

ROUGH DRAFT

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The site at Bermuda was designed with the same concepts as those used at Canaveral in that it was considered to be a backup to the Mercury Control Center in certain instances such as command control following an abort decision. The next slide shows an overall view of the Operations Room at Bermuda. It can be seen that the layout and the consoles are similar to those at the Control Center. No further details will be presented here but suffice it to say that the same basic philosophy in performing flight control was used. Certain additional computing facilities are provided at Bermuda because of the necessity to perform the backup function of determining the conditions of the orbit and certain times of retrofire associating with aborts. These facilities will be discussed in more detail.

The remote sites were primarily designed so as to provide information to the control center on the status of the astronaut and the capsule and to keep the astronaut updated on mission progress. A picture of a remote site operations room is shown in the next slide. There are three Flight Controllers at each site supported by approximately 20 to 30 engineers and technicians dependent upon the detailed equipment at each of the sites. Each site has a Capsule Controller and Aeromedical Monitor and a Capsule Systems Monitor. The duties of these monitors are adequately described by their titles and the data is displayed in minute and strip chart form in a similar manner to the Control Center.

Now let us consider in some detail the facilities and data required to perform the Flight Control function. Perhaps the most important and by far the most complex system is the computing and data flow facilities required.

The next slide presents the various sources of tracking data and computing systems which are required to make the various decisions regarding launch, orbit and reentry. In order to provide information on trajectory during launch, the orbital phase, times of retrofire, and impact prediction, the sources of data as shown on this slide are required. Two IBM 7090 computers are provided at the Goddard Space Flight Center in Washington, D. C. These computers perform all of the computations necessary for all phases of the flight. The method in which data is supplied to these computers is thus dependent upon the flight phase and let us consider first the launch and orbital insertion period. Because of the critical nature of this phase multiple sources of data are provided for redundancy and for decision and action should an aborted flight occur. The Atlas missile is controlled by the G. E. - Burroughs tracking and computing system and this data is considered the primary source during the launch phase. Positions and rate data are transmitted by means of high-speed data lines to the Goddard computer and some of the trajectory displays such as altitude, time to go, downrange distances, and certain guidance commands, are supplied directly to the MCC. Should this data system fail or an abort occur, data is provided on these same high-speed data lines from the AZUSA or FPS-16 radar systems through the IBM 7090 computer at the AMR to the Goddard computer. In addition, raw data from these systems can also be used. As noted, information on the various events which occur during the launch are provided to the computer from the MCC. The Bermuda data from both the FPS-16 and Verloft radars provide similar trajectory displays through an IBM 709 computer. In addition, the data from this computer or directly from the radars is supplied through an automatic teletype transmission system to

the Goddard Center. Once the capsule is in orbit, data from the various radar systems shown at the remote sites are transmitted by teletype to Goddard and automatically processed in the computer to update the various displays at the MCC. Also, once the reentry maneuver has taken place, this tracking system will provide data for accurate impact prediction.

The data obtained from these facilities are presented in the Control Center to the Flight Dynamics Officer and Retrofire controller in both plotboard and digital display form. Four plotboards are used as shown in the next slide which is a picture of the retrofire and Flight Dynamics Officer's console and the four plotboards are used for display. The plotboard on the far left is used to present impact prediction; the other three present trajectory information with regard to the launch insertion and orbit phase. The data displayed on these three charts during the launch phase is presented in the next slide. One of the plots presents altitude and crossrange deviation as a function of downrange distances and another velocity and acceleration as a function of elapsed time. These quantities are used to give an indication of the missile performance especially during the first portion of the flight. One of these same plots after a certain elapsed time, switches to plotting the yaw error signal to the missile and the insertion altitude, that is, the altitude to which the computer is guiding the missile as a function of time-to-go to cutoff. These quantities also give an indication of missile performance. The most important chart used is the plot of flight path angle versus velocity ratio, that is, the ratio of the present velocity to the velocity required for orbit at the desired altitude. The plot is presented to the Flight Dynamics Officer in two different scales such that when the velocity

ratio reaches 0.9, the scale is greatly magnified to allow the important GO-NO-GO decision to be made at the time of booster cutoff. During the flight, the Flight Dynamics Officer uses these charts to determine that the missile is performing satisfactorily, and, in addition, uses these data to determine the time of abort should an abort for astronaut or capsule systems malfunctions become necessary. During the last 15 seconds of flight, he concentrates on the magnified plot of flightpath angle. From this plot he can determine that the proper orbital parameters have been achieved and the computer, through means of lights on this same plotboard, makes the GO-NO-GO recommendation at the same time. At the same time, the computer presents the various times of retrofire associated with the cutoff conditions achieved, that is, if an abort or NO GO decision is made, the time of retrofire required to land in a particular recovery area will be displayed, and if a good decision is reached, the time of retrofire at the end of a normal three-orbit mission and the time at the end of each orbit will be displayed. The plotboards continue to give data on the position of the capsule and certain other parameters regarding reentry orbit depending upon the decision made at cutoff. As data is received from the remote sites, the times of retrofire and the other trajectory information are continually updated. Also, information necessary for acquisition is supplied to the remote sites by teletype from the computer. Certain information with regard to times of retrofire associated with particular contingency recovery areas is supplied to each site. This will be discussed in more detail by Mr. Thompson in a later paper.

As can be seen from this discussion of information and data requirements, a highly complex communications system is required. This system must provide means for transmitting radar data and acquisition information to and from sites around the world and certain pertinent information on the status of the astronaut and capsule systems. The entire communications network to accomplish this task is a subject of its own and cannot be discussed in detail. However, certain aspects of the system are necessary to the understanding of flight control. Teletype to all sites is provided and, in all cases, redundant pads are used because of the desire for high reliability and the high density traffic during certain phases. Voice communications are provided to all of the command sites, that is, Bermuda, Mueha, Australia, Hawaii, Guaymas, New Mexico, and the California site and, in addition, Woomera, Australia, and all other sites in the continental U.S. Experience today has shown that fairly reliable communications can be maintained although there is a time for serious propagation problems. Teletypes, of course, has an inherent lag and, on the average, requires six to ten minutes to transmit a message to any given site and receive a reply. Voice communications to all sites would be helpful and provide for simpler operational procedures but is not considered a necessity.

There are many aspects of the Mercury Network which should be considered, such as construction, selection of sites, instrumentation tests, countdowns, etc., which should be discussed but cannot be, because of the limited time. However, it should be emphasized that the network and the operational planning required should be considered in the design of the space vehicle. If this is not done, the ground support necessary to the

mission will be less than desired and, in addition, its completion will lag the space vehicle and, therefore, tend to pace the program. Another point which can be considered is the onboard instrumentation. This instrumentation should take into account the ground flight control necessary for accomplishing the test objectives.

In an attempt to give a better understanding of how the control of the flight is achieved the rest of the paper will deal with the details of how flight control is performed during the phases of the flight. Of course it must be recognized that an orbital flight on which these procedures will be exercised has not as yet been accomplished and the information to be presented is the result of a number of simulated flight tests in which the astronauts and the flight controllers have participated. However, the Redstone launches and the Atlas suborbital flights have been used to demonstrate these techniques and have, so far, with minor changes, proven to be adequate. In fact, the Redstone flights were planned on the basis of an orbital launch in order to exercise these techniques.

The next slide gives a pictorial presentation of the important launch phase and orbital insertion. Just previous to liftoff the final calculation checks are made with the astronaut to assure proper systems functions and reaffirm that the communications systems are functioning properly. The final phases of the countdown and the lift-off are transmitted to the astronaut by the capsule monitor in the Mercury Control Center. As the lift-off occurs the astronaut confirms that the on-board clock and timing devices have been started and that the communications are still okay. During this early phase of the flight trajectory information from the range safety plotboards ^{is transmitted} /by voice to the control center to assure that the proper trajectory is being followed. The astronaut makes a range safety communications report every thirty seconds indicating such quantities as acceleration, oxygen, and cabin pressure. The ground flight control monitors are monitoring the various systems parameters continuously

during this period. One of the most critical points in the launch occurs at about 30,000 feet or at about 70 seconds following at which time the cabin pressure seals and is maintained at 5-1/2 psi. A communications procedure with the astronaut is used to assure that if the cabin pressure and suit pressure were to fail abort action by the astronaut or the flight director could be taken to prevent an excessive altitude being reached by the capsule. Continued surveillance is made by the monitors and the astronaut is kept informed of the trajectory and the status of the flight from both a missile and capsule point of view. As staging of the Atlas occurs at about 200,000 feet this event is confirmed by both the astronaut and the ground controllers and 20 seconds later confirmation is given by the astronaut that the tower has jettisoned properly. In all cases the astronaut is prepared to perform manual backup should it be required. After this period while the booster is being propelled by the sustainer engine all of the flight control monitors are making a close analysis of capsule systems performance and astronaut conditions such that about four minutes and 30 seconds a final GO-NO-GO decision can be made in conjunction with the astronaut. This decision is a commitment to orbit of the astronaut and capsule systems. Certain ground rules are formulated and agreed upon many weeks in advance of the flight upon which this GO-NO-GO decision is made. From this point on almost complete attention is given to missile performance in the form of trajectory displays to ascertain that the proper orbital parameters are achieved, that is, the proper velocity, flight-path angle, and altitude. The conditions which are achieved are immediately transmitted

to the astronaut and the astronaut confirms that proper separation of the capsule has been achieved and that a turnaround maneuver has been properly initiated and maintained. Should a GO decision be achieved the astronaut would be informed either by the Cape or the Bermuda site of the times of retrofire calculated by the computer for a proper reentry at the end of the designed mission. If the computer indicates a NO GO condition the astronaut would be so informed and the times of retrofire necessary for landing in a preferred recovery area would be indicated to him and to the Bermuda flight controllers. The actions to be taken by the ground control and the astronaut would, of course, be dependent upon the final cutoff conditions. Of course, these actions can be extremely time-critical and the communications procedures to be followed have been worked out by intensive training in this particular area. The insertion takes place about midway between Canaveral and Bermuda in approximately one minute after this time control of the voice link and command to the capsule is given to Bermuda. Bermuda actually acquires the capsule RF links at about a minute and 30 seconds before cutoff. Also, summary information and other pertinent data regarding the launch phase is immediately transmitted by voice and teletype to all remote sites. All of this information is being monitored by the recovery control center located adjacent to the flight control operations room and is kept informed in almost real time of the experienced landing points of the capsule.

Let us now consider that orbit has been achieved and take a look at the activities at a typical remote site. The next slide again gives a pictorial presentation of the procedures following during a normal pass in an orbit which passes fairly close to overhead. This period lasts for

approximately five to six minutes. The station has received messages both from the control center and other sites on astronaut and systems performance and acquisition messages and certain times of retrofire from the computer. The acquisition messages are received 30 minutes, 10 minutes, and 5 minutes previous to the horizon time of the capsule. Upon making the initial voice contact and acquiring telemetry signal the astronaut immediately reports his condition and certain instrument readings for direct telemetry comparison. He, in turn, is given a time of retrofire for the end of this particular orbit and the next contingency recovery area in order that he may know the most up to date information should an emergency develop at any time. Because of the importance of the time of the capsule clock the astronaut indicates his elapsed time since lift-off and the time of retrofire sent in to the clock. These are compared with telemetry and transmitted back to the Goddard computer and used in calculating future times of retrofire. Of course, during this time radar data from the site is being transmitted to the same computer for updating the orbit characteristics. The astronaut is informed of the progress of the mission and is kept updated on certain matters concerning recovery and worldwide weather. Then, if necessary, the astronaut could make a complete status report to the site regarding systems functions such as any changes he may have made, his physical condition, any communications phenomena or problems, how he has been able to navigate and anything concerning mission control which he may desire for review. Also, over some sites certain tests will be made in conjunction with the ground to ascertain the astronaut ability to perform in the space environment. Following loss of contact

with the capsule the site will immediately transmit a message to the control center and all other sites regarding the status of the astronaut and capsule systems.

This process is followed as the capsule progresses throughout the orbit. Of course, certain other procedures with regard to clock setting and retrofiring are followed at command sites, such as Muchea in Australia, and the California sites. The retrofire maneuver is performed by a countdown from the ground to the astronaut and would be initiated similarly by the astronaut and the ground command. The on-board clock will be used primarily as a backup to these commands. The control of the capsule throughout orbit retrofiring and reentry will vary from flight to flight in order to evaluate both the astronaut's capability and the systems performance.

In order to train both the astronaut and the ground crews in flight control problems and to develop the procedures necessary to flight control facilities were constructed both at the control center and at Langley which allow complete flight simulation. At both of these facilities a procedures trainer is provided in which not only the normal mission can be flown but almost any conceivable malfunction can be assimilated. Outputs from this trainer are provided to the flight control consoles and complete realism can be obtained including such problems as telemetry and radio noise, dropouts fails readings, etc. In addition, complete trajectory simulation is combined with this operation such that the entire launch orbit and reentry phases can be duplicated. These facilities have proven to be extremely useful to the operation and, as has been stated by the astronaut, is considered one of the most important training devices to be

developed for Project Mercury. Such facilities will be a mandatory requirement for the Apollo program. These facilities should be considered during the design phase of the actual vehicle so that ground crew and astronaut training can begin as soon as possible.

It is realized that only a cursory look has been given to the Mercury network and the flight control aspects of the project. Engineers from the divisions responsible for these aspects of the project are devoting time to the Apollo program and the Apollo contract is urged to take advantage of the Mercury experience through these people.