12p

FACILITY FORM 602

N65-88719
(ACCESSION NUMBER)

(THRU)

(PAGES)

(CODE)

TMX-57497
(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

[redacted]

Code 2a

PILOT SAFETY PROGRAM FOR MERCURY-ATLAS LAUNCH VEHICLE

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INTRODUCTION

When the Atlas ballistic launch vehicle was chosen by NASA to lift a Mercury astronaut into orbit around the earth, it was recognized that the Atlas launch vehicle had not been designed as a man-carrying vehicle, but rather as a ballistic weapon system. The design and development technology of ballistic launch vehicles and their basic reliability are far different from that of aircraft, which today are based on many thousands of hours of flight time and well-established operating experience and procedures. The NASA, therefore, established a requirement for the development of a highly reliable system to permit pilot escape. The NASA undertook the design of a spacecraft–launch–vehicle separation system, while the U.S. Air Force team developed an automatic system to detect launch-vehicle failure. Recognizing the overall safety requirements, Aerospace Corporation proposed a specific Mercury pilot safety program. This program was implemented as a team effort of NASA, the U.S. Air Force Space Systems Division, various associate contractors, and Aerospace Corporation. The key program efforts are summarized in figure 1.

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DESIGN RELIABILITY

The pilot safety program can best be viewed against the background of a typical launch vehicle's reliability as a function of time. Figure 2 demonstrates the increment of safety needed for manned flight over the basic reliability of the launch vehicle itself. It is virtually impossible to obtain the high launch vehicle reliability necessary in the time period scheduled for a given program—in this case, for the Mercury program. It would have been desirable to incorporate a step function in the reliability curve to improve the reliability of the launch vehicle to a somewhat higher level prior to a manned flight; however, a major redesign and a very extensive test period would have been required to demonstrate that higher reliability actually could be obtained. The basic Atlas reliability, consequently, was accepted and, to fill the gap between the basic reliability shown by the bottom curve and the desired higher level for manned flights, a special safety device was added. This device is the abort sensing and implementation system (ASIS), which is explained in detail in the discussion of reliability augmentation. The ASIS automatically senses a malfunction of the launch vehicle and triggers the separation mechanism of the Mercury spacecraft to separate the spacecraft from the Atlas launch vehicle before the malfunction results in a major disturbance which could endanger the astronaut.

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It is, of course, recognized that the overall Mercury mission cannot be saved by the abort sensing system; however, adequate pilot safety is provided by separating the spacecraft from the Mercury launch vehicle prior to a major malfunction. As shown by the upper curve in figure 2, it is not expected that 100-percent reliability can be achieved even with pilot safety augmentation devices. Although the abort sensing system is a highly reliable device, it is doubtful that it will provide adequate pilot safety for every possible malfunction. It does, however, provide the highest attainable degree of safety for the Mercury astronaut during the Atlas-powered portion of his flight, and it is believed he is at least as safe as he would be in a new, experimental-type aircraft.

In order to preserve the experience and reliability achieved in the Atlas ICBM program, the number of changes made to the Atlas to convert it to a launch vehicle were held to an absolute minimum. The major modifications are shown in figure 3.

QUALITY ASSURANCE

The purpose of the quality assurance program is to assure the best quality, workmanship, and reliability possible for all hardware used in the Mercury/Atlas launch vehicle. It consists in part of an educational program for contractor and subcontractor personnel. Under this program, training courses, lectures, and presentations are given by General Dynamics/Astronautics (GD/A) to their engineering, inspection, factory, and subcontractor personnel to make them aware of the importance of the manned space flight program and its objectives. Literature pointing out key points and items of this program is also distributed.

The program also provides for selection of certain components and subsystems. Selection criteria include such considerations as clean inspection records and predetermined operating times prior to acceptance. Additionally, items with major repairs or refurbishment are not accepted. Spare parts are also selected to the same criteria and are specially allocated for use in launch vehicles for the Mercury program. Each selected or allocated component, part, or subsystem is identified by a special decal signifying an accepted Mercury component. All components identified by this decal are stored in a specially designated and controlled area.

END PRODUCT EXCELLENCE

The purpose of the factory roll-out inspection is to assure that the Mercury/Atlas launch vehicle is complete in every respect, functionally acceptable, and ready for delivery to the U.S. Air Force. The inspection team consists of members of the U.S. Air Force Space Systems Division (SSD), the Air Force plant representative, and specialists of the Aerospace Corporation for various technical areas, such as autopilot, pneumatics, ASIS, propulsion, electrical systems, and guidance. The technical team members review the general launch vehicle progress on a continuing basis to identify potential problem areas. All component records, subsystem test data, and composite test records are evaluated.

The composite test is the final contractual U.S. Air Force factory acceptance test of the launch vehicle. This test is performed in the presence of the U.S. Air Force inspection personnel with the various systems operating simultaneously under nominal flight-simulated conditions. The functional acceptability is based upon the evaluation of the data from this test.

Complete and satisfactory documentation of component and subsystem selection, and of all test data, engineering change proposals, failure, consumption and data reports, and so forth, are required prior to the end product acceptance. The contractor is also required to submit a detailed report covering the status of qualification of critical items on the launch vehicle. No shortages are allowed; the launch vehicle must be functionally complete in every respect prior to delivery in order to be sure that it has been checked out as a complete launch vehicle system.

The technical team members prepare a final report covering the assembly and test history, as well as all discrepancies uncovered and corrected on the launch vehicle up to the time of delivery to the U.S. Air Force and to the Atlantic Missile Range (AMR).

PILOT SAFETY

The second principal program is to provide an adequate level of pilot safety. It is the purpose of the reliability augmentation effort to close the gap insofar as possible between the basic Atlas launch vehicle reliability and the desired pilot safety level of 100-percent. In order to achieve this goal, the ASIS was developed.

RELIABILITY AUGMENTATION

The ASIS is a highly reliable system for sensing any impending catastrophic failure of the Mercury/Atlas launch vehicle and for automatically generating an abort command to shut down the propulsion system and activate the Mercury spacecraft escape system prior to the time that the astronaut might be placed in jeopardy. The fundamental logic of the ASIS is one of continuous monitoring of certain critical launch-vehicle performance parameters in such a manner that if preselected tolerances are exceeded, an abort command signal will be generated and the spacecraft escape sequence will be initiated automatically.

In order to determine which performance parameters should be monitored by the automatic abort system, previous Atlas flight test data were analyzed to locate those parameters which indicated impending catastrophic failure during flights when such failures occurred and which did not indicate failure on successful flights.

The ASIS is designed to eliminate inadvertent aborts resulting from failure of its own sensing instrumentation or circuitry. Redundant wiring, sensors, and electronic components are utilized to counteract the effect of any single component failure.

Figure 4 shows the location of various electromechanical sensors throughout the launch vehicle which monitor the critical systems.

Various manual abort capabilities supplement the automatic abort system, as follows:

(1) The test conductor can initiate an off-the-pad abort.

(2) The NASA Mercury Control Center can initiate an abort.

(3) The astronaut can terminate the mission at any time throughout the entire powered flight.

(4) The range safety officer can generate a manual engine cut-off command and thereby activate the automatic airborne abort system.

In addition to five successful ASIS development flights on the Atlas launch vehicle, a very extensive reliability test program was conducted to assure reliability under extreme environmental conditions. Extensive failure mode analyses were conducted in order to select components whose failures, however unlikely, would be in the fail-safe direction. There was a successful flight of the complete system in the open-loop configuration on MA-1 and successful flights in the closed-loop configuration on MA-2, MA-4, MA-5, MA-6, MA-7, and MA-8. The MA-3 flight was prematurely terminated. However, a successful abort was initiated and saved the spacecraft, which was flown again on MA-4.

TEST SITE OPERATIONS

The efforts of the factory roll-out inspection assure that the Mercury launch vehicles are in the best possible condition when they arrive at AMR. This condition must be maintained in the hangar and on the launch complex. It is, therefore, very important to have stringent control over the hardware configuration and to have complete and accurate documentation of any hardware changes. The replacement of any component (particularly, selected components), if required, is closely monitored by quality control personnel of the U.S. Air Force. A sufficient number of selected spare parts, components, and subsystems are stored in a specially designated area at AMR. No hardware can be removed from Mercury launch vehicles to support other Atlas flights without specific approval of the U.S. Air Force. Only persons necessary to perform required tasks are permitted access to Mercury launch vehicles on the launch complex.

A Flight Safety Review Board determines whether the launch vehicle is ready for launch. For manned flights, participation on the Flight Safety Review Board is usually of high level, under the chairmanship of the senior Air Force representative. The final Flight Safety Review Board meeting is attended by a team of four NASA personnel. This meeting essentially is a presentation by the Flight Safety Review Board to the NASA Operations Director and concludes with a recommendation on committing the launch vehicle for manned flight. A technical team made up of personnel from the NASA, U.S. Air Force, Aerospace, GD/A, and the chief field representatives of Rocketdyne, General Electric, and Burroughs reviews for the Board the entire history of the launch vehicle since its arrival at AMR and presents its recommendation on the technical flight readiness of the launch vehicle. The Flight Safety Review Board must determine that all possible efforts to insure a successful mission have been made, that the launch vehicle is in the highest state of technical readiness, and that any reservation on the part of participating agencies has been considered. It then conveys its recommendation to the NASA Operations Director for his consideration in conjunction with the corresponding recommendations from the Capsule Review Board, Tracking Network, and other agencies.

The described procedures, plus the abort sensing and implementation system, have permitted NASA to begin its manned space flight program without the delay necessary to design and test a special launch vehicle, at no sacrifice to pilot safety.

FUTURE APPLICATIONS

The experience with the Mercury program clearly shows that future manned systems must incorporate a pilot safety program. Even systems specifically designed for manned flight will require a pilot safety program to assure that man-rating actually was achieved as designed and that the man-rating reliability is and can be maintained, which is a most important factor.

As a result of the efforts expended by the entire Mercury team, the following basic concepts were gradually recognized as the governing mechanisms for maximizing mission success:

(1) The team approach concept

(2) The systems engineering approach

(3) An aggressive failure analysis program

(4) A hardware quality assurance program

These control functions are sufficiently logical and general in content to allow their application to almost any complex system development project requiring a high degree of reliability.