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MISSION CONTROL FOR MANNED SPACE FLIGHT

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SYNOPSIS

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 and to qualify the vehicle for operational rather than research and development usage.

The manned spaceflight program uses a pure research and development vehicle which is normally operating very close to the limit of its design envelope. In addition, the full spectrum of engineering techniques is applied to the development of a manned space vehicle.

This paper traces the development of the real-time controlling agency from its concept through a Mercury mission to Project Apollo. In the course of this paper the flight-control tasks are identified and developed commensurate with the time frame allowed.

INTRODUCTION

Many papers have been written on the subject of operational plans and procedures for the Mercury program. It is the purpose of this paper to present a general survey of one particular aspect of operations, namely flight control. In this paper the growth of flight control for Project Mercury and the plans for the following programs, Gemini and Apollo, are discussed.

Until quite recently, research and development testing of aircraft usually followed the pattern of a fixed flight plan with a predetermined set of tests followed by postflight analysis. The flight-envelope boundaries were approached slowly because in-flight evaluation by the pilot and possible observers was limited by the available instrumentation and the ability to develop real-time solutions. The action in the event of emergencies was to return quickly to a more acceptable part of the flight envelope and, if necessary, abandon the aircraft.

More recently, 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 when contingency situations arose.

The missile age brought with it the development of a ground-to-air data link by which information and commands could be sent from a monitoring ground crew or automated system to the vehicle in order to modify its flight plan.

The one significant point which was brought to bear in the manned space flight program was that the vehicle traveled almost to the extremes of its limit design envelope on every flight; and the need for a ground-based crew to monitor, evaluate, recommend -- if necessary -- command became evident. The work that this ground crew accomplished is defined as flight control.

The fundamental aims of the flight-control crew are the safety of the astronaut and the successful completion of the mission. By far the largest task is the determination and recommendation for a course of action essentially in real time in the event of a contingency situation. The course of action may be an alternate mission, a change in mode of operation, or premature termination of the mission. In Project Mercury, the definition of real time varies from a matter of seconds to about an hour, depending on the phase of the mission.

The following transcript of the MA-5 mission illustrates the rapidity of the evaluation and decision process of the flight control team. High thruster activity indicated an out of orbit mode in the automatic stabilization and control system; and if this anomaly continued, the reaction control system fuel supply would probably have been depleted prior to the end of the third orbit. The flight control team at Hawaii identified this condition, and the decision actually to terminate the mission occurred during this 12-second period. This discussion took place between the California Spacecraft Communicator (CapCom) and Systems Monitor and the Flight Director at the Mercury Control Center.

CAL	CAL thruster activity on 69 and 70
CAPE	Roger
CAPE SYSTEMS	Did he say activity or no activity?
CAL	Activity on 69 and 70
CAPE	You've got 12 seconds
CAPE	Go ahead with retrofire
CAL	Thruster activity on roll at CAL
CAL	5, 4, 3, 2, 1, fire
CAPE	Roger
CAL	Retros fired
CAL	Fire 180813
CAPE	Roger
CAL	We have confirmation of retros 1, 2, and 3 fired
CAPE	Roger
CAPE	Roger, understand
CAPE	Did you copy, Recovery?
CAPE	Standby for time
RECOVERY	Roger, standing by

MISSION CONTROL

The objective of mission control is to increase the probability of mission success and crew safety. Any deviation from a nominal mission requires that a decision be made, and this decision may either increase the chance for mission success or jeopardize the overall mission objective and, thereby, affect the life of the space crew member. In order to augment the analysis and decision-making capability, every concept, function, procedure, and system must be designed and implemented with mission success as the primary objective.

The mission control organization for Project Mercury was implemented to provide centralized control of remote sites capable of data exchange and command control. The organization, exclusive of technical support personnel, consisted of 16 flight controllers in the Mercury Control Center and 42 flight controllers at the remote sites. This organization, shown in figure 1, was responsible for the detailed conduct of the mission from vehicle lift-off to landing.

Flight control is the portion of mission control pertaining primarily to the aspects of flight dynamics, vehicle systems operation, and spacecraft crew performance and can be defined as the integration of the spacecraft crew and the ground personnel necessary to accomplish manned space flight.

Flight control consists of five phase-oriented tasks. They are defined as follows:

1. The preflight-preparation task represents the largest single part of the mission-control function. It consists of the development of the operational concepts, the determination of facility and personnel requirements, and the detailed flight operations training. Included are the preparation of mission documentation and operating procedures, the preparation of mission logic and associated computer programs, and the training of operating personnel.

2. The mission-control task consists of supervision and coordination of mission ground support, the command control of unmanned vehicles, and the direction of the overall mission.

3. Spacecraft-systems and crew-performance analyses enhance mission success and crew safety by supplementing the crew in analyzing the telemetered and voice data to determine systems status.

4. Flight profile analysis consists of monitoring the flight program, development of alternate profiles when contingencies occur, the coordination of changes to the mission plan in real time, and the determination of GO-NO-GO status for subsequent phases as based on data from systems, flight dynamics, and crew performance.

5. Postmission analysis is a detailed review of the mission operations, vehicle system performance, and the performance of the spacecraft crew.

During the initial phases of Project Mercury, flight controllers were obtained on a part-time basis from the engineering organizations within the Space Task Group (now Manned Spacecraft Center), and a relatively small group accomplished the premission preparation tasks and performed the postmission analysis. However, with the advent of the actual Mercury missions, it was recognized that a full-time organization was required to perform this function.

The ability to control a mission is a function of the preflight preparation, the experience levels of the flight control team, and the quality and type of data obtained from the network in real time. All aspects of the mission are reviewed, and the operational concepts are developed and compared with the test objectives. The systems are studied on the basis of their operational function and utilization, and failure modes are identified. As a result of this premission analysis, mission profile deficiencies are identified. The results of these studies are documented in three primary handbooks:

1. Mission Rules
2. Vehicle system schematics
3. Trajectory working papers

Each document is designed to allow rapid reaction to a contingency and to provide accurate real-time decisions.

As a result of this documentation, it becomes obvious that some automation is required, primarily in the area of trajectory analysis. A real-time digital computing system is provided for this purpose.

A major purpose of the documentation is the formulation of contingency plans and the criteria and methods for implementing these plans. This formulation, in fact, forms the largest part of the real-time flight control problem.

The Mission Rules are premission guidelines for decision making and contain most of the contingencies that can occur during a mission. For certain time-critical cases, the Mission Rules include the detailed procedures necessary to implement this decision.

Another primary document is the Flight Control Handbook which primarily contains the current spacecraft system schematics. These schematics, as typified by figure 2, define a total system operation and

contain: (1) a power source, (2) components and controls, (3) displays for the astronaut, and (4) displays used by the flight controllers.

If a malfunction is indicated by telemetry or by astronaut readout, the probable cause or failure can normally be isolated through one schematic, and the necessary action, if any, can be taken.

The third major document utilized during the mission is the trajectory working papers, which contain most of the launch abort trajectories, the reentry trajectories, and the nominal orbital trajectories. The logic utilized to develop this document is essentially the same as the logic utilized in developing the computer programs for a specific mission. The tracking information obtained from the network is processed by the computers; then it is presented to the flight dynamics personnel via plotboards and digital displays. A flight dynamics console is shown in figure 3.

TRAINING

Personnel training is accomplished in the following three phases:

1. Individual
2. Team training
3. Network training

The individual training is accomplished by briefings, detailed systems and operational studies, preparation of mission documentation, and observation of mission operations. Flight controllers participated in the preliminary Mercury flight both as individuals and later as teams to build up their capability to perform their eventual task.

The team and network training is necessary to develop the decision capability of the flight control organization. The team assignments are usually made three months prior to a mission and, after the systems updating briefings, the teams begin an intensive period of training in the spacecraft procedures trainer and site console trainers. During this phase, the flight controllers are trained in both the command-communicator and systems-engineer positions. A third flight controller will fly the spacecraft procedures trainer, which provides both telemetry and communications inputs to the console trainers. These exercises primarily consist of normal and contingency procedures associated with portions of the actual flight plan. When the team training is completed and the required confidence level is attained, the third phase of training begins.

This phase, in preparation for a live mission, normally commences two weeks before the mission. Simulation exercises have been previously taped and transmitted to the network sites. A simulated mission normally begins at four hours before lift-off with a vehicle and network countdown. This simulation affords a checkout of the prelaunch procedures and the test sequencing. At simulated lift-off, the procedures trainer provides closed-loop telemetry and voice data to the Mercury Control Center operating positions.

The procedures trainer, shown in figure 4, is normally manned by the mission or backup astronaut for these tests. This action provides for the indispensable integration of the spacecraft crew and ground personnel and establishes the required confidence between these personnel. Trajectory data are provided from taped data to the switching and distribution area and eventually to the flight dynamics plotboards. Whenever possible, the ground systems are used in the same manner as they would be for an actual mission. This procedure develops confidence in the systems and is particularly important in the case of the real-time computer complex. At the time corresponding to the loss of communications at Cape Canaveral, the simulation becomes open-loop. The network sites at acquisition transmit radar information from prepared paper tape through the teletype lines to the computing center. The telemetry data are played into the remote site displays, and the flight controllers evaluate and respond to the data. Figure 5 shows a remote site console group.

The network training exercises all aspects of flight control and aids in perfecting the Mission Rules and operational procedures. The final objective of these exercises is the development of confidence in the readiness of the network equipment and flight controller personnel prior to initiating the terminal countdown.

The increased complexity of the Gemini and Apollo missions is partly a result of the mission profiles -- for example, the larger incremental velocity capabilities of the space vehicles and the subsequent capability to change the orbital parameters. This complexity results in a significantly enlarged tracking and computation requirement. In addition, for Project Gemini both the Gemini spacecraft and the Agena target vehicle have this incremental velocity capability. The command control of this capability in the Agena systems by ground personnel is essential to mission success. The basic tasks of flight control are essentially unchanged; however, the expansion of the systems to include the in-orbit maneuvering capability required greater automation of the orbit-determination and command-generation function.

The complexity associated with the mission profiles will require greater data exchange both from the spacecraft to the ground and between the ground sites themselves. The bulk of the telemetry data will be

assimilated by a number of highly specialized remote site personnel. In addition, significant amounts of these data will be automatically transmitted to the Integrated Mission Control Center (IMCC).

INTEGRATED MISSION CONTROL CENTER

The Integrated Mission Control Center facility, shown in figure 6, is to be implemented in Houston, Texas. This new facility will provide the centralized control capability necessary for the conduct of the Gemini and Apollo missions. The facility includes dual mission operations control rooms capable of various combinations of simultaneous real-time missions, simulation exercises, or system checkouts. At the present time, it is not planned to conduct two missions simultaneously. The real-time computing complex will be utilized at IMCC to assist in providing better real-time decision capability for both the vehicle systems and trajectory analysis. Basically, the IMCC will be staffed and operated the same as the Mercury Control Center; however, the mission analysis capability within the IMCC will be enhanced by the development of mission support specialists. This procedure will enable most flight control personnel to concentrate on a specific system or mission phase. At the network remote sites, the flight control teams are essentially the same as those for Mercury missions with the addition of a systems monitor for the Agena vehicle or the Apollo Lunar Excursion Module and the S-IVB launch-vehicle stage.

The IMCC mission operations room will direct the facilities and organizations necessary for accomplishment of the mission. These facilities and organizations include the following:

1. Internal and external computing facilities
2. Communications facilities
3. Network stations and flight control teams
4. Launch facilities
5. Spacecraft and flight crew

Personnel within the mission operations control room represent the primary decision-making group associated with the mission. The Operations Director is responsible for the overall performance of the mission. He has delegated much of this authority from lift-off through landing to the Flight Director. The Flight Director is supported by a staff of approximately 15 personnel, as indicated on the organizational chart in figure 7.

GEMINI

Rather than develop a description of each position in the mission operations control room, significant portions of the Gemini mission which detail flight control operations for both manned spacecraft and unmanned flight vehicles are presented. The Flight Director will again direct the mission operations from the lift-off, through powered flight, to recovery of the spacecraft and crew. The Flight Director will continue to receive inputs concerning the performance of the spacecraft and its systems, the launch vehicle, and the flight crew from flight control personnel; and on the basis of their analysis, and by correlation with the detailed mission rules, he will direct continuation or abort of the mission.

The basic objective of the Gemini mission is to place a target vehicle in orbit and follow it with a manned vehicle which is to rendezvous with the target vehicle with a minimum of fuel usage and the shortest time. This mission adds several tasks to mission planning.

First, the countdown of both vehicles must be conducted in the same period; second, the launch time and launch azimuth of the second vehicle are extremely critical if the objectives are to be met.

There is about a 20-minute period each day when launch can occur into the correct orbital plane and with an acceptable phase difference. This time period corresponds to a plane error of 0.4 degrees and a phase difference of 70 degrees. Of course, larger errors can be accommodated if the velocity capability of the Agena is used.

The launch phase remains the most critical period of the flight. However, a redundant guidance system with automatic and manual switchover has been provided in the Gemini-Titan configuration. In addition, ground monitoring will determine requirements for switchover for malfunctions which occur at a slower rate. The Gemini spacecraft has a manual abort system unlike the present Mercury abort system which is automatic. This manual system results in a much more reliable sequence system but requires very close monitoring, with short decision and response times both in the spacecraft and on the ground. A Ground Flight Controller will assist the astronaut in identifying valid abort requirements.

Network Flight Controllers will continue to monitor the normal progress of the mission and to determine the course of action in the case of abnormalities.

These abnormalities may be associated with trajectory deviations, in which case velocity corrections must be determined and transmitted to the remote sites and thence to the spacecraft. They may also be associated with spacecraft systems malfunctions, in which case corrective actions must be determined or an alternate flight plan, which may result in early termination of the mission, must be provided.

Preplanned mission documentation and computer programs will again be used to assist in determining the course of action in the case of contingency situations. One point which should be mentioned is that, in the case of Gemini, the crew has a much greater onboard capability than before. The computer controlled guidance and navigation system together with the propulsion system provides the crew with the capability to complete a normal mission without further trajectory assistance once the initial ephemeris of the two vehicles has been properly established by the ground system.

The personnel at the ground stations will assist the astronauts in vehicle checkout prior to reentry. They will also update the onboard computer with the latest information for reentry and insert the correct retrofire times. The reentry of the Gemini vehicle will be similar to that of the Mercury spacecraft. The main difference from Mercury is the capability to modulate lift during the reentry. The lift modulation combined with the paraglider landing system may require additional flight-control support. At the present time, studies are being made of the utilization of a radar controlled, ground-controlled intercept type of approach for assisting the crew in the landing phase.

During the reentry phase, the IMCC will direct the recovery force to the proper landing area and aid them in recovery of the flight crew. During this period, flight control will continue to maintain contact with the crew and support them as required. After the mission, the flight controllers -- both at the IMCC and remote sites -- will be required to undergo a detailed post mission analysis in order to determine actions and problem areas for future missions. Although the Gemini mission with its two vehicles, one manned and one unmanned, will require detailed analysis of a large quantity of information, the flight control team with its training and aided by automatic aids will be able to evaluate this information, reach a decision, implement this decision, and take action to support the flight crew and assure the successful completion of the mission.

APOLLO

The early Apollo missions will be conducted in a manner similar to that of the Gemini missions. However, as the missions increase in both frequency and complexity, the manpower requirements necessary to support these missions will become excessive. Test programs are now underway at the Bermuda site to provide computer processing of spacecraft data. The site data processing will be combined with wide-band data lines to transmit the tracking, telemetry, and voice data to the IMCC for evaluation and decision. The ability to provide a highly skilled flight-control team with near continuous full bandwidth data is the ultimate objective of flight control.

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The Apollo lunar mission and all subsequent manned space vehicles will continue to require the support of a ground flight control team. Whenever a vehicle is probing the envelope of ultimate performance and expanding the bounds of known space, Flight Control will aid in providing the added margin toward mission success.

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