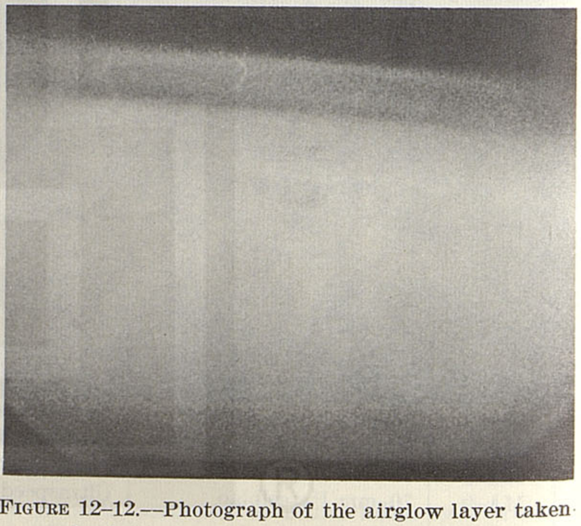

FIGURE 12–12.—Photograph of the airglow layer taken by Astronaut Cooper on the MA–9 flight.

lay in initiating the sequence or an error in exposure time could have caused these unsatisfactory results since the gradient in zodiacal light intensity varies quite rapidly near the sun.

The airglow photographs, however, were of quite usable quality. A representative photograph from this experiment is shown in figure 12–12. Preliminary analysis of these photographs by Dr. Edward P. Ney and associates at the University of Minnesota has shown them to be useful in determining surface brightness of the airglow layer. These photographs also were found to be valuable for assessing the height of the layer with varying latitude, in measuring the angular width of the band, and in determining angular displacement above the earth's horizon. Considerably greater discussion of this phenomenon is presented in paper 19.

Radiation Experiments

Some form of radiation measurement has been included on all Mercury space flights to record the dose received by the astronaut and to furnish experimental information on the space radiation environment over the Mercury altitude profile.

Generally, data obtained during these experiments were measured by the following method:

(1) Studies in which film or lithium-fluoride thermoluminescent detectors were used to measure the dosage to the astronaut.

(2) Emulsion packs and ionization chambers to measure the radiation level inside the spacecraft.

(3) A package containing Geiger-Mueller tubes to measure the electron flux external to the spacecraft.

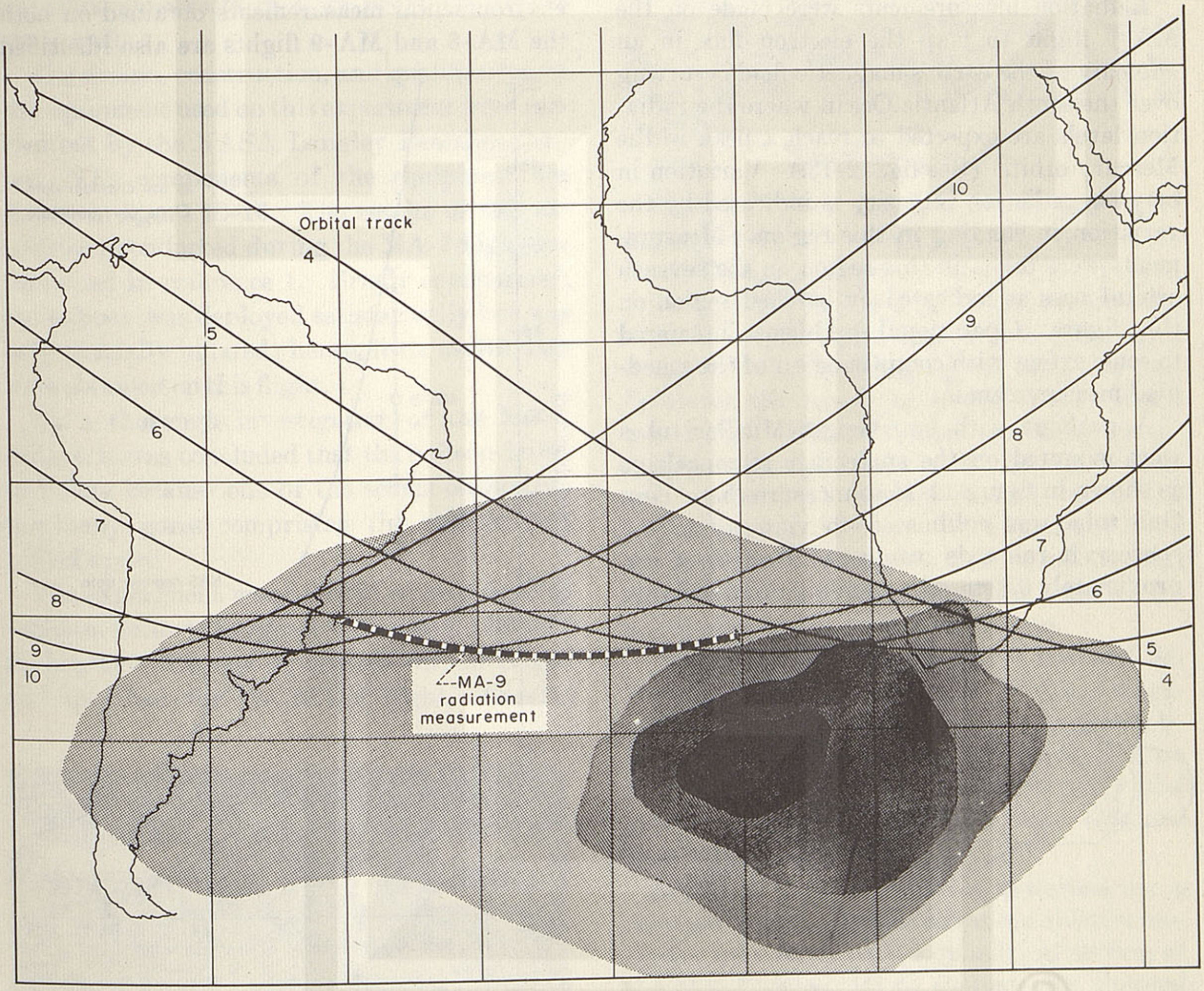

FIGURE 12–13.—Variation in predicted flux at 100 km in the anomaly of the earth's magnetic field over the South Atlantic on the MA–9 flight. Increased flux density shown by increase in amount of shading.

Film badges and thermoluminescent detectors used to monitor the electron dose to the astronaut were mounted on the helmet and on the chest and thigh of the astronaut's undergarments on each of the final two manned orbital flights. Evaluation of these detectors has shown that the radiation dosage received by the astronaut is quite low, less than that normally received by a man from cosmic radiation in 2 weeks on the surface of the earth.

Emulsion packs carried on the MA–8 and MA–9 flight at several locations inside the spacecraft as well as an ionization chamber mounted on the spacecraft hatch were used to assess the radiation level inside the spacecraft. Data obtained from these devices generally agreed with results derived from the film badges and showed a very low radiation level inside the spacecraft.

Radiation measurements were made on the MA–9 flight to map the electron flux in an anomaly of the earth's magnetic field occurring over the south Atlantic Ocean where the radiation levels are expected to reach a peak in the Mercury orbit. (See fig. 12–13.) Variation in between radiation intensity is indicated by the variation in shading in this region. Measurements were taken in this region on the seventh orbital pass as indicated by hatched region on this figure. Operational problems interfered to some extent with completing all of the scheduled measurements.

A package with two Geiger–Mueller tubes were mounted on the spacecraft retropackage as shown in figure 12–14 to measure these data. One tube was collimated to view along the spacecraft roll axis over a solid angle of approximately 0.8 steradian as illustrated in figure 12–14. The other tube viewed essentially a hemispherical area about a direction 40° below the roll axis.

The uncollimated tube was shielded to reject all electrons having energy levels less than 2.5 mev to avoid saturation, and because the radiation level in the anomaly was much lower than anticipated the shielded tube was never energized sufficiently to record usable data. Usable data were recorded by the collimated tube.

Results obtained from these Gieger–Mueller tubes and emulsion package measurements from both the MA–8 and MA–9 missions, summarizing the decay of the artificial electron belt created by the July 1962 atomic explosion, are shown in figure 12–15. The solid curve defines the decay in percent of initial flux based on unpublished riometer data of Dr. Gordon Little of the National Bureau of Standards (NBS). The environmental measurements obtained on both the MA–8 and MA–9 flights are also identified

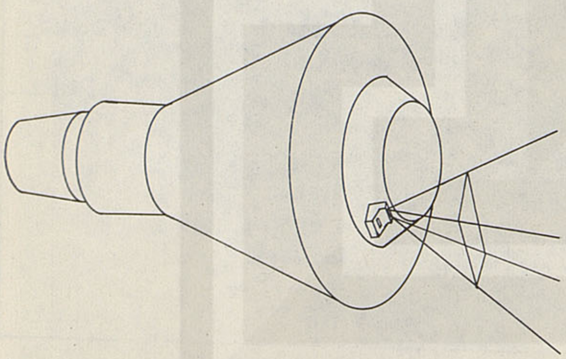

Figure 12–14.—Geiger-Mueller tube installation on the MA–9 spacecraft.

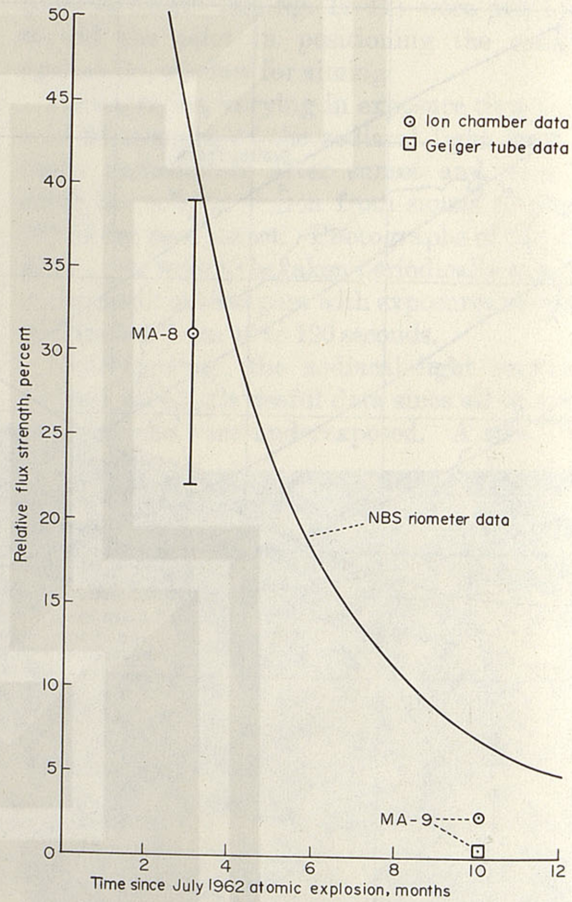

Figure 12–15.—Results showing artificial electron flux decay in the magnetic anomaly over the South Atlantic.

in the figure. The electron belt is shown to have decayed as predicted by several orders of magnitude during the time period between MA–8 and MA–9 flights, possibly because of atmospheric collisions or other processes.

Tethered Balloon Experiment

A 30-inch mylar inflatable sphere was packaged in the antenna canister of both the MA–7 (see ref. 1) and MA–9 Mercury spacecraft. These balloons were to be ejected, inflated, and towed at the end of a 100-foot nylon line through one orbital pass to measure the drag experienced by the balloon throughout the orbit. The measured drag could then be readily converted into air density over the Mercury altitude profile. In addition, it was hoped that the astronaut could obtain some sightings yielding visual data on objects in close proximity to the spacecraft.

The design, construction, and qualification of the equipment used on this experiment were carried out by the NASA Langley Research Center. The components of the equipment are shown in figure 12–16. The results of this experiment conducted during the MA–7 flight are contained in reference 1. Briefly summarized, the balloon was deployed satisfactorily but was only partially inflated; hence, little useful data were obtained on this flight.

By a thorough investigation of the MA–7 failure, it was concluded that the balloon failed to inflate because one of the seams connecting the many gores comprising the balloon skin pulled apart.

The experiment was believed to have been of sufficient value to be repeated on a later Mercury flight; therefore, new equipment was developed and qualified for the MA–9 flight. Careful control of balloon construction was maintained throughout the development program and numerous deployment and inflation tests were conducted by the Langley Research Center to insure the quality of the device. These tests were conducted with the flight equipment under conditions which closely simulated the space environment without a single failure. Numerous squib firings were made, without a single failure, to insure that either one or both of the squibs used to unlatch the cover of the canister would accomplish this task. The assembled unit was carefully checked after installation on the spacecraft and was found to be satisfactory. It was, therefore, believed that this experiment was well qualified for flight, but unfortunately the balloon failed to deploy in flight. Failure was attributed to some malfunction in the squib-firing circuit that released the hatch cover of the balloon canister. The exact cause of this malfunction could not be determined because the circuit was contained in the spacecraft antenna canister which is jettisoned prior to landing.

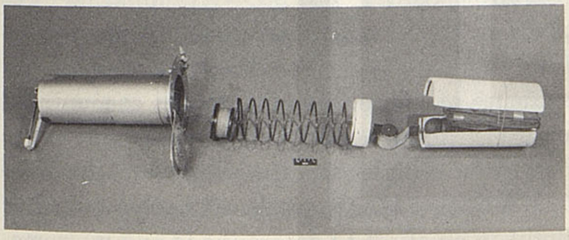

FIGURE 12–16.—Balloon canister assembly.

Miscellaneous Studies

Study of liquid behavior at zero gravity.— An experiment sponsored jointly by the NASA Lewis Research Center and the NASA Manned Spacecraft Center was developed to examine the behavior of fluids of known properties in a weightless state by using a given container configuration and was flown on the MA–7 mission (see ref. 1). Basically, this experiment was intended to provide data that would complement and extend work already carried out at the Lewis Research Center. Data obtained from this study were expected to provide information relating to the tankage and fuel transfer requirements on future space missions.

The results of this experiment are well defined in reference 1 and other NASA publications dealing with this subject. It need only be noted here that the limited results obtained on this experiment generally tended to verify past experimental and theoretical data obtained from laboratory studies.

Study of various ablative materials on a Mercury flight.—Several advanced ablative materials were flown on the cylindrical section of the MA–8 spacecraft to evaluate the thermal performance of each. These materials were

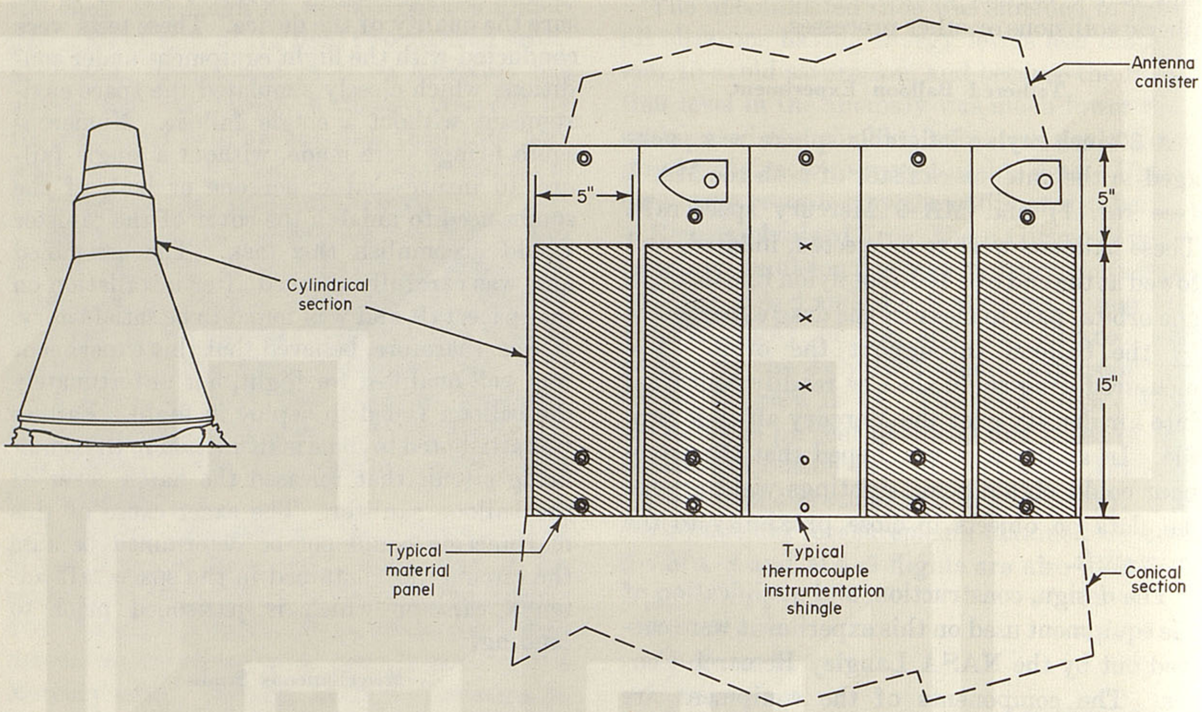

Figure 12–17.—Location of ablation panels on the Mercury spacecraft used for the MA–8 flight.

located as shown in figure 12–17. Each ablative panel was 15 inches long and 5 inches wide. Each sample was centered on a beryllium shingle and was attached to the shingle at the cone–cylinder junction of the spacecraft. The materials were bonded to each of these shingles, and temperature–sensitive paints were applied to the rear face of the shingles to assist in determining the temperature profiles present along the ablation panels during reentry. (See ref. 2.)

Upon completion of the MA–8 flight, each strip of ablative material was removed from the spacecraft and examined to determine char depth and temperature distribution and to examine the material for delaminations, pitting, and cracks.

It was not possible to compare the panels collectively because of significant circumferential variation in heating around the cylindrical section, probably caused by a spacecraft angle of attack of 2° during high heating. As expected, all samples showed an increasing thermal exposure and char depth with length aft (away from the blunt end) along the specimen. No material, regardless of the heat rate to which it was exposed, showed any marked superiority in performance over that of the other specimens although the elastomeric materials did prove superior to hard ablation materials in limiting the growth or delamination of intentional cutouts. Surface effects and imperfections noted during preflight ground testing were also evident during the postflight analysis, but to a lesser extent. However, the scaling effect when comparing the relatively large specimens flown with those tested in a ground facility has not been established.

Micrometeorite studies.—Examination was made of all the spacecraft flown on manned orbital flights during the Mercury Project for evidence of micrometeorite impact encountered in orbit. Macroscopic surveys were made of the beryllium shingles and the window of the MA–6, MA–7, and MA–8 spacecraft before and after flight in an effort to determine if any micrometeorite impacts could be detected. Microscopic

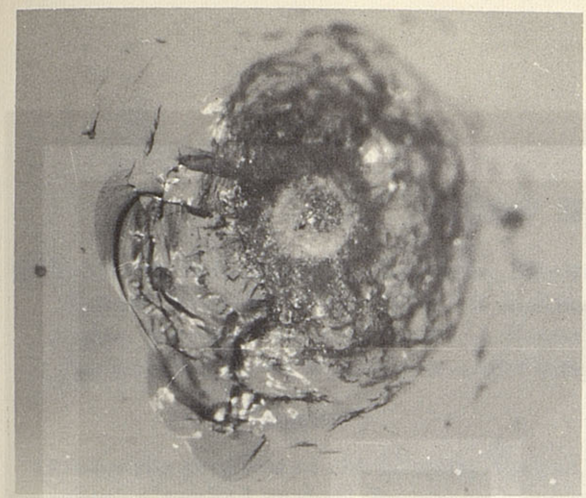

FIGURE 12–18.—Photograph of the surface pit on the window of the MA–9 spacecraft. X42, top and bottom lighted.

surveys were made of the areas in which any indications of impact were noted. As a result of these examinations, no evidence was found that could be construed to be a micrometeorite impact.

Microscopic mapping of the vycor window of the MA–9 spacecraft was performed before and after the mission. During the postflight survey, one small surface pit was detected on the outer surface of the MA–9 spacecraft window. A photograph of this pit is shown in figure 12–18. This surface pit has the circular shape, depth to width ratio, and general characteristics of a hypervelocity impact in basalt. Further analysis is in progress to ascertain whether or not the pit resulted from a micrometeorite impact or was caused by spacecraft debris encountered during reentry.

References

1. BOYNTON, JOHN H., and FIELDS, E. M.: *Spacecraft and Launch–Vehicle Performance.* Results of the Second United States Manned Orbital Space Flight, May 24, 1962. NASA SP–6. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 1–14.
2. BOYNTON, JOHN H., and FISHER, LEWIS R.: *Spacecraft and Launch–Vehicle Performance.* Results of the Third United States Manned Orbital Space Flight, October 3, 1962. NASA SP–12. Supt. Doc., U.S. Government Printing Office (Washington, D.C.), pp. 1–11.

13. FLIGHT DATA REPORTING

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Summary

During the progress of the Mercury Project an effective method evolved for the postflight data processing, analysis of systems performance, and timely reporting of the results of the analyses. This method was a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. It was learned that there is a need for extensively planning the report preparation effort and establishing procedures for expediting data processing in order to provide engineering data rapidly and in readily usable forms. It was also learned that for a report to be effective, it must be factual, carefully written, and edited.

Introduction

The success of a complex technical endeavor, such as Project Mercury, depends to a great extent on the ability to analyze and report rapidly the very large amount of information which is generated. Rapid availability of information was essential to maintain the Mercury schedule, since the developments from any mission might need to be implemented for subsequent missions.

Extensive planning and scheduling was done to facilitate the acquisition and preparation of data. The flight data and information were examined to determine weaknesses and malfunctions in the performance of manufactured systems and human organizations, and to verify the proper performance of these systems and organizations. When these analyses had been made, they were summarized and a brief, accurate, and factual report was written so that the management of the program would have available all significant information to aid in making necessary decisions. This primary report of the results for each flight, the Postlaunch Memorandum Report, is discussed in detail in this paper.

This paper describes the techniques employed to process raw data into usable form, to obtain the overall analysis of mission results, and to report those results to management.

The processing of certain data, such as the trajectory information from the radar tracking network, and the numerous reports that were made by the spacecraft contractor and other supporting organizations after each mission, are not discussed in this paper.

Scope

Data Sources

The flight data with which this paper is primarily concerned were those data available from the spacecraft onboard tape recorders since these tapes contained the most complete data and were available for quick processing. The onboard tape included information pertaining to the operation of the spacecraft systems, the astronaut's physiological conditions, the pilot's voice communications, and other special measurements. A list of typical measurements is presented in table 13–I. Most of this information was also transmitted to the ground and recorded by range network stations, and some of the information was displayed in real time to monitoring personnel. These range-recorded data have often become critical to the analysis conducted after the flight, in addition to serving as a complement for the onboard recorded data. Since the spacecraft sank in deep water following the Mercury-Redstone 4 (MR–4) flight, the onboard-recorded data were not recovered, and the range-recorded data became the only source of information from this flight. In the Mercury-Atlas 9 (MA–9) mission, the tape supply of the onboard recorder was insufficient to provide continuous recording for the entire mission; therefore, the range-recorded data were used to supplement the onboard-recorded data.

Table 13–I.—List of Typical Recorded Flight Measurements

- Flight accelerations in three axes
- Physiological measurements
  - Body temperature
  - ECG
  - Blood pressure
  - Respiration rate and depth
- Events (approximately 20)
- Environmental control system
  - Oxygen supply pressures
  - Suit pressure and temperature
  - Cabin pressure and temperature
  - Static pressure
  - Heat exchanger temperatures
  - Oxygen and carbon dioxide partial pressures
- Electrical system
  - Instrumentation reference voltages
  - Main, standby, and isolated bus voltages and current
  - Fans and ASCS bus a-c voltages
  - Inverter temperatures
- Communications system
  - Command receiver signal strength
  - Command receiver on-off
- Reaction control system
  - Automatic and manual fuel pressures
  - Fuel line and thruster temperatures
- Stabilization and control system
  - Control stick positions
  - Spacecraft attitudes (gyros)
  - Spacecraft attitudes (horizon scanners)
  - Automatic system high and low thruster actuation
  - Spacecraft attitude rates
- Onboard time
  - Time since launch
  - Time of retrosequence initiation
  - Time since retrorocket ignition
- Structural heating
  - Heat shield temperatures
  - Retrorocket temperatures
  - Shingle temperatures
- Experiments
  - Balloon drag
  - Radiation flux density

The pilot's comments recorded during the mission and in postflight debriefings were an important source of information. This information was used in many cases in defining the performance of the spacecraft or launch vehicle systems when the measured data were lacking or permitted ambiguous interpretations. Even more important, the pilot's debriefings and reports were the only source of information regarding many of his observations.

Additional sources of information during various flights were provided by a variety of cameras which were carried onboard the spacecraft and used to photograph the instrument panel, the astronaut, the view through the spacecraft window, and, for the unmanned Mercury-Redstone and Mercury-Atlas flights, the view field of the periscope.

Analysis

The analysis of the flight data began at the launch site during the flight and continued until the Postlaunch Memorandum Report (PLMR) was completed. The analysis of problems requiring study beyond the publication date of the PLMR was continued to completion, and the method of reporting the final results is discussed in the following section of this paper.

Reporting

The results and analyses for each mission were (or will be) presented in five formal NASA reports, which are listed in table 13–II.

The first of these reports, issued in the form of a telegram approximately 2 days after the end of the mission, gave a broad overall summary of mission results as they were known at that time. For most of the flights this report was issued within a day of the end of the mission in order to disseminate the available information as quickly as possible; however, for the MA–9 flight it was found that more time was needed to gather and summarize significant information, and as a result this telegram was issued 3 days after the end of the flight. This first report had a very limited distribution, going only to those organizations directly concerned with the mission.

The second of these reports, also issued in the form of a telegram approximately 6 to 10

Table 13–II.—Mercury Postflight Reports

Type of Report	Approximate period to report completion, days[a]						Classification	Content
	MR–3	MR–4	MA–6	MA–7	MA–8	MA–9		
Telegram (preliminary)	1	1	1	1	1	3	Confidential	Broad overall summary of mission results as known at that time.
Telegram (Interim)	[b]	[b]	7	7	9	10	Confidential	Updated version of preliminary telegram describing status and problem areas.
Postlaunch Memorandum Report (PLMR)	11	10	11	14	19	26	Confidential	Contains all detailed spacecraft data and description of resolutions of problem areas or status of investigations of unresolved problems. This report contains 95 to 98 percent of all important information that would come from the mission.
Public Release [c]	30	30	44	80	90	130	Unclassified	Summary report of mission results for distribution to the public.
Technical Memorandum (TM) or Working Paper (WP)	41[d]	60[d]	[e]	[e]	[e]	[e]	Confidential	Official presentation of detailed analysis of mission. This report is an updated version of PLMR with latest information and in a format suitable for distribution to the technical community.

[a] Elapsed calendar days from end of mission to completion of final review and editing.
[b] Interim telegrams were not used for MR–3, and MR–4.
[c] See references 1 to 5 and this document.
[d] WP.
[e] TM, in preparation.

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days after the end of the mission for the more recent manned missions, had a dual purpose. The first purpose was to show any significant changes to the information contained in the first telegram, and the second purpose was to describe the status of the analysis of the mission results at that time with emphasis on any problem areas. Any problems encountered during the mission were of particular interest since such problems might have a direct effect on the schedule or the prepartions for the next mission; as a consequence, little time was spent in this second telegram discussing systems that had exhibited satisfactory performance. This telegram had the same limited distribution as the first telegram.

The third type of report, the PLMR, was bound into one or more volumes depending on the amount of information contained. This report was completed in a period of 10 to 26 days, and contained 90 to 95 percent of the significant information that would come from the flight. The amount of time needed to complete the report depended primarily on the amount of data collected during the mission. This report was the most important of the postflight reports in terms of its usefulness to the program management in the timely prosecution of the program. This report had a relatively wide distribution within NASA.

The fourth of these reports was a summary of the important highlights of the mission, with classified information deleted to permit release to the public (see refs. 1 to 5).

The fifth of these reports was issued as a working paper (WP) for the Mercury-Redstone manned flights. The WP was used for rapid dissemination of information, and the format and quality of presentation was not suitable for general distribution outside NASA. For the manned Mercury-Atlas flights the fifth report will be issued as a Technical Memorandum (TM), suitable for distribution outside NASA. These TM's (one for each mission) will be distributed within the scientific community after publication. Both the WP's and TM's contained, or will contain, the significant information published in the PLMR's plus any additional results that became available after publication of the PLMR.

The remainder of this paper will be limited to discussion of the preflight and postflight activities related to the PLMR.

Report Planning and Organization

Planning

In the early days of the Mercury Project, the planning and organization for postflight analysis and reporting of mission results did not need to be very elaborate, and these plans were made known to the participants on an informal verbal basis. A NASA Project Engineer was responsible for all aspects of a particular flight.

For the first few flights, such as the pad-abort flight and early Little Joe flights, the flight time was measured in minutes, with a relatively small amount of data collected. The analysis and reporting effort, though intensive, was correspondingly small in terms of the number of people involved and the total amount of time spent when compared to the later orbital flights. All of this analysis and report preparation was done at the launch site at Wallops Island, Virginia.

The plans for organizing the analysis and reporting efforts continued on an informal basis through the Little Joe phase of the Mercury Project and extended into the Redstone and Atlas phases. As the flight time, amount of data, and number and complexity of the systems to be analyzed increased, and the number of personnel grew, it became difficult and then virtually impossible to disseminate by verbal discussions and telephone calls the work assignments, schedules, changes in plans, et cetera, to the participating personnel. To circumvent these difficulties, informal memorandums came into increasing use. As a result, prior to the MA–5 flight a data processing, analysis, and reporting schedule was prepared for the first time, and was in the form of a five-page memorandum. This memorandum, which was distributed to all participating personnel and to the necessary organizations, outlined the schedule for data processing and noted when and where various types of data would be available, the assignment of individuals to various sections of the PLMR, and the detailed schedule for the writing and editing of the various sections of the report. This procedure was found to be effective, and the memorandum grew steadily in scope and detail as the need for additional information became evident through the subsequent orbital missions. For the MA–9 mission this memorandum had grown to 31 pages. It contained such things as personnel assignments, data-availability and report-preparation schedules, schedule of the pilot's postflight activities including debriefings, locations of various facilities where people would be working on data analysis and report preparation, and a definition of the responsibilities and work scope of the organizational elements participating.

Organization

The organization of the effort of the analysis and reporting went through a continuing evolution as the Mercury flight program proceeded, up through the PLMR for the MA–5 flight. By this time, a method of organizing the effort had evolved which was satisfactory in producing in a short time a reasonably complete and factual report, written with sufficient clarity.

As in the case of the dissemination of the plans, the organization of the effort for analysis and reporting was relatively small and informal for the first few flights of the Mercury Project. The effort was headed by the NASA Project Engineer for that particular flight, who largely determined the scope of the analysis effort and edited the various sections of the PLMR.

During a part of the early phase of the Mercury-Atlas and Mercury-Redstone flights, as the analysis and reporting became more complex because of the increasing complexity of the flights, additional NASA organizational elements became more deeply involved in the analysis and reporting. Because of this, there was a movement to create an editorial board consisting of one member from three or four of the major organizational elements involved, with each member having equal responsibility and authority. One of the early Mercury-Atlas reports was prepared under the direction of a three-man editorial board but this arrangement was quickly found to be unworkable mainly from the standpoint of settling policy and procedural questions that inevitably arose during each analysis and reporting effort. The method of managing this analysis and reporting effort reverted for the next flight to an arrangement with a single organization responsible for the effort. This arrangement was kept throughout the remainder of the Mercury Project.

Prior to the first manned Mercury–Redstone (MR–3) flight, the increasing responsibilities for data analysis and reporting had resulted in the assignment of key technical personnel to duties on editorial boards or Senior Editorial Committees headed in each case by the appropriate project engineer. The function of this editorial board was to actively participate in the planning and monitoring of postflight systems testing, data analysis, and editing of sections of the report.

The membership of the editorial board during the early flights changed from flight to flight, but usually one or more members were the same for at least two flights in order to provide continuity and some consistency of effort. The PLMR editorial board for MA–5 and a majority of the systems-performance analysts were for the most part the same people who had served in those capacities for the PLMR for MA–4, and these personnel assignments remained relatively constant for the remainder of the Mercury Project.

As an example of the organizational arrangement of the reporting team, figure 13–1 shows

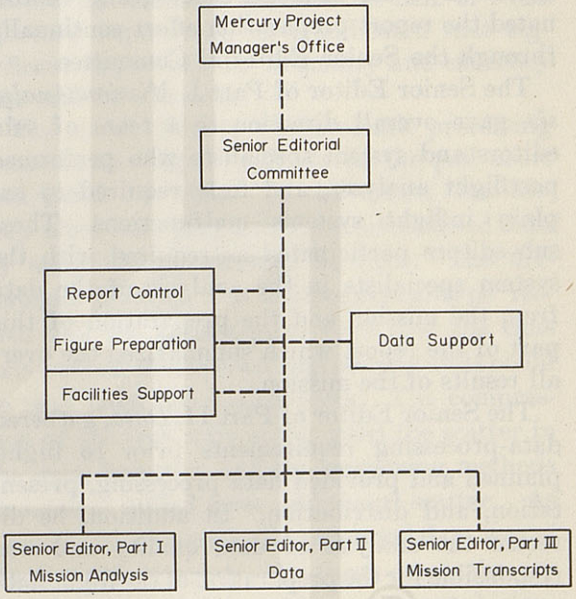

FIGURE 13–1.—Functional relationships for editorial and support personnel.

the major elements of the task organization for the MA–9 report. The Senior Editorial Committee members and the supporting members were drawn from various elements of the NASA Manned Spacecraft Center, and for the period of the PLMR preparation the members reported functionally to the Chairman of the Senior Editorial Committee. As each member's part of the task was completed, he returned to his parent organization.

The functions of the elements shown in figure 13–1 are described briefly below:

The Manager's office provided the overall directions for the postflight test program. In addition, the Manager's office reviewed the PLMR for technical accuracy, completeness, and policy, immediately prior to printing.

The Senior Editorial Committee comprised the senior editors of the separate parts of the report and the MA–9 backup pilot and these persons directed and coordinated the detailed efforts of postflight testing, analysis, and reporting. The members of this committee also performed a continuous review and editing of the individual sections of the report in an effort to maintain continuity and technical agreement among the sections of the report. The Chairman directed the planning of the overall reporting effort prior to flight, provided intermediate and final editorial reviews of major portions of the report, acted as official representative of the Manager's office, and coordinated the report preparation effort continually through the Senior Editorial Committee.

The Senior Editor of Part I, *Mission Analysis*, gave overall direction to a team of sub-editors and system specialists who performed postflight analyses, and tests required to explain inflight systems malfunctions. These sub–editors participated as required with the system specialists in the analysis of the data from the mission and the preparation of this part of the report which summarized the overall results of the mission.

The Senior Editor of Part II, *Data*, gathered data-processing requirements prior to flight, planned and provided data processing, presentation, and distribution. In addition, he directed the analysis of data quality and was responsible for the preparation of the flight data section of report.

The Senior Editor of Part III, *Mission Transcripts*, managed the preparation and editing of the various voice transcripts for both flight communications and post flight debriefings, and planned and conducted the postflight scientific debriefing.

The functional organization shown in figure 13–1 was used in the overall management of the mission analysis and reporting. A more detailed breakdown of the functional organization of the Part I effort is shown in figure 13–2 to illustrate the depth of organizational detail needed. The personnel for each assignment were drawn from throughout the Manned Spacecraft Center, with assistance from other NASA centers and contractors as needed.

The need for a well-planned organization can best be illustrated by noting that for the MA–9 PLMR analysis and reporting effort, contributions were made by personnel from fourteen NASA organizations, four contractor major organizational elements, numerous organizations of the Department of Defense, the U.S. Weather Bureau, and several colleges and universities. During this analysis and reporting period, approximately 20,000 man-hours were spent by approximately 130 people in producing a 1,000-page 3-volume report in 26 days.

Analysis of Mission Results

Data Processing

To meet the needs for processed data to be used for analysis and reporting purposes in the shortest possible time, several decisions were made as experience was acquired. The maximum use would be made of electronic data processing to provide data in the most readily usable form. Where necessary, manual effort would be used, in addition, to provide the data in a format which would require the least additional manipulation on the part of the analyst. In processing the data the initial format would be made as nearly as possible of a quality that would be suitable for final report use. In this way the data would be prepared for its various types of usage by photographic reproduction rather than by recomputing, rescaling, and replotting. The requirements of the analysts would be determined as far as possible well in advance of the generation of the data in order that the parameter arrangements, scale selection, and priority might be determined. As

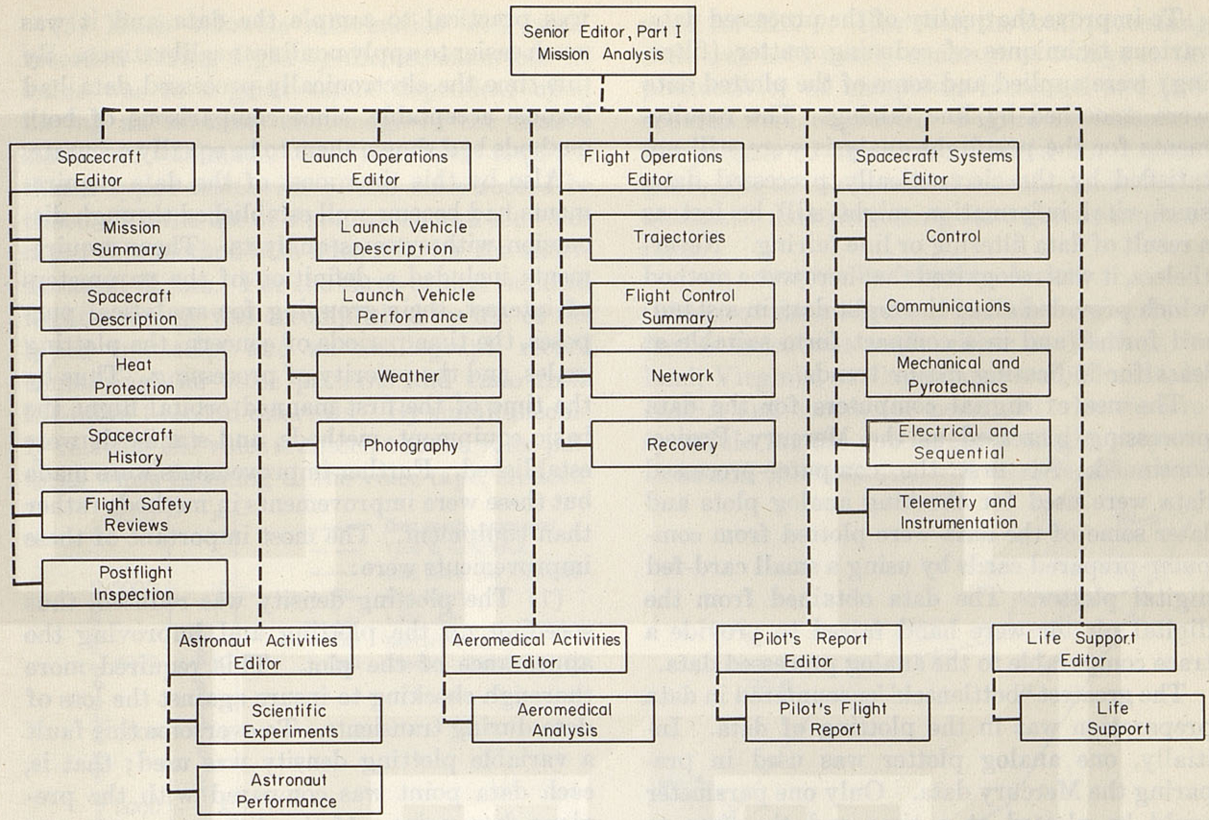

FIGURE 13–2.—Typical functional organization for Part I of report.

successive flights were made, formats were standardized to enable comparison between the data from various flights, thus providing an additional constraint.

When the electronic data-processing method became operational, a decision was made to process all applicable data during one effort for each flight. To permit parallel processing, several copies of the onboard tape were prepared. If the processing results were to be accurate, the tape copying had to be carefully checked. To accomplish this, oscillographic records were prepared from the master and tape copies. These oscillographic records were visually compared. If visual inspection indicated any differences, the records were compared by superimposing records over a back-lighted glass plate. If there were any significant differences between the records, the tape copy was rejected.

The automatic data-processing capabilities were not easily obtained. Data reduction processes may introduce errors at many points in the system. The accuracies of the basic spacecraft data system were sufficiently high to require more care in the reduction of the data than was the general practice. Utilization of experiences gained from the preceding flights were required to obtain the product quality and processing efficiency attained on MA–9. The Mercury experiences have indicated that significant improvements in quality and efficiency can still be attained.

The initial effort to use automatic processing methods was begun with the off-the-pad abort and Little Joe tests. In this effort, time-history plots were prepared from telemetered data by using analog plotting methods. The differences between the oscillographic-type records and the analog plots were that the time axis was compressed and engineering units could be read from the analog plots. The compression of the time axis accentuated the scatter in the data, however, and the processing methods themselves added some additional scatter. As a result, the electronically processed data lacked the desired accuracy. In these cases, the analysts continued to use the oscillographic recordings as a primary source of data.

To improve the quality of the processed data, various techniques of reducing scatter (filtering) were applied and some of the plotted data were smoothed by line fairing. The requirements for the postflight analysis were still not satisfied by the electronically processed data, since vital information might still be lost as a result of data filtering or line fairing. Nevertheless, it was recognized that here was a method which provided all of the flight data in a standard format and in a compact form suitable at least for indicating major trends.

The use of digital computers for the data processing increased as the Mercury Project continued. At first the computer-processed data were used for checking analog plots and later some of the data were plotted from computer-prepared cards by using a small card-fed digital plotter. The data obtained from the digital plotter were hand faired to provide a trace comparable to the analog processed data.

The greatest "bottleneck' 'encountered in data preparation was in the plotting of data. Initially, one analog plotter was used in preparing the Mercury data. Only one parameter could be plotted at a time and the time to plot was the same as real time. At the time of the MA–5 flight, four analog plotters were in use and they were operated at a speed of eight times real time.

Because of the difficulty in making corrections to the analog plots when graph paper was used, it was decided to plot on a clear plastic film. This innovation speeded the plotting process by making it possible to erase an error rather than replot several parameters on a new page, and by providing a means for superimposing analog plotted data onto digitally plotted data for related parameters. The plastic film was also less affected by temperature and humidity changes than was graph paper.

It was not until the MA–6 mission that digital computers and digital plotters became the primary processing tools. Prior to this mission, the computer was used to prepare tabulations of data in engineering units, and some digital plots were prepared. But now a faster general purpose computer and a magnetic-tape-fed plotter were available. It became the exception rather than the rule to use analog plotters. With these faster tools available, it was practical to sample the data and it was much easier to apply nonlinear calibrations. By this time the electronically processed data had become acceptable, since comparisons of both methods had shown them to be equally accurate.

Also by this time most of the data requirements had become well established through discussion with systems analysts. These requirements included a definition of the parameters of interest, their grouping for analytical purposes, the time periods of concern, the plotting scales, and the priority of processing. Thus by the time of the first manned orbital flight the basic equipment, methods, and standards were established. Further improvements were made but these were improvements in methods rather than equipment. The most important of these improvements were:

(1) The plotting density was reduced, thus speeding up the plotting and improving the appearance of the plot. This required more thorough checking to insure against the loss of data during transients. To overcome this fault a variable plotting density was used; that is, each data point was compared with the previous data point. If the difference was more than a predetermined amount, both the previous point and the present point were plotted. If the difference was less than the predetermined amount, a point was plotted at fixed intervals of time.

(2) Instead of rewinding a plotter tape to plot a second parameter on a page, time was saved by plotting the second parameter in reverse.

(3) Special photographic techniques were used to minimize replotting. Analysis plots, normally made with expanded horizontal scales for detailed work, were photographically reduced in the horizontal axis without reduction in the vertical axis. Thus working plots were compressed in length for use in the reports without it being necessary to replot.

(4) A developmental program was initiated to permit the determination of heart rate by digital means. Such a method became a necessity on the longer flights in order to obtain a complete time history of heart rate. The method developed provided the time between beats so that an average over any selected period of time could be obtained. Statistical treatment of these data was thus made possible.

(5) Much valuable information was voice-recorded during flight by the astronaut but its value was to a great extent dependent upon having an accurate knowledge of the time a statement was made. Early methods required that a typed transcript of the voice record be timed with the use of a stopwatch and the voice tape; this method was adequate for the short-duration flights. For the three-orbital manned flights, timing was accomplished by use of the typed transcript and an oscillograph record containing the voice patterns and time from lift-off in 1-second intervals. By simultaneously relating the voice transcript to the voice patterns while listening to the voice tape, an accurate time for each communication was determined. For the longer 6-pass and 22-pass orbital flights, a method was developed to automate this process to some extent. A magnetic tape recording of the voice, with spacecraft time recorded on a second track, was played while an operator followed the typewritten text. At the first word of each communication in the text, the operator pressed a switch to compute and record the time. This process permitted the rapid preparation of a complete and accurately timed transcript of all of the pilot's voice communications.

Figure 13–3 provides some statistics related to data processing for each flight. As may be noted, the number of data points processed increased rapidly for the longer duration flights; for example, 14 million data points were processed for MA–9. However, the total processing time was held nearly constant at 5 days as the productivity of manpower increased and procedures were improved. Figure 13–4 shows a comparison of the time required for manual processing as compared with semiautomatic and automatic data processing for a given sample of data.

Systems Performance Analysis

Most of the analysis of the Mercury systems' performance was made either at Wallops Island, Virginia, or Cape Canaveral, Florida, by NASA and contractor personnel who were responsible for the spacecraft preflight preparations and checkout and who were familiar with

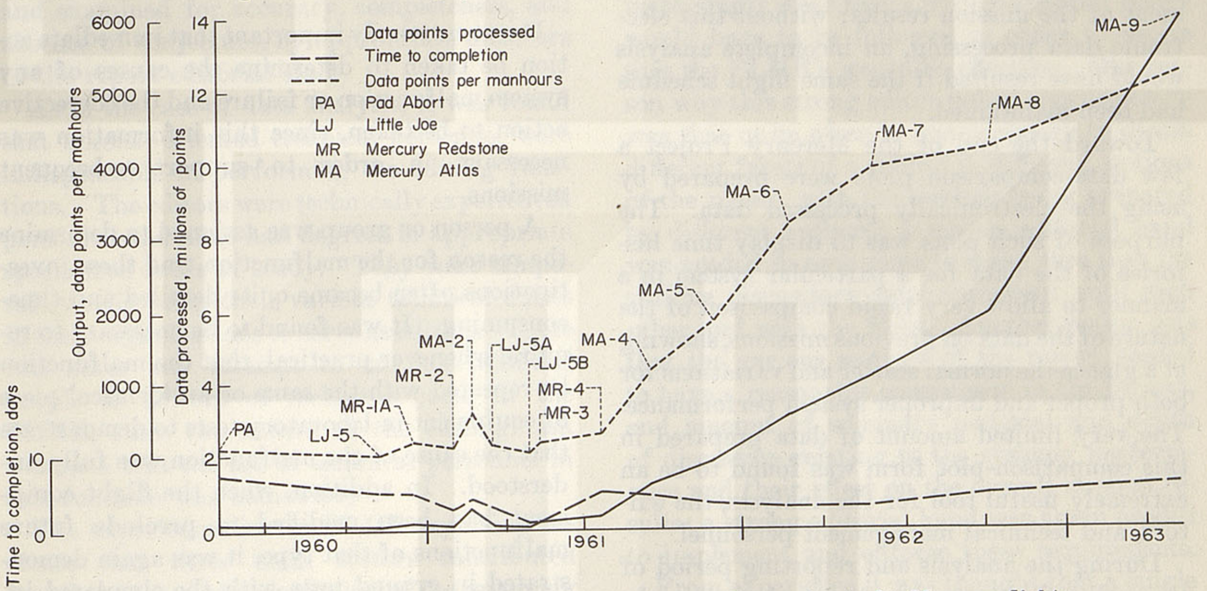

FIGURE 13–3.—Number of data points and processing time and rate for Mercury flights.

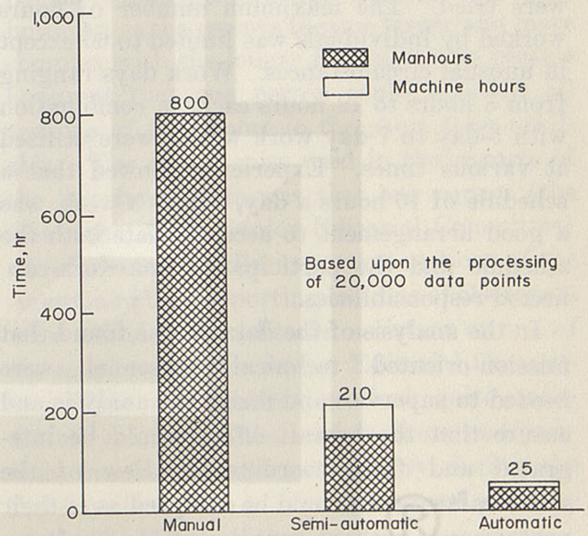

FIGURE 13–4.—Comparison of data processing techniques.

these systems. The majority of the analysts had extensive experience in appropriate specialty fields.

As discussed in the Data Processing section of this paper, the major portion of the analysis of the early flights in the Mercury Project was made by using oscillograph records and hand-processing only those portions of the records that seemed to be significant. This hand-processing was time-consuming and several days were required to obtain an appreciable amount of data in the form of engineering units plotted against time. The conversion to electronic data processing was a most important factor during the later missions in permitting a rapid assessment of the mission results; without this electronic data processing, an incomplete analysis would have resulted if the same flight schedule had been maintained.

Toward the end of the Mercury Project a few data-comparison plots were prepared by using the electronically processed data. The purpose of such plots was to display time histories of the data for a particular system in a manner to allow very rapid comparison of the nature of the data on previous missions, showing at a glance the normal scatter and variations for both proper and improper system performance. The very limited amount of data prepared in this comparison-plot form was found to be an extremely useful tool for the analysts, the editors, and technical management personnel.

During the analysis and reporting period of the earlier flights, various types of work weeks were tried. The maximum number of hours worked by individuals was limited to 60 except in unusual circumstances. Work days ranging from 8 hours to 12 hours each, in combination with 5-day to 7-day work weeks, were utilized at various times. Experience showed that a schedule of 10 hours a day, 6 days a week, was a good arrangement to accommodate both the schedule and the participants' non-work-con nected responsibilities.

In the analysis of the data, it was found that mission-oriented technical personnel were needed to supervise and direct the analysis and ensure that the overall effort would be integrated and fully coordinated. Few of the spacecraft systems could be analyzed as to their performance without considering the performance of other systems and the particular phase of the mission in question. For example, the temperature of the pilot's pressure suit was directly controlled by the operation of the suit heat exchanger; however, there was an indirect effect resulting from the temperatures in the spacecraft cabin, which in turn were affected by the operation of the cabin heat exchanger, the amount of electrical power being used (heat generation), and whether or not the spacecraft was in the sunlight or in the earth's shadow. Thus an analysis of the suit temperature could not be made without considering possible effects from these secondary sources of thermal disturbance.

Postflight Tests

It was extremely important that immediate action be taken to determine the causes of any system malfunction or failure and the corrective action to be taken, since this information was necessary in order to support subsequent missions.

A person or group was assigned to determine the reason for the malfunction, and these investigations often became quite detailed and time-consuming. It was found to be necessary to require, whenever practical, that the malfunction be repeated with the same or an identical piece of equipment in laboratory tests to demonstrate that the cause of the malfunction was fully understood. In addition, when the flight equipment had been modified to preclude future malfunctions of that type, it was again demonstrated in ground tests with the simulated inflight environment that the modification would do its intended job.

An example of postflight testing that could not be accommodated to the above philosophy of duplication on the ground of inflight malfunction was occasioned by the MA-1 inflight structural failure. It was impossible to duplicate this failure in ground testing, since the inflight loads spectrum resulting from vibration, acceleration, aerodynamic drag, unsteady airflow, and noise could not be simultaneously applied in ground tests. The postflight investigation was therefore centered around tests on the structure of the front end of the launch vehicle, and on the adapter between the spacecraft and the launch vehicle. These tests, and a concurrent analytical investigation, did not conclusively define the exact cause of the failure but did show that strengthening the front end of the launch vehicle and stiffening the adapter would be sufficient to prevent a similar failure. These changes were incorporated in the MA-2 mission, and the flight demonstrated that the modifications were satisfactory.

Report Preparation

The preparation of the PLMR actually began just prior to the mission when some sections of the report that dealt with preflight activities were written. The main body of the report containing the sections of technical significance was generated during approximately the last 5 to 10 days prior to issuance of the report. During this time, the rough drafts were prepared and examined for accuracy, completeness, and absence of conjecture, by appropriate members of the report editorial staff.

As in the case of data analysis, it was found that mission-oriented technical personnel were indispensable in performing the editing functions. The editors were technically experienced personnel and most had degrees in appropriate specialized fields of study. They were temporarily relieved of their various technical duties in their organizations to serve as editors. There was never any attempt to use non-technical people as editors of technical parts of the PLMR, since the nature of the editing task was such that the use of technical personnel in this function was mandatory .

The experiences in the PLMR reporting indicate that three main factors contributed heavily to the rapid completion of the reporting phase:

(a) All reporting participants were relieved as completely as possible of their day-to-day responsibilities so that they could devote full time to the reporting task. In addition, when possible they were physically relocated to a place away from their usual duty locations in order to minimize distraction by non-reporting duties.

(b) A steady and intensive work week schedule was utilized, consisting of approximately 10 hours per day, 6 days per week.

(c) The editors exercised close and constant supervision of reporting personnel in their tasks of writing the sections of the report, with emphasis on the need for completeness, clarity, accuracy, and absence of conjecture or speculation.

It was quite difficult, of course, to separate key technical personnel completely from day-to-day duties, since these duties needed their continuous attention. However, it had to be done to a large extent, or the postflight analysis for a mission would have proceeded at a relatively slow pace and the program schedule could have suffered. The steady and intensive work schedule of 10 hours per day and 6 days per week, necessary to meet the analysis and reporting schedule, was maintained for two to three weeks on occasion without any apparent ill effects on the work output.

As the reporting of the Mercury mission results progressed from flight to flight it became increasingly clear that a strong editorial policy would have to be followed in order to insure that the PLMR's would be effective. One reason why this strong editor policy was necessary was that quite often it was necessary to dicuss different facets of a subject in different sections of the report, with the sections being prepared by different authors; a strong editorial hand was needed in such cases to make sure that the various discussions were consistent with each other and with the facts. Another reason was that the various sections of the report needed to have a reasonable consistency in the format, and amount of summary material and depth of discussion relating to the systems' performance and their effect on the overall mission results; a strong editorial hand was again needed to implement and enforce these requirements.

From experience it was thought that a single person should perform the final editing task; however, as the reports became larger and more complex with the longer flights, it also became apparent that one person could not edit all sections of the report in the short time available. The compromise used in the reports of the last few flights was that one person (the Chairman of the Senior Editorial Committee) edited the technically important sections of the report, and the supporting sections of the report were edited by an editorial assistant or one of the members of the Senior Editorial Committee. This arrangement worked quite satisfactorily, although the work load on the Chairman was very great, particularly during the few days just prior to final typing and printing of the PLMR.

During the period just prior to printing the report, the senior editorial committee reviewed and edited all sections of the report. This review was accomplished to insure that the various sections were compatible in the discussions and treatment of common subject matter. The report was then reviewed in detail by the staff of the Project Managers Office for accuracy and technical emphasis. It was found that the various reviews and editings of the sections of the report and the report as a whole were necessary, although publication of the report was delayed somewhat by this process. Experience showed that the most useful report resulted from a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. It was also found that a report was ineffective if it was not complete, clear, and factual.

Conclusions

As the Mercury Project progressed from the relatively simple flights to the more lengthy orbital missions, the postflight data processing, mission analysis, and reporting, went through a steady evolutionary process. A number of lessons were learned and are summarized as follows:

Data Processing

(1) Electronic data-processing equipment can accurately process quantities of data that are impossible to accomplish in the same time with manual methods.

(2) Analysis requirements must be determined in advance and data processing must be planned to supply these needs.

Analysis

(1) Mission-oriented technical supervisors are needed to supervise the analysis in order to insure integration and coordination of the effort.

(2) Extensive time-history data are essential to the analysis of spacecraft system performance.

Reporting

(1) A report should have all of its technically important sections edited carefully by one person if the report is to be of maximum usefulness.

(2) A report, to be useful, must be a compromise between the conflicting requirements of completeness, clarity, and technical accuracy on the one hand and an early publication date on the other. Such a report is ineffective if it is published quickly but is not complete, clear, and factual.

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14. SPACECRAFT PREFLIGHT PREPARATION

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Summary

This paper presents the evolution of test philosophies and procedures used in preflight checkout of Mercury spacecraft at Cape Canaveral, Fla. The impact on preflight operations of tight schedules, mission changes, discrepant performance of ground and spacecraft equipment, and new information gained from ground testing and flight are discussed. Included in this discussion are numerous examples to illustrate the kinds of problems that were encountered and their effects on preflight operations. In addition, this paper presents the lessons learned in preflight preparation and checkout over the 4-year span of the program.

Test operations personnel learned that only formalized testing with all inter-dependent systems operating simultaneously would provide a flight-ready spacecraft. Tests emphasized astronaut safety and included participation of the astronaut as often as possible. Few substitutes for actual flight equipment were permitted during spacecraft assembly, rigging, and testing. Such matters of quality control as cleanliness, component limited-shelf and limited-operational life, and equipment failure, influenced the test philosophy. Validation and troubleshooting of spacecraft systems revealed the need for many more test points to be provided for in-place testing. Repair and bench testing of failed equipment reemphasized that the equipment needed to be made more accessible for removal and reinstallation. Rapid feedback of test results and failure analyses to design and manufacturing personnel was necessary and led to the increase of inspection and on-the-spot failure analysis. Digital checkout equipment was developed and proved that digital computer systems were superior to analog methods in providing information and control to test engineers.

Introduction

Preflight preparation and checkout experience began at Cape Canaveral in 1959 with the Big Joe boilerplate spacecraft. This spacecraft was the first to be launched in Project Mercury. The Big Joe spacecraft was designed and built by the National Aeronautics and Space Administration (NASA) to determine the aerodynamic and heating characteristics of the Mercury shape.

In the following year, a variety of test and checkout equipment and the first production spacecraft arrived at Cape Canaveral. During the next 2 years, the techniques and procedures for preparation and checkout of spacecraft for manned flight were developed and refined.

By the time of the early manned flights, these preparations and procedures had been proved through operational experience. A formal but flexible operations routine had evolved, incorporating close coordination with design, mission management, manufacturing, and quality control groups. For example, components were inspected and tested before installation; and work to be done on the spacecraft was described in detailed work sheets. This procedure controlled the disturbance of spacecraft components and assured that the status of the spacecraft configuration was known at all times. Detailed test procedures had been written, and step-by-step test results recorded. Checklists had been established to guide spacecraft assembly and configuration before each test.

Spacecraft Assembly

In preparation for spacecraft testing, component mockups and simulators were constructed and used as substitutes for components that were fragile, dangerous to handle, or in short supply. However, it was found that these mockups and simulators could not be constructed accurately within a reasonable cost and time schedule, and therefore they proved to be of marginal value.

For example, wooden pyrotechnics mockups did not properly establish cable fits, and substitute escape towers did not establish clearances. This resulted in delays and difficult working conditions when modifications had to be made while at the launch pad. Other simulators did not work because of the high packaging density and multiple interfaces inside the Mercury spacecraft.

Ultimately, it was deemed necessary to fit-check all flight items simultaneously, and, where substitutes had to be used, exact flight types were required. Because better facilities for mechanical modifications were available at the point of manufacture, experience indicated that complete assembly of the spacecraft should be accomplished at the factory; this was true even for those components which had to be removed for shipment.

Test Preparation

General

In the early planning stages of Project Mercury, it was thought possible to deliver flight-ready spacecraft to Cape Canaveral, conduct a single, total spacecraft test in the hangar, and launch very soon thereafter. However, it was demonstrated that more preflight preparation was required at the launch site and formal procedures evolved from experience.

Before spacecraft testing was begun, very careful preparations were made. Each step had to be formalized through configuration documents, checklists, and test procedures. The ground-support equipment was tested to prove its readiness. Test complexes were checked for compatibility with the particular spacecraft. The spacecraft was put into test position and its configuration conformance to test plans was established; of particular concern were proper cabling and plumbing of all systems. Then the spacecraft was connected to the complex and testing was begun.

Various efforts were made to accelerate preparation of the spacecraft; for example, when the spacecraft was idle, as during periods when data were being analyzed, efforts were made to continue work on the apparently-unaffected systems. However, it was found that this work would adversely affect the test setup and thereby the spacecraft preparation schedule. Mercury components were so closely packed that there was little room for a man to work inside the spacecraft without accidentally damaging such things as cables, tubing, connectors, or cameras. Generally, it was ruled that only test-associated work would be done on a spacecraft while it was being tested.

Early in the program before systems interrelationships had been completely analyzed, some equipment was damaged when tests of one system influenced another. For example, reaction control system (RCS) valves in a dry state overheated when activated by the automatic stabilization and control system (ASCS).

As test crews and planners gained experience in attending to these many details, test plans became more reliable. Offsetting this experience were the number of modifications made to the spacecraft to accommodate mission flexibility and safety and to improve systems performance. As a result, plans and procedures were constantly changing.

Test Philosophy and Procedure

Gradually, a set of guidelines evolved which were used as the basis for all testing. Two principles served as foundations for checkout procedures throughout this evolution. The safety of the astronaut was considered foremost, and secondly, all philosophy was directed toward a test plan which would guarantee a flightworthy spacecraft at lift-off. These were expanded to six principles which were applied to all spacecraft tests.

Building block approach to testing.—The operational status of each system and each component in the system was functionally verified before that system was operated concurrently or in conjunction with another system with which it might have an interface.

End-to-end testing.—During testing, the initiating function and end function took place sequentially as would actually occur in flight. The use of artificial stimuli was minimized. Implementation of this guideline was most evident in the hangar-simulated flight test.

Isolation and functional verification of all redundancies.—All redundant signal paths were isolated and functionally proven by end-to-end tests. These included redundancies between the spacecraft and launch vehicle and redundancies within the launch complex.

Interface testing and verification.—There were two basic interfaces in Mercury: The spacecraft to launch vehicle and the space vehicle to ground complex. These interfaces included RF, hardwire, and mechanical features. Tests involving these interfaces were consistent with the test philosophy previously discussed, namely, end-to-end testing and testing of all redundancies.

Mission profile simulation.—Simulated mission tests, which included the spacecraft, launch vehicle, and ground complex, were designed to approach functionally actual mission conditions as nearly as possible. This procedure included simulating real-time functions through orbit insertion. The astronaut was aboard for these simulations and functioned as he would during the actual flight. These simulated flights were made both in Hangar S and at the launch pad. Figure 14–1 shows preparations being made for a simulated flight test of a spacecraft in the altitude chamber.

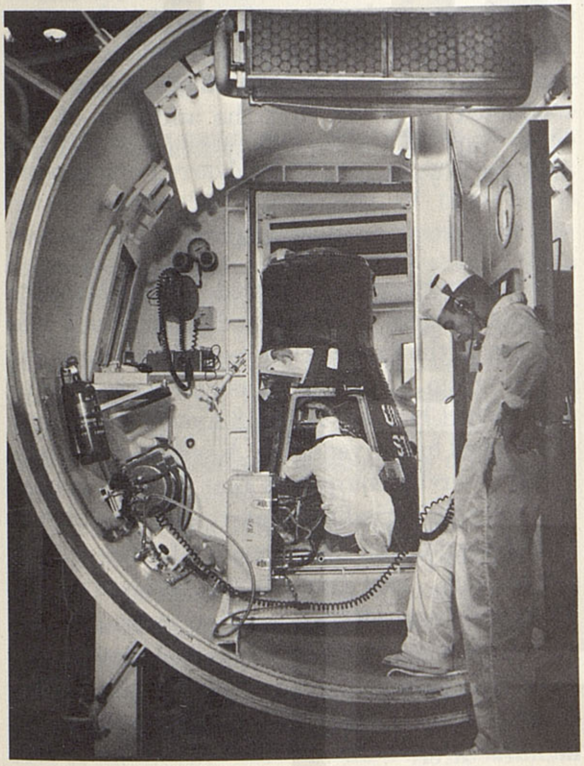

FIGURE 14–1.—Spacecraft being prepared for simulated mission test in altitude chamber at Cape Canaveral.

The astronaut as an integral part of the system during tests.—The astronaut was considered part of the total system and functioned during systems test and mission simulations as he would during the actual mission. This resulted in a dual advantage. The system tested was closer to flight configuration when the astronaut was included, and the astronaut became intimately familiar with the spacecraft and spacecraft system. Figure 14–2 is a photograph of a spacecraft on the RF tower for communication tests. This test, with Astronaut L. Gordon Cooper, was made to determine voice clarity under simulated flight conditions.

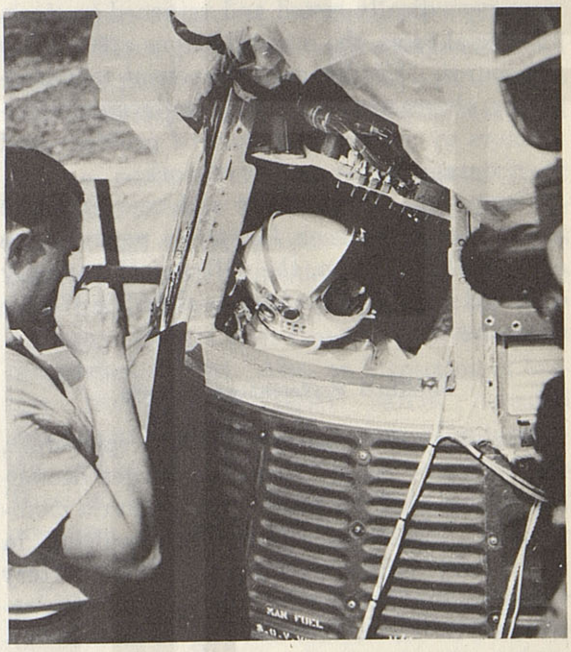

FIGURE 14–2.—Astronaut Cooper in spacecraft on RF tower for communications test.

Component Acceptability

Components of proven design were planned for use in Project Mercury. In order to insure that only properly-operating items of these proven designs were used for flight, not only spare parts but also many components installed in the spacecraft were subjected to testing at

Cape Canaveral. Numerous component failures were experienced during these spacecraft tests; in addition, during 1962 and 1963 approximately 50 percent of component spares were rejected after testing. These failures were discovered by rigorous preinstallation acceptance (PIA) tests which in most cases exceeded the test conditions that could be achieved after component installation. These tests increased confidence that replacement components in a state of incipient failure would not be installed in Mercury spacecraft.

Control of the stock of spares also was tightened to assure that qualified replacements were available when troubles occurred. Spares which were significantly affected by shelf life were periodically tested and returned to stock. In special cases, the inspection was extended to the source. Vendor and component manufacturing plants were visited by engineers and inspectors to convey the nature of problems and to encourage higher quality of work.

Component acceptability and rejection rate was governed by such factors as performance criteria modification, the delivery of partially qualified items, and inadequate shelf life of some components.

Modified Performance Criteria

During systems tests of Mercury spacecraft, the effects of electrical-current surges demonstrated the need for performance criteria modification. These current surges, resulting in momentary variation (transients) of the battery voltage, occurred during testing and were attributed to the normal starting of mechanical-electrical systems, such as the orbital timing device or the spacecraft cameras. As a result of these voltage transients, energized timers would occasionally exhibit early time-out, interference would appear in instrumentation amplifier outputs causing faulty indications, and noise would appear in the astronaut voice channels. The solution to these problems required inclusion of a special battery for the maximum altitude sensor, the addition of capacitors to circuits with time relays as a protective measure to prevent early time-out, and the replacement of components with like items that demonstrated low susceptibility to voltage transients.

Extensive voltage-transient tests were added to spacecraft checkout procedures to prove equipment immunity to these effects. These procedures were frequently quite involved.

High voltage problems were encountered in ground power supplies. Electrically-regulated power supplies operating over long lines tended to react and surge to high voltages and cause loss of remote sensing, and they were abandoned in favor of lead-acid batteries.

Partially Qualified Equipment

Equipment not fully qualified for flight when delivered included tape recorders, ECG amplifiers, water traps for the environmental control system (ECS), and impedance pneumographs.

Tape recorders were brought to acceptable status by careful shop asembly and testing. The electrocardiogram (ECG) amplifiers were redesigned and rebuilt. Internal voltage regulators and feedback loops were modified. Rebuilt units were requalified in detail. Later, new models were specified for vendor development based on experience with the originals.

In some cases, flight systems had to be modified to accept new components, and special systems tests had to be devised to be sure that the effects of the modification were not serious. For example, the environmental control system performance depended upon closely balanced pressures and flow, and testing of the system was conducted to insure that the addition of the water trap did not degrade system performance in the MA–9 spacecraft.

Shelf Life

Many components procured for the Mercury Project proved to have inadequate shelf life because of the time period required to complete the program. Such items as rockets had to be refurbished because of an 18-month shelf limit established by the vendors. A system was established whereby equipment that utilized rubber O-rings was periodically exercised or returned to the vendor for replacement of time-critical components. For example, the Environmental Control System (ECS) negative-pressure relief valves were operated at prescribed time intervals, and the Reaction Control System (RCS) relief valves were reconditioned by the manufacturer.

Another problem involved deterioration of the solder connections of nichrome bridge wires to the electrical connectors of many pyrotechnic initiators. This deterioration resulted in a gradual increase in the resistance of squib circuits. This was precluded by establishing a time limitation of 6 months between date of soldering and actual use.

Test Equipment and Procedure Changes

The need to prove the acceptability of spacecraft equipment required many changes in procedures and test equipment at the Cape. Component and systems simulators were used less and less in spacecraft testing even to the point of requiring participation of the astronaut, fully suited.

Bench simulators were made more realistic. Voltage-transient generators and ECG simulators were added to the Cape's test equipment. Battery source impedance and load impedances were more carefully simulated as was line noise character. There was, also, an increased tendency to operate equipment on the bench in exact connection with production models of their companion components and systems. Camera solenoids and transmitters were properly connected to and operated with instrument systems during final bench tests before spacecraft installation.

Quality Assurance

Some equipment and components such as rockets and pyrotechnics could not be fully validated before use. Reliability of these items was almost entirely dependent upon good design, workmanship, and qualification. This workmanship requires great patience and attention to detail even under the tedium of production lines. Considerable progress has been made in promoting this extreme attention to detail which directly contributes to the success or failure of each spaceflight mission and the safe return of the astronaut.

In the MA–9 mission, the three retropackage umbilicals and one of the two spacecraft-to-adapter umbilicals failed to separate from the spacecraft. Each of these contained two squibs, and initiation of either squib should have resulted in explosive disconnection. Postflight analysis revealed that the umbilicals failed to separate from the spacecraft because the squibs were not loaded with the appropriate charge.

As the Mercury Project matured, it became evident that the use of proven and qualified components did not result in the reliabilities desired to satisfy man-rated system requirements. A more-rigid quality control procedure was required in all aspects of component and system assembly. The need for this requirement was typified by the number of discrepancies (performance or configuration deficiencies) to be corrected for the MA–9 backup spacecraft. A total of 720 system or component discrepancies were recorded, of which 526 were directly attributed to a lack of satisfactory quality of workmanship. Of this number, 444 required specially-scheduled time to correct.

Additionally, flight-safety considerations required that inspection be made of all parts and components scheduled for the space-flight program. These inspection requirements extended from the parts vendor to the Cape in order to locate and reject every defective or marginal part.

As a result of inspection, fourteen 1,500 watt/hour storage batteries were rejected for case leakage during preparation for the MA–8 mission. Several incidents of leakage were due to tooling holes not being plugged during manufacture. Others were from case cracks or undetermined sources. Also, an inspection of battery vent-pressure relief valves revealed dimensional deviations in valves after assembly, and improperly applied potting adhesive. Three of these valves failed to operate at proper pressures. These defective batteries were rejected following inspection at the Cape.

Five failures were experienced on gas-pressure regulator assemblies in the MA–8 reaction control system (RCS). An investigation of the failed assemblies revealed that internal scratches, inadequate cleanliness, and improper torquing of end caps were contributing causes of these failures.

Also in the RCS, an examination of failed gas-pressure vent valves revealed damaged O-rings. In one case an O-ring was found to be scuffed, while in another case the O-ring had a metal fragment driven into the material.

The MA–8 spacecraft was demated from its launch vehicle and returned to Hangar "S" to replace the manual selector valve in the RCS due to a leakage encountered during a preflight pressure check of the system. Upon removing the valve, it was noted that the valve had been installed out of alinement so that an excessive side-load was induced into the valve internal parts.

During an inspection of the escape-tower wiring for the MA–6 primary and backup spacecrafts, it was found that the electrical connectors had improperly-soldered joints. Additionally, it was discovered that improper insertion of the conductor wire into the solder had been made as a result of the use of an 18-gauge wire with a 20-gauge solder pot.

In Project Mercury, thousands of man-hours were expended in testing, calibration, assembly, and installation of a variety of hardware that later failed to meet performance specifications or that malfunctioned during systems tests in a simulated space environment. When malfunctions occurred or when these components failed to meet specifications, it was necessary to remove, repair, or replace them, a procedure which could have been avoided in a large percentage of cases if adequate attention to detail during manufacture or thorough inspection before delivery had been exercised.

Component Accessibility

Mercury spacecraft were literally packed with equipment and components were installed three deep in some instances. Limited interior working space, which posed a severe handicap to preflight preparation, resulted in a certain amount of wiring and equipment damage during normal work and test operations. Repair was a continuing work item during all phases of spacecraft modification and checkout. Any system affected by these repairs or modifications had to be reverified by test.

Extensive changes and modification were caused primarily by component or subsystem malfunction, as well as extension of mission requirements.

As an example, it became necessary to replace MA–6's life-limited carbon dioxide absorber in the ECS, since more time than had been planned was required to check out the system. This replacement required no less than eight major equipment removals and four revalidations of unrelated subsystems. It caused an overall delay of nearly 12 hours. By way of comparison, it took only an hour and a half to replace the carbon dioxide absorber itself. Ten and one-half hours were used to gain access to the absorber and then to restore the spacecraft to its original condition.

The number of removals of equipment is an index of the amount of modification, repair, and servicing required as the program progressed. Figure 14–3 exemplifies the amount of work required at Cape Canaveral.

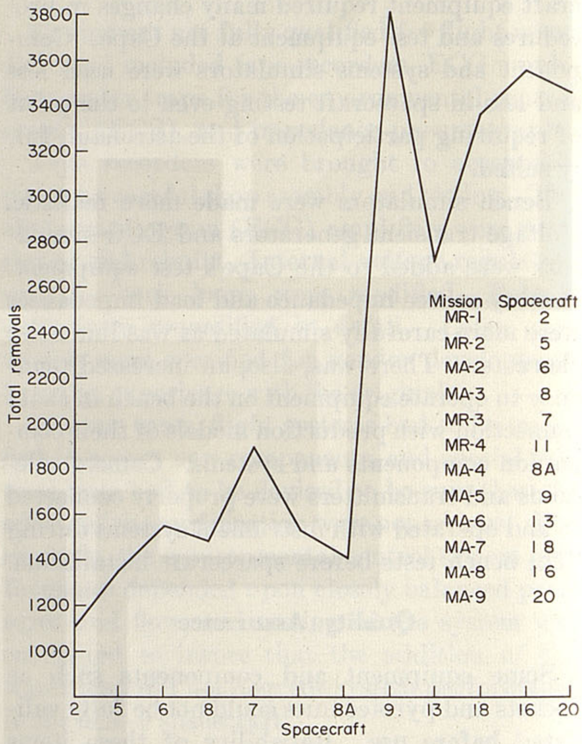

FIGURE 14–3.—History of equipment removals for Mercury spacecraft for rework service and replacement.

Cleanliness

Early in the Mercury program motion pictures of the inside of a spacecraft in orbit showed washers, wire cuttings, bolts, and alligator clips floating in the cabin. The cabin fan became plugged on an early unmanned flight with similar free-floating debris.

Such evidence led to more care in the habits of technicians working inside the spacecraft. A periodic tumbling of the spacecraft to dislodge and expose dirt and loose objects became standard practice at the Cape. Figure 14–4 shows a spacecraft in the tumbling fixture during a cleaning operation, and figure 14–5 shows the debris removed.

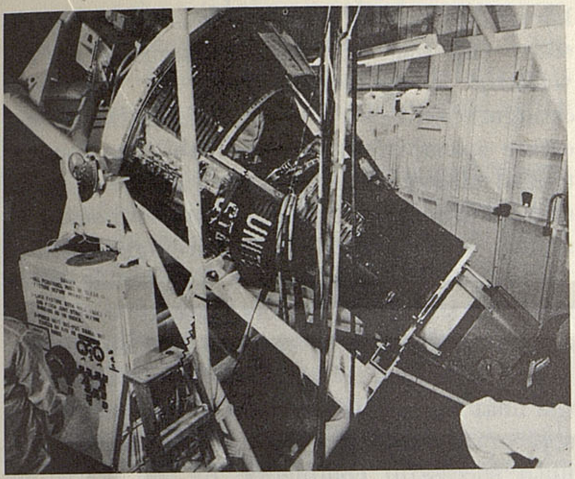

FIGURE 14-4.—Spacecraft being tumbled to remove debris left during work periods.

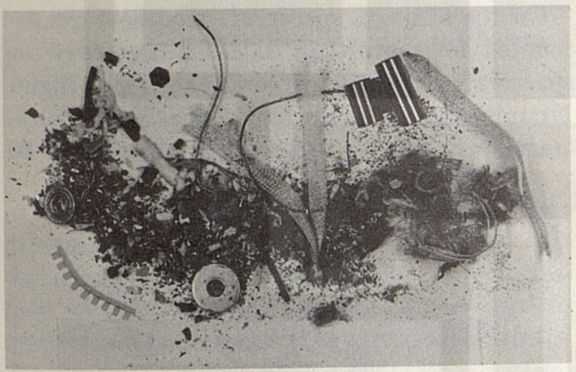

FIGURE 14-5.—Debris removed from spacecraft during tumbling.

Technicians generally were not aware of the strict cleanliness required in handling components of the ECS and RCS systems. It became necessary to specify handling procedures for these highly dirt-sensitive components. Many parts were kept in sealed plastic bags until installation was to begin, at which time ultra-clean handling methods were used. Vendors have delivered many items of spacecraft equipment which contained wire ends, solder balls, and stray hardware. Such items as gums, powders, lubricants, chips, and hydrocarbons have appeared on components where they could not be tolerated for proper operation. Hydrogen peroxide systems have yielded some decomposables which could have caused extreme reaction. Breathing oxygen and drinking water also have been contaminated. As a result, all consumables were chemically analyzed before being put into their spacecraft containers, and a variety of equipment which was found to contain contaminating deposits was carefully inspected and cleaned before being used. This equipment included astronaut suits, valves, hoses, and tubing.

Provisions and Procedures for Troubleshooting

It can be seen from the preceding discussion that there was a great need for troubleshooting spacecraft components both in spacecraft and on the bench. As a consequence, facilities at the Cape were expanded to include a malfunction investigation laboratory, staffed with experienced specialists in such areas as X-ray, spectroscopy, microscopy, and chemistry. Also, because of the need to qualify many spacecraft components, a laboratory of test equipment was developed and fully equipped with environmental chambers, shaker table, accelerator, impact tester, and pressure testing equipment.

Absence of Test Points

In Project Mercury, it was necessary to add ground support equipment to that provided with the spacecraft and to devise means for testing individual components in the spacecraft. Test points were not available and interconnecting cables and tubing had to be broken into for tests. This invalidated the very circuit or pressure system that was being tested.

Preplanned Troubleshooting

In Project Mercury it became necessary to plan exact steps and equipment configuration before troubleshooting was begun. Expected values in response to stimuli that had been carefully defined were listed in documents prepared in advance. It was found that preplanned troubleshooting procedures significantly reduced testing time.

In addition to drawings and standard spacecraft test procedure, the contractor provided logic diagrams and detailed drawings and specifications of systems and components. Systems consisting of many separate circuit elements were detailed by separate subsystem diagrams showing all wire routing throughout the spacecraft. As an example, instrument systems were broken down to show each sensor and

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its signal conditioning and cable connections. This was in addition to overall system cabling diagrams and detailed drawings of repairable items including mounting details that were provided. These drawings were invaluable for troubleshooting.

Scheduling

To accomplish spacecraft preflight preparations and checkout within schedule objectives, it was necessary to increase the number of spacecraft undergoing preflight preparations at Cape Canaveral from one to two, or three, at any given time. This approach provided additional time for preflight preparations of each spacecraft without a corresponding increase in the time interval between successive missions.

Preflight Preparation

Preflight preparations and checkout operations included: (1) modifications to update the untested spacecraft configuration based upon knowledge gained from previous flight experience; (2) modifications as extensive as reworking a spacecraft from a suborbital configuration to an orbital configuration to increase spacecraft systems capabilities for extended mission requirements; and (3) changes and modifications resulting from component or system malfunctions during preflight testing.

Changes of considerable magnitude were made at the Cape only because it was more efficient and less time consuming than returning the spacecraft to the factory. In any event the final flight configuration of any particular spacecraft could not be entirely determined until successful completion of the preceding mission. This required that final configuration changes be accomplished at the Cape if the schedule was to be maintained.

On the average, spacecraft modifications accounted for more than half the time that the spacecraft remained at the Cape prior to flight. Examination of the average time that the spacecraft spent at Cape Canaveral shows that 60

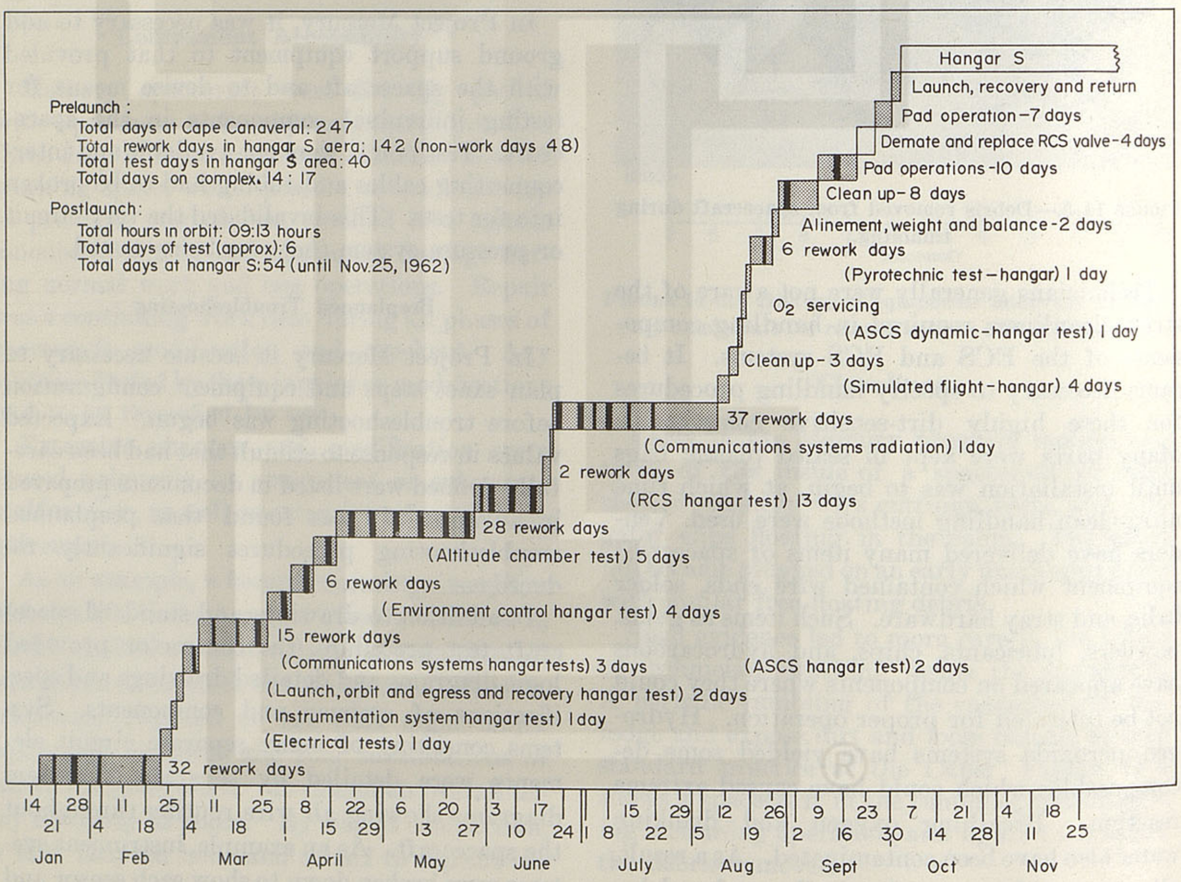

FIGURE 14–6.—Test and work schedule for prelaunch preparation of spacecraft in Hangar S.

the spacecraft and permanently wired to test points. Pulse code modulation—a form of digital data—allows compression of data so that hundreds of measurements can be sent over one cable. By this means, test configuration problems can be greatly reduced. Spacecraft can be moved from place to place with much less breakdown and buildup of test configurations.

As the Mercury Project progressed, many different methods of data presentation and distribution were investigated. Through these efforts, it was demonstrated that data of the pulse form could be consistently transmitted by radio frequency or by cable. The receiving and conversion equipment which was used for about 4 years proved to be a reliable and accurate means for presenting data to test engineers.

In an effort to make data more immediately useful to these engineers, printers and digital displays were added. It was gradually realized that this immediacy was of prime importance to men who had to make constant decisions as to the state of their systems. These studies of improvements needed in spacecraft checkout led to the design of a digital computer-controlled system capable of automatic checkout of manned spacecraft. It also had the capability of use as a completely manual system controlled by test engineers miles from the spacecraft, thereby allowing a natural evolution to automatic checkout. An experimental model was assembled and proved during hangar and pad tests of Astronaut Cooper's spacecraft.

Technical, Configuration, and Mission Reviews

Close coordination between preflight operations personnel and those of other organizations, including contractors, subcontractors, vendors, the Department of Defense, the ground complex, the network, and other NASA centers was maintained continuously to insure that interface compatibility of operations planning as well as equipment left no significant problems unresolved.

Throughout Project Mercury, a continuing series of technical, configuration, and mission review meetings were conducted to resolve problems, to initiate action where necessary, to coordinate activities on a wide variety of matters affecting each Mercury mission and to provide technical direction where required. In addition, engineering specialists from these organizations met frequently at Development Engineering Inspections (DEI) at the spacecraft manufacturing plant to review in detail the hardware being produced so that results of current experience were reflected in this hardware. Each of these efforts provided management a valuable tool for directing effort along the desired channels. A significant management device employed during the project to assure mission success was the spacecraft Flight Safety Review meeting held prior to each launch. At this meeting, every activity connected with the spacecraft was discussed in detail between management and engineering specialists to determine the flight readiness of the spacecraft. The criteria established for this review was that a Mercury launch would not take place in the face of unresolved difficulties that might affect mission success or flight safety.

Conclusions

The foregoing discussion has presented in detail the lessons learned in preflight preparation and testing during the Mercury Project. The conclusions that have been drawn from this experience follow:

(1) Test procedures incorporating the techniques of end-to-end testing, interface verification, and astronaut participation should be documented and continually updated.

(2) Spacecraft should be completely assembled at the factory, using a minimum of simulated hardware.

(3) The number of component malfunctions during testing proved the need for better quality control and inspection procedures.

(4) The lack of test points, spares, and formalized troubleshooting procedures often hindered rapid malfunction analysis and corrective action.

(5) Limited shelf life and operational life of components create spares problems and possible delays in launch schedules.

(6) Pursuance of exacting cleanliness procedures reduces the possibility of component and system malfunctions.

(7) An automatic checkout system can provide complete real-time test documentation and better control of test operations by test engineers than an analog system.

15. FLIGHT CONTROL OPERATIONS

By JOHN D. HODGE, *Asst. Chief for Flight Control, Flight Operations Division, NASA Manned Spacecraft Center;* and DANIEL T. LOCKARD, *Flight Operations, NASA Manned Spacecraft Center*

Summary

An organization was established at the beginning of Project Mercury to provide support to the astronaut in all phases of the mission. This organization was to monitor and direct the mission to insure a greater margin of safety for the astronaut, provide support necessary for mission success by extending the analysis capability of the astronaut, and record data for detailed postflight analysis.

To be able to accomplish the assigned tasks, it was necessary to plan operational requirements, generate documentation for real-time use, and train personnel specifically for the job of flight control.

As the program progressed from the planning stages through manned orbital flight, flight control progressed in its ability to provide better support.

All Mercury flights were successfully supported by flight controllers at the Mercury Control Center and sites located throughout the world. During the program a number of difficulties occurred which required changes and improvements to methods used in the early flights. Most of these difficulties were corrected and flight control provided the necessary support to contribute significantly to the success of the program. Because of the experience gained in the Mercury program the flight control organization is now more qualified to progress to the more complex programs planned for the future.

Purpose of Flight Control

At the beginning of the Mercury program, it was recognized that a ground-based crew would be needed to aid the astronaut in monitoring the spececraft systems, to evaluate systems performance, and to advise the astronaut on the proper action necessary in case of a spacecraft malfunction. Also, the ground crew would have the capability to command reentry of the spacecraft in unmanned vehicles and in manned vehicles should the necessity arise. In addition, it was necesary that the flight control organization record information for postflight analysis. The major objectives of flight control were:

(1) Assist the astronaut during critical mission phases where additional close monitoring and direction would insure a greater margin of safety.

(2) Provide support as required in conducting the flight plan to contribute to mission success.

(3) Extend the system analysis capability of the crew and make available experts in all vehicle systems should they be needed to support the crew.

Flight control is the team work existing between the spacecraft crew and a worldwide ground crew to accomplish manned space flight. This task covers the entire premission preparation phase and terminates with the recovery of the spacecraft and crew. Flight control was broken into five separate tasks:

(1) Preparation of the ground and flight crews prior to launch, which includes the detailed development of Flight Plans, countdowns, Mission Rules, and training of personnel in vehicle systems and ground network operations.

(2) Execution of mission control, which includes the direct supervision and coordination of all aspects of mission real-time ground support and the control of the launch vehicle and spacecraft crew during flight.

(3) Supplement the vehicle systems analysis capability of the spacecraft crew, primarily by the compilation, reduction, and evaluation of telemetered and voice data from the spacecraft and its crew.

(4) Assistance to the spacecraft crew in attaining the mission objectives. This task requires participation in the development of an optimum flight program, provision and coordination for real-time ground support necessary for execution of this optimum Flight Plan, modification of the Flight Plan in real time as required, and assistance in preparation for subsequent mission phases.

(5) Participation in postmission analysis, recommendations, and the preparation for subsequent flight programs.

History of Communication Between Ground and Pilot

The development of a complex vehicle requires the parallel development of a test and control organization to provide the support necessary to accomplish the test objectives.

The advent of air-ground data links has allowed a ground-based crew to monitor the test in progress, to modify the flight if necessary, and to recommend the most expeditious course of action to be taken in the event of a contingency situation. The missile age brought about the development of a ground-to-air data link by which information and commands could be sent from a monitoring ground crew to the vehicle to modify its flight plan.

In the early planning stage of Project Mercury, it became evident that an extensive tracking and data-acquisition network would be required. The presence of man in an orbiting satellite demanded that considerably different requirements be placed on the tracking network than had previously been necessary for unmanned vehicles. The most significant of these requirements was that it was now imperative that the network respond rapidly to contingency situations to insure adequate safety of the astronaut. In order to meet the new requirements and to analyze the progress of the flight, the tracking network combined previously used methods of monitoring. These methods are telemetry and radar and voice communications which are discussed as follows:

(1) Telemetry and radar, which were used to monitor and track satellite and missile systems, provided a means in Project Mercury not only of analyzing launch vehicle performance and trajectory progress but also of monitoring spacecraft systems and making medical analyses of the astronaut's physical status.

(2) The voice conversations between the astronaut and the spacecraft communicators around the world proved to be invaluable. The ability of the astronaut to make observations and relay them to the control center, to verify telemetry data, to update the retrofire timer, to exchange information with the ground, and to carry on discussion of problem areas proved to be the best tool for flight-control analysis. Voice communications also proved to be a primary method of making a medical analysis of the astronaut's physical status.

Development of Flight-Control Operations

Network Requirements

In the planning stages for manned flights, the design criteria for the tracking network were established. These requirements were:

(1) A central control facility able to coordinate a worldwide network of tracking stations.

(2) Continuous monitoring of the powered-flight phase of the mission.

(3) A worldwide network capable of monitoring a spacecraft while in orbit.

(4) Voice, telemetry, radar tracking, and command capability at the time of retrofire for a planned reentry.

(5) A recovery force capable of astronaut rescue in case of an emergency as well as recovery after a normal reentry.

Development of Detailed Flight Control Operational Planning

As preparation began for manned space flight, it became apparent that a need existed for a well-trained control organization in order to perform the flight-control tasks previously mentioned. As in the case with any engineering or scientific undertaking, the ability to control a mission successfully is primarily a result of premission planning.

Documentation.—At the beginning of the project, the different organizations connected with the Mercury program published a number of documents in which the method that should be used to accomplish the flight-control task was described in detail. Some of the documents were revised and used in Astronaut Cooper's flight. However, the majority of the documents proved to be too cumbersome for real-time use and too difficult to keep updated for use by the flight-control organization. Consequently, some of these documents were revised, others were discontinued, and new ones which would be more adaptable to use in real time were written. As a result of the experience gained by the use of these documents, several specifically designed for flight control were published.

The most difficult task of flight control is that of being prepared to make a real-time decision. A real-time decision by flight control could result in an action to change the entire mission. The action based on this decision may range from a slight variation of the flight plan to immediate termination of the mission. The documentation to be used by flight control personnel not only must have all necessary information available to research a problem, but also must contain information that can be quickly located, if time is limited. The most significant documents that evolved through experience and use were Mission Rules, Flight Plan, Flight Controller Handbook–1, and the Trajectory Working Paper.

Mission Rules: A fundamental approach to the analysis of systems failures in any flight-test program is to formulate a set of probable component failures and their respective countermeasures which may either rectify the problem, provide for the safety of the occupant, or protect the equipment. This compilation of preplanned actions for each flight is called Mission Rules. In no other document are the actions of the crew and the flight control teams so well defined. Each rule is carefully scrutinized by the flight controllers and astronauts for possible ramifications which need more clarification. This document shows the integrated actions of the spacecraft crew and ground-support personnel which are required to establish an efficient team that may be called on to take life-saving actions should an emergency situation arise.

These Mission Rules are put to the final test during the extensive series of simulations prior to the mission. Some of the rules may be modified as a result of the realistic situations created by the simulation. A Mission Rule Review is held the day before launch to assure a consistent interpretation and a complete understanding of the rules. A page from the Mission Rules for orbital reentry is shown in table 15–I.

Flight Plan: The Flight Plan for the manned Mercury missions consisted of a time-referenced step-by-step list of the astronaut's activities during an individual mission and the necessary supporting information. It was basically written as a guide for the astronaut in conducting the mission, but it also served as a focal point for the coordination of all the inputs into the mission and the coordination of the ground-controller activities with those of the astronaut. In addition, it served as a basis for premission training, simulations, system tests, and detailed management in meeting the mission objectives.

The formulation of the Flight Plan required the coordination of inputs from many organizations into a sequence that not only met the mission objectives and ground rules, but also could readily be performed by the astronaut. The inputs into the Flight Plan were concerned with the astronauts, the spacecraft systems, flight controllers, medical requirements, and experimental considerations. As these inputs were received, they were arranged to meet the requirements of astronaut usage, reliability, priority, Mission Rules, and ground control. In order to obtain the maximum amount of useful information from the flight, the Flight Plan was continuously coordinated with and reviewed by the various input organizations and finally approved by the Operations Director.

The Flight Plan, as an operational document, served several purposes. Primarily, it provided the astronaut with a coordinated schedule of his activities during the mission. It also outlined part of the astronaut's preflight training. The Flight Plan further served to inform the flight controllers of the astronaut's planned activities and was used as a tool to help coordinate the activities. In addition to the activity schedule, the Flight Plan provided the normal and emergency procedures and checklists for the control of the spacecraft and procedures for conducting experimental and medical activities. During the mission it provided a basis from which changes could be made because of system malfunctions or alterations in the requirements. Also, it provided nonoperational organizations with information concerning the activities scheduled for an individual mission. See table 15–II for sample page from flight plan.

Table 15–I.—Mission Rules—Orbital Reentry

Revision	Item Condition—Malfunction	Ruling	Notes, Comments, Standard Operation Procedures
	8. Failure of one suit fan.	8. Continue mission.	
	9. Failure of both suit fans.	9. Select EMER O_2 rate ASAP and reenter at next planned landing area.	
2	10. Smoke, fumes, unusual or annoying odors in suit circuit.	10. Switch suit fans. If this does not clear up the fumes or smoke, go to EMER O_2 rate and try further to isolate cause. If cannot isolate, reenter next planned landing area.	10. Check suit PCO_2 reading.
	11. Smoke, fumes, fire, unusual or annoying odors in cabin.	11. Close faceplate, attempt to isolate cause. If source isolated and no other Mission Rules are violated, continue mission. If fire, decompress.	
	12. Faceplate will not reseal. a. Cabin pressure above 4.6 psi. b. Cabin pressure below 4.6 psi.	12a. Reenter next planned landing area. b. May require contingency landing area reentry or ASAP reentry if cabin pressure below 4.0 psi.	12. Astronaut should get spacecraft in RETRO ATTITUDE and prepare to reenter.
	13. Conditions for selection of EMER O_2 rate.	13. Astronaut should select EMER O_2 rate when: a. Suit pressure below 4.0 psi. b. Respiration rate increasing to 40 breaths/min. c. Unsatisfactory operation of suit heat exchanger that is not corrected. d. Rise in partial CO_2 reading to 7.5 mm Mercury. e. Smoke, fumes, unusual or annoying odors in suit circuit.	

Table 15–II.—Excerpt From Flight Plan

Orbit	AOS	Site mode	LOS	Action	Remarks
21	32:05	ASCS Orbit		A—Turn ON cabin fan and cabin coolant flow for precooling prior to reentry.	
21	32:15	ASCS Orbit	32:20	A—Radiation experiment ON for 5 minute period.	
21	32:22	ASCS Orbit		A—Tape recorder—PROGRAM. Take horizon definition photographs.	
21	32:23	CSQ ASCS Orbit	32:30	A—TV ON for pass. Oral temperature. Blood pressure.	The astronaut cannot talk for a period of 3–5 minutes during oral temperature taking.
21	32:40	HAW ASCS Orbit	32:46		
22	33:33	ZZB ASCS Orbit	33:39	A—Tape recorder—CONTINUOUS. Complete stowage and preretrosequence checklists. Check manual proportional and FBW-high thrusters if required. Readout fuel and 0_2 quantities.	
22	33:57	CSQ ASCS Orbit	34:03	A—TV ON for pass. C and S-band radar beacons. CONTINUOUS. Report checklists—COMPLETED. CSQ—Confirm astronaut ready for retrosequence. Confirm retrosequence time setting. A—Squib switch ARM at retrosequence minus 5 seconds.	

Flight Controllers Handbook: The first document designed specifically for flight controllers was published in December 1960. This book was designed to contain operational information needed by a flight control team to analyze spacecraft systems problems. Schematics, logic diagrams, and other publications were used to prepare schematics oriented for operational utilization. This document, entitled Flight Controllers Handbook No. 1 (FCH–1), was used from the MA–3 mission until the end of the Mercury Project. During this time, the FCH–1 was modified and revised to include more system details. The final document contained highly detailed functional schematics of spacecraft systems, yet the arrangement of these schematics along with notes explaining details provided information very adaptable to real-time use. The schematic diagram, shown in figure 15–1, was taken from the Flight Controller's Handbook.

Trajectory Working Papers: Real-time decisions concerning flight dynamics are of paramount importance to the astronaut's safety and to mission success. Should the flight trajectory vary from the precalculated nominal during launch, there is no time for analysis, and corrective action must be immediate. In order to aid the flight controllers in making these fast decisions, a flight dynamics document was prepared to provide a ready reference of charts, curves, tables, and other data illustrating the expected normal trajectories, calculated allowable limits, and timed sequence of events. This document contained not only information pertaining to all the conditions necessary for insertion of the spacecraft into orbit, but it also contained curves for calculating retrofire times and making reentry landing predictions. Table 15–III and figure 15–2 are examples of information contained in the Trajectory Working Paper.

Training.—In November 1960, training courses were organized for NASA personnel who were to become flight controllers. The classes covered basic spacecraft systems. Because of the limited number of personnel available to man a worldwide tracking network, it was necessary to borrow personnel from other organizations to be used as flight controllers on a part-time basis. However, it was soon discovered that this arrangement was not adequate. Since these people were responsible to their own organizations except during a mission, they were not available for premission planning and postmission analysis. In addition, the flight-control tasks interfered with their responsibilities to their own organizations. As a result, it was determined that full-time flight controllers were needed. The first full-time team of systems monitors came to NASA in January 1961, and new techniques of instruction were incorporated through the experience gained in the preceding class. These systems monitors learned the spacecraft and ground systems and conducted the succeeding flight-controller training classes. The following facilities and aids were used in the flight-controller training program: classroom lectures, Mercury procedures trainer, and training documentation.

An updated formal training course was held in April 1962 and consisted of 156 hours of classroom lectures on spacecraft and ground systems. The original NASA flight controllers were the instructors and were responsible for the training lesson plans. The FCH–1 manual was the primary source of information for the lectures on spacecraft systems. Within one year, a total of six classes were conducted without any significant changes in the format.

The Mercury procedures trainer was utilized in training flight controllers in network operational procedures, spacecraft communications, and systems analysis. The first Mercury procedures trainer was installed at Langley Air Force Base, Va., in 1960 and became operational the latter part of the year. The remote site console simulator was also installed at Langley. For a description of the procedures trainer and the simulator, see paper 10. This remote-site simulator was designed to operate from outputs of the spacecraft procedures trainer for simultaneous site-vehicle training. Initially, the procedures trainer was used primarily by the astronauts for systems training, and there was limited availability for use by the flight controllers. In 1961 a Mercury procedures trainer was installed at Cape Canaveral, and more time was then available for the Flight Controllers to train on the one at Langley. The trainer configuration was continuously updated to make it identical with the spacecraft used for the real-time operation.

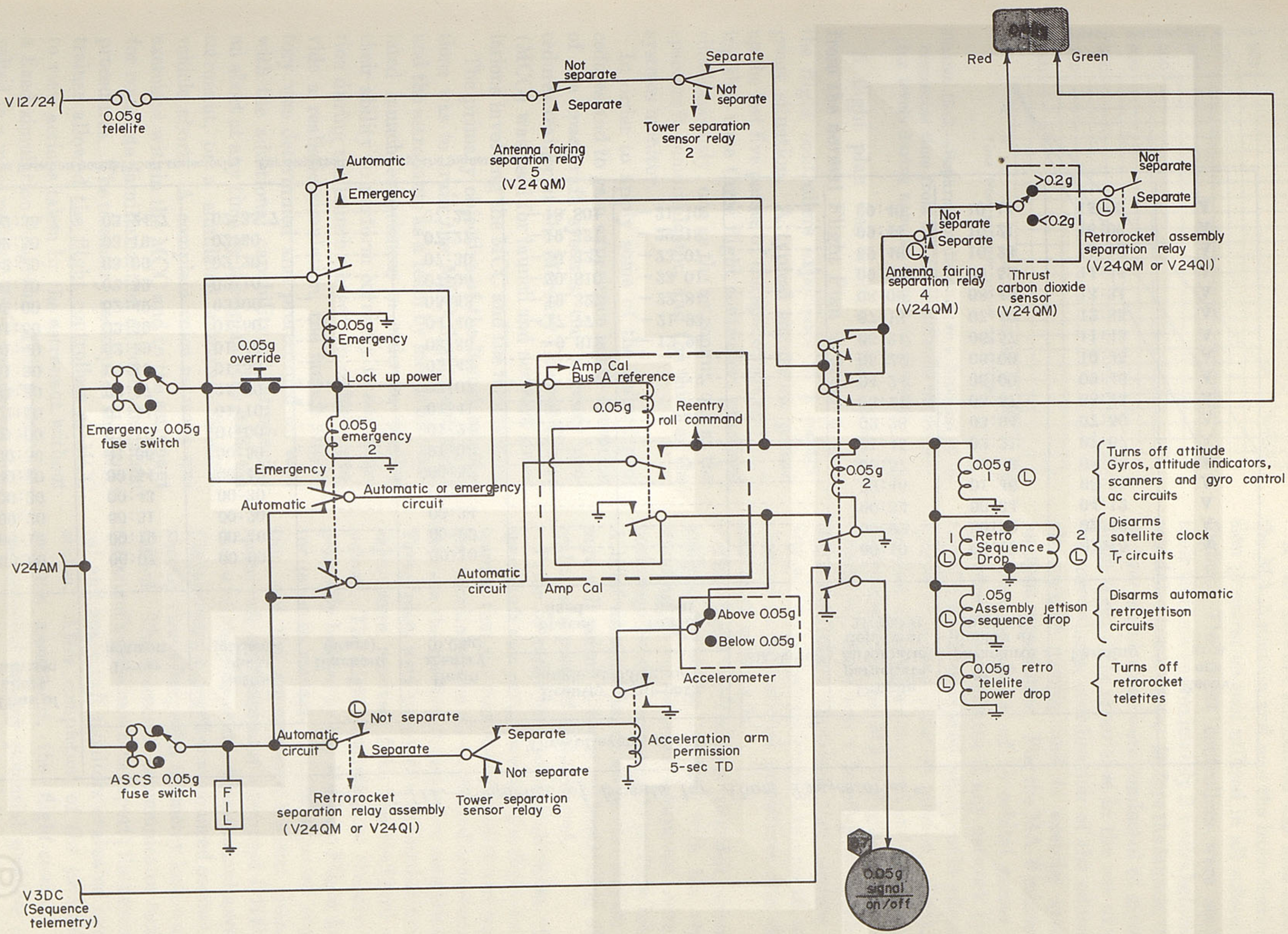

FIGURE 15-1.—Schematic diagram of 0.05g sequence.

Table 15–III.—Sequence of Events for Abort Trajectories [a]

Time of abort, min:sec	Time of event, min:sec										Recovery area
	Tower jettison	Retro-pack jettison	Blackout (start)	Begin reentry (0.05g)	Reentry flight-path angle at 0.05g, deg		Blackout (end)	Drogue parachute automatic deploy at 21,000 ft	Main parachute deploy at 10,000 ft	Landing	
					Space-fixed	Earth-fixed					
00:00	00:07	00:00	----------	00:10	----------	----------	----------	00:10	00:10	01:15	A
00:10	00:19	00. 10	----------	00:22	----------	----------	----------	00:22	00:22	02:18	A
00:20	00:31	00:20	----------	00:34	----------	----------	----------	00:34	00:34	04:12	A
00:30	00:43	00:30	----------	00:46	----------	----------	----------	00:46	01:46	05:33	A
00:40	00:54	00:40	----------	00:57	----------	----------	----------	00:57	01:43	06:09	A
00:50	01:06	00:50	----------	01:08	----------	----------	----------	01:45	02:21	07:07	A
01:00	01:18	01:00	----------	01:24	----------	----------	----------	02:28	03:04	07:50	A
01:10	01:41	01:10	----------	01:41	----------	----------	----------	03:21	03:57	08:43	A
01:20	02:07	01:20	----------	02:07	----------	----------	----------	04:24	05:00	09:46	A
01:30	02:19	01:30	----------	02:42	----------	----------	----------	05:23	06:00	10:45	A
01:40	02:29	01:40	----------	03:36	−9. 812	−12. 94	----------	06:21	06:57	11:43	A
01:50	02:39	01:50	----------	04:46	−17. 77	−21. 93	----------	07:13	07:49	12:35	A
02:00	02:49	02:00	----------	05:48	−19. 327	−22. 81	----------	08:09	08:45	13:31	A
02:10	02:59	02:10	----------	07:05	−20. 810	−23. 01	----------	09:22	09:59	14:45	A
02:20	03:09	02:20	----------	07:30	−20. 327	−23. 07	----------	09:46	10:23	15:08	A
02:30	03:19	02:30	----------	07:22	−19. 321	−29. 18	----------	09:44	10:21	15:06	A
02:35. 7	03:24. 7	02:35. 7	----------	07:23	−18. 801	−21. 10	----------	09:40	10:16	15:02	A

[a] Times based on normal abort trajectories. For dispersed trajectory, the sequence changes.

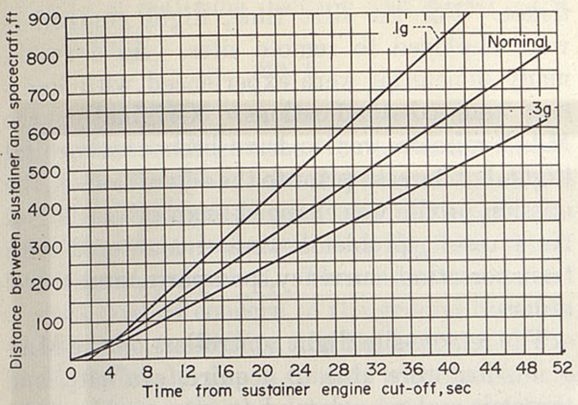

FIGURE 15–2.—Separation distance as a function of incremental time from SECO for different thrust sensing levels during nominal thrust conditions.

A flight plan was written which deviated from the normal Flight Plan in order to give the flight controllers experience in a contingency situation. A typical simulation picked up the last five passes of the spacecraft and during that time three flight controllers practiced simultaneously: one as the astronaut, one as the spacecraft communicator, and the third as the systems monitor.

In order to apply some of the defined procedures and to gain experience in the operation of the spacecraft systems, the Mercury procedures trainer at the Mercury Control Center (MCC) was used for launch and network simulations involving the MCC and the remote sites.

The primary objective of the launch simulations was to train the MCC flight controllers and the astronauts as a team by means of simulated launch experiences in order to develop their ability to perform correctly in any situation during the launch phase. In order to provide a realistic simulation, the launch trajectory was determined and prerecorded on tape with the additional capability of introducing an abort at any time by the operations staff, the astronaut, or a simulated automatic launch-vehicle abort. A complete voice network was exercised within the MCC and to the astronaut for complete familiarization of communication procedures. The telemetry backups of the MCC trainer allowed the flight controllers at MCC to view actions taken by the astronaut without a fixed simulation program. This practice resulted in a more realistic flight simulation than that afforded by the taped simulations used at the remote sites.

A full network simulation was first used for the MA–3 mission and was the basic final mission preparation tool utilized in all subsequent flights. The flight controllers were sent to their stations approximately 2 weeks before the scheduled launch date. Before the launch, three or four simulations were conducted to give the flight controllers experience in the use of correct procedures, coordination of the efforts of all support groups, and to exercise systems analysis capabilities. For the MA–9 mission, a real-time simulation of 18 orbital passes was performed to determine if any network operational difficulties existed which could affect the success of a long-duration mission. Thus, the problem areas were uncovered and solved before deployment for the MA–9 flight. After each simulation, there was a briefing in which the flight controllers explained their actions and any problems were reviewed. As a result, many changes to operational procedures and documentation were made.

The flight controller's detailed systems-analysis capability coupled with his understanding of the network equipment were the basic requirements necessary to perform his job. A brief examination of an orbital station passage will permit a better understanding of the real-time aspects of flight control.

Prior to radar and voice acquisition of the spacecraft at a particular site, the flight-control team at that site received systems status reports and monitored the air-to-ground transmissions between the spacecraft and other network sites. Trend plots were prepared and acquisition messages were received from the Goddard computers. The flight controllers at the site were generally briefed by the Mercury Flight Director prior to contact. At the expected acquisition and the approximate horizon time, the spacecraft communicator attempted UHF contact with the astronaut. Almost simultaneously the telemetry supervisor announced contact, and shortly thereafter, solid telemetry lock was obtained. The spacecraft communicator took the astronaut's systems status report; the aeromedical and spacecraft monitors evaluated systems status. After completion of the preliminary systems assessment, the flight-control team concentrated on any potential problem areas. If a problem existed, the data were rapidly evaluated and notification was sent to the MCC and network by either voice or teletype. If time did not permit or if loss of communications with the MCC did not allow instructions to be given by the Flight Director, the flight controller had to be prepared to advise the astronaut. In order to provide the proper advice to the astronaut, the flight controller must rely on his knowledge of Mission Rules and spacecraft systems.

Flight Control Chronology

The ability of the ground crew and the astronauts to work together as a team has contributed greatly to the success of Project Mercury. The astronauts' confidence in the flight-control organization and its ability to advise and direct their actions when problems occurred greatly simplified the flight control task.

MR–3 AND MR–4

America's first manned space flight, Astronaut Shepard's flight (MR–3), was performed satisfactorily despite the tension involved with the first manned launch.

The flight-control operations of Astronaut Grissom's flight (MR–4) were smoother than those of the MR–3 flight, indicating the benefits obtained from flight-test experience. Information provided by all sources allowed a good analysis of the flight to be made in real time. From launch through landing, the flight was completely normal from the standpoint of flight control. However, early release of the spacecraft hatch caused the spacecraft to flood with water after landing and it was not recovered.

MA–3, MA–4, AND MA–5

Although the MA–3, MA–4, and MA–5 flights were unmanned, they provided valuable experience to the flight-control team. In MA–3 and MA–4 a mechanical man was used to exercise the Environmental Control System. In MA–5, a chimpanzee was on board.

The MA–3 flight of April 25, 1961, was the first attempt to orbit a Mercury spacecraft; however, because of a launch-vehicle guidance malfunction, the mission was aborted shortly after lift-off. From the viewpoint of the flight control organization, a tremendous amount of experience was gained from this orbital attempt. For the first time, flight controllers were deployed to remote sites. As a result, many difficulties were experienced with logistics and communications. Originally, the MA–3 mission was to have been a suborbital flight, but 3 weeks prior to the actual launch, the mission profile was changed to an orbital flight. As a result, problems were encountered with transportation, currency, passports, and travel orders.

The remote-site flight controllers on the MA–4 mission were able to acquire, evaluate, and transmit real-time data; however, problems developed because of the delay in preparation of summary and postpass messages. The major concern during this mission was the inability of the sites to acquire C- and S-band radar tracking. The inability of the sites to acquire C-band radar tracking was attributed to poor spacecraft antenna radiation pattern which was corrected for later flights. Failure to track S-band at several sites was determined to be the result of personnel error. This difficulty was corrected by further training of the maintenance and operational personnel at the remote sites.

For the MA–5 mission, the telemetered data from the spacecraft were of good quality and all sites received total coverage. Data transmission from all sites was good, and the Goddard conference loop was utilized for the first time to provide real-time voice data to MCC from sites that had access to a telephone cable for voice capability. The MA–5 mission was originally scheduled for a three orbital-pass mission, but a series of problems caused termination of the flight at the end of the second pass. The apparatus used to measure the chimpanzee's psychomotor responses malfunctioned. In addition, there was a suit and cabin temperature increase; however, a control-system malfunction causing high fuel usage was the reason for termination of the flight. If the flight had been allowed to continue an insufficient quantity of fuel would have been available for retrofire and reentry. The decision to terminate was made and executed in 12 seconds in order to be able to bring the spacecraft into a planned landing area. The decision was made, and the California spacecraft communicator commanded retrofire. The MA–5 flight proved to be a fine example of the importance of being prepared to make a real-time decision and to act on it immediately.

MA–6

Because MA–6 was the United States' first manned orbital flight, the events which occurred are quite familiar. At the beginning of the second orbital pass over Cape Canaveral, the telemetry data indicated that the heat shield had become unlatched. This indication caused a great deal of concern to the ground crew because of the possibility that the heat shield was loose. While he was in contact with the Hawaii station during the third pass, Astronaut Glenn was asked to put the landing-bag switch in the automatic position to determine if the landing-bag deploy light would come on. The astronaut did not get an indication which meant that the problem was probably an instrumentation failure. However, after further analysis it was decided that the safest approach was not to jettison the retropackage so that the retropackage straps could hold the heat shield in its proper position during reentry until sufficient aerodynamic force was exerted on the shield to hold it in place. Another problem was a partial failure of the automatic stabilization and control system (ASCS), but this problem was handled very adequately by the astronaut's using manual backup and fly-by-wire (FBW) control.

MA–7

For the MA–7 mission, the air-ground contact procedures were reviewed and negative reporting procedures were initiated to eliminate unnecessary conversation with the pilot and network teletype traffic. The only major systems problem was the improper functioning of the ASCS. Astronaut Carpenter was forced to perform a manual retrofire since attitudes could not be controlled by the ASCS.

MA–8

As far as the flight was concerned, the MA–8 mission was a "textbook flight," in which no problems of any importance developed. As a result of the excellent performance of Astronaut Schirra and the spacecraft, the flight-control task became one of monitoring, gathering data, and assisting the astronaut with the Flight Plan.

MA–9

Permission.—The flight controllers began deploying for the MA–9 mission on April 30, 1963, and by May 5 all teams were at their sites.

Onsite prelaunch preparation began with launch simulations at Cape Canaveral and Bermuda. A total of ten launch simulations were conducted, five on May 2 and five on May 4.

The network simulations began on May 7 with two simulations being conducted on that day. In the first simulated mission, the systems-analysis capabilities of the flight controllers were exercised by a failure of the FBW high thruster control followed by a loss of cabin and suit pressure integrity. The second simulated mission contained a 1-second-late sustainer engine cut-off resulting in an overspeed insertion which caused a higher than normal apogee. These conditions tested the ability of the flight dynamics officer and retrofire monitors to calculate new reentry areas and retrofire times. Also, all the flight controllers were tested in their ability to adjust to an abnormal sequence of acquisition-of-signal and loss-of-signal times.

On May 8 the first simulation contained noisy and intermittent telemetry data, and the flight controllers were required to obtain data from backup recorders. The second mission contained a leaking regulator in the manual fuel pressurization system. During the second orbital pass a Military alert was simulated, which caused a reevaluation of the Mission Rules concerning loss of two-way communication with the spacecraft.

The first mission of the third day of simulations, May 9, was primarily an aeromedical monitor exercise with the astronaut experiencing a simulated heart attack. The second mission of the same day contained another systems problem with a failure of the main fans inverter and the standby inverter. Reentry was initiated by the California station when the Guaymas station experienced a failure of the air-ground transmitting capability. Landing was approximately 1,100 miles downrange from nominal because of a failure of the third retrorocket to fire.

The last simulation was on May 12 and an attempt was made to exercise both the range maintenance and operations personnel and the flight controllers. During the mission the 10.5-kc voltage-controlled oscillator drifted in frequency, and this action required the telemetry ground-station operators at the remote sites to adjust the discriminator center frequency control constantly, and the flight controllers to analyze the pulse-amplitude-modulation wave train on the backup recorders.

Throughout the simulations, the intent was to provide the flight controllers and support personnel with the atmosphere of an actual mission. For that reason, each mission began with lift-off, and reentry was determined by the condition of the spacecraft and the astronaut without regard to any set pattern of orbital or reentry simulations.

The performance of the site simulation teams, and particularly the astronaut simulators, was outstanding throughout the MA–9 simulations. Probably the most often heard criticism of the MA–9 simulations was the fact that 3 consecutive days of network simulations were scheduled. This rigorous schedule imposed extremely long hours on the maintenance and operations personnel as well as the flight controllers.

Mission.—The network countdown for MA–9 was initiated on May 14 at 2:00 a.m. e.s.t. The spacecraft–launch-vehicle countdown proceeded normally. The network radar-computer data test was completed on schedule, and the mandatory equipment at all stations was operating satisfactorily with the exception of the Bermuda FPS–16 radar, which had failed the slew tests in both azimuth and range. The slew tests were scheduled to be rerun for Bermuda, and the "C" computer at Goddard was standing by to check the Bermuda data. Bermuda estimated that it would take an hour to isolate the problem. Reruns of the radar-computer data tests indicated the azimuth and elevation data were good; however, some dropouts were experienced in range.

At T–60 minutes, a series of short-duration holds, eventually totaling 2 hours, were called because of problems with the diesel generator used for moving the gantry. The fuel system on the diesel was changed and the count was resumed at 9:09 a.m. e.s.t.

The Bermuda radar had passed the test performed during the hold; however, there was still a 14-percent error rate in the range data. Continual status reports were obtained from Bermuda, and the performance of the radar was marginal for the T–45 minute liquid-oxygen status check. A final slew test was performed with Bermuda at T–20 minutes, and the error rate on these data was unacceptable. It was determined at this time that the radar would not be able to support the mission and the launch attempt was canceled at 10:00 a.m. e.s.t.

The Bermuda station began immediate troubleshooting of the FPS–16 system, and the Goddard computer was placed on a standby status to run data slew tests with the radar when it was repaired. The problems were isolated to the preamplifier in the azimuth digital data channel and the shift register in the range digital data channel.

The count was recycled for 24 hours and the network count was resumed at 2:00 a.m. e.s.t. on May 15. All primary network systems were operational when the countdown was initiated.

The confidence summaries transmitted by the network to verify the site patching and calibrations were very good. No major discrepancies were noted in the network voice communications; however, Zanzibar, Canton Island, Rose Knot Victor, and Coastal Sentry Quebec stations were influenced by propagation and several repeats were required from the stations. The May 15 countdown was continuous except for a short hold for the launch vehicle ground support equipment. The countdown was resumed within approximately 4 minutes and lift-off occurred at 8:04:13 a.m. e.s.t.

The powered-flight phase was normal, and all launch events occurred at the expected time. The performance of the guidance and data systems was excellent. A clear go condition was evident at insertion, and orbit lifetime was not considered to be a problem. All vehicle systems performed satisfactorily through launch and the air-ground communications were better than those of the previous mission.

After spacecraft separation from the launch vehicle, the astronaut manually performed a FBW-low turnaround maneuver. Shortly after the completion of this maneuver, the Bermuda station advised the MCC that they had observed approximately a 6° F rise in cabin and suit dome heat-exchanger temperatures. The astronaut was informed of this situation and increased the coolant flow. When the astronaut acquired voice communications with the Canary Islands station, he said that the dome temperature warning light had come on, which indicated that the suit dome temperature was below 51° F. The astronaut was required to monitor this temperature throughout the flight and to make frequent adjustments to the coolant control valve. The cabin temperature rose from 94° F at launch to approximately 118° F when the spacecraft passed over Muchea as a result of the exit heat pulse; subsequently, this temperature began to decrease slowly to a value of between 90° F and 100° F. All spacecraft systems were functioning normally, and MCC advised the Guaymas station to transmit to the astronaut the go decision for seven orbital passes. Throughout the flight, cabin air temperature appeared to vary slightly as a function of the spacecraft a–c power configuration. During the periods when the ASCS 115v a–c inverter was powered for an appreciable time, the temperature rose to a maximum value of 105° F; and when this inverter was powered down, the temperature decreased slowly over a period of several orbital passes to a value between 85° F and 95° F.

The first discrepancy occurred over Cape Canaveral at the beginning of the second orbital pass. When the telemetry was commanded by the ground, a series of repetitive telemetry calibration signals occurred. It was decided that the programed telemetry calibration function would be turned off during the sleep period so that it would not interfere with normal telemetry.

At the beginning of the fifth orbital pass, the astronaut turned the cabin fan and cabin heat exchanger off as indicated by the Flight Plan. It was noted subsequently that turning off the cabin cooling did not materially affect the cabin temperature. The astronaut opened the outlet port of the condensate trap, and whenever this trap was activated, it is believed that the system performed satisfactorily. It was noted early in the flight that the actual power consumption was less than predicted. This surplus electrical power was utilized to obtain more beacon tracking during the later phases of the flight. The C-band beacon was powered up three times prior to passes over the Hawaii station to enable tracking by the Range Tracker ship.

Fuel usage was also less than expected, and all reports indicated that the astronaut was managing his fuel supplies exceptionally well. The astronaut made several attempts to deploy the tethered balloon, in support of air-density studies and visual tests; however, all attempts were unsuccessful. After ground analysis of this system, it was decided that no further attempt would be made to deploy the balloon.

The most serious trouble of the flight was reported over Hawaii during the 19th orbital pass. The Hawaii spacecraft communicator contacted the astronaut and received a report that the 0.05g green telelite had come on and that the astronaut had placed the ASCS 0.05g fuse switch and the emergency 0.05g fuse switch to off. The main concern at MCC was to establish the state of the amplifier-calibrator (auto pilot) unit and to determine what functions of the ASCS were lost as a consequence. There was no need for planning early mission termination at this time as no Mission Rules had been violated and there was an effective control mode remaining on both the automatic and manual control systems.

After analysis and discussion of the problem, it was decided that the first step was to have the astronaut power up the ASCS bus as the spacecraft passed over Guaymas. Subsequently, over Cape Canaveral, the gyros were slaved to the horizon scanners; and after about a minute of operation, no gyro or scanner deviation from the gyro caged condition was noted. This situation indicated that the gyro and scanner power actually was off and that the 0.05g circuit was latched up. It was realized at this time that a manual retrofire would be required and that a checklist must be prepared for the astronaut. The remote-site flight control personnel on standby status were called to their stations and advised to be prepared to attempt to relay communications to the astronaut if directed by the MCC.

While he was in contact with the Coastal Sentry Quebec, the astronaut was requested to turn on the telemetry and C-band beacon to allow the Range Tracker to check its radar data. These data were very important since the retrofire maneuver would be performed manually. While the spacecraft was passing over the Hawaii station, the astronaut was requested to place the ASCS 0.05g and emergency

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0.05g fuse switches to the on position and to select the ASCS automatic mode to verify the 0.05g event. If the spacecraft began to roll as it would normally do when the 0.05g indicators were valid, the ASCS would be latched in the reentry mode. The astronaut verified this roll rate and the 0.05g event which were again confirmed by telemetry over the Guaymas station.

At this point the flight controllers knew the exact configuration of the ASCS logic and the required configuration for reentry. After completion of these tests, it was determined that the ASCS would provide proper attitude control and roll rate for reentry after the normal 0.05g event time. The manual retrofire checklist was completed and thoroughly reviewed by the MCC flight control team. This checklist was relayed to the spacecraft via the spacecraft communicator on the Coastal Sentry Quebec and written down by the astronaut. The astronaut was advised to "take Green for go" which was a coded means of telling him to take a dexadrine pill. The purpose for taking the pill was an added precaution to be sure that he was alert for the manual retrofire maneuver. The flight surgeon was not concerned over the astronaut's condition but he was not certain the astronaut was thoroughly rested from his sleep. On acquisition by the Zanzibar station on the 22nd orbital pass, the astronaut reported that the ASCS inverter had failed and the standby inverter would not start. These failures meant that the pilot could no longer have automatic control after 0.05g but would have to introduce the reentry roll rate manually. The failure of the inverters to start required that a revision be made to the checklist previously transmitted to the astronaut. The revision consisted of changing only one switch position on the earlier checklist.

Prior to retrofire, the Coastal Sentry Quebec acquired the spacecraft and the reentry procedures were reviewed. The astronaut was given time hacks at retrofire minus 60 seconds, minus 30 seconds, and a 10-second terminal countdown. The telemetry immediately confirmed the retrofire and the astronaut indicated that his attitudes were good and confirmed that all three retrorockets had ignited. Reentry blackout was confirmed by the Range Tracker ship within 2 seconds of predicted time which indicated that the landing point would be close to nominal.

The network flight-control teams performed well during this flight. Communications between the ground and the astronaut were precise and conveyed the necessary information. The flight control teams utilized the proper contact and reporting procedures that were developed for this flight test. The operations messages provided much useful real-time data, and no difficulty existed in determining the precise status of the spacecraft, the astronaut, or the mission. The entire mission period from deployment through recovery was an extremely smooth and well coordinated effort. The cooperation between the flight astronauts and the flight control personnel had a significant influence on the success of the MA–9 mission.

Concluding Remarks

The flight control organization has played a significant role in the first space flights and has made a major contribution to the success of the Mercury program. A wealth of experience and information has been gained from the project. Some of the more important are as follows:

(1) Documentation used by flight control had to be easy to update, contain detailed information, yet be put together in such a manner that the information could be found quickly in real time.

(2) People could not be borrowed from other organizations on a part-time basis to be flight controllers. It not only disrupted their own organizations but prevented them from being able to devote the required amount of time to the flight control task. As a result, it was learned that full-time flight controllers were a necessity.

(3) It was also discovered that a flight controller had to have the following special qualification: The flight controller must be a technically trained individual. It became apparent he should be an engineer or oriented toward engineering with a wealth of experience in system analysis.

(4) It was also found that a continuing program of training was necessary to keep flight controllers proficient in knowledge of spacecraft systems and operation procedures.

(5) The network and launch simulations held prior to the actual mission were found to be a necessity. In simulations, mistakes are made

and corrected. Simulations are run until the entire network is functioning as a team and complete confidence is gained in the ability of the flight controllers to respond correctly to any emergency.

(6) Because of the experience gained in Mercury it has become obvious that the more complex missions of Gemini and Apollo will require more automation. In order to be able to process the information in real time and arrive at a proper decision, it is necessary that more data processing aids be utilized.