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SPACECRAFT ENVIRONMENTAL SYSTEMS DEVELOPMENT PROGRAMS

(NASA TMX-51447)

By

Frank H. Samonski, Jr. [1964] 7p (Refs)

NASA Manned Spacecraft Center
Houston, Tex~~as~~

6021604

Presented to the

School of Aerospace Medicine

~~Available to NASA Offices and NASA Centers Only.~~

AFB
Brooks ~~Air Force Base~~,
~~San Antonio, Texas~~
~~February~~ 3-7, 1964

3-7 Feb. 1964

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INTRODUCTION

The development of the Project Mercury environmental control system included a formal reliability test program, the object of which was to demonstrate that the mean time between component failures was well beyond the mission requirement of 28 hours. Since the ultimate mission duration for both the Gemini and Apollo systems is 14 days, a comparable test program is impractical. In planning for and proceeding toward interplanetary exploration flights, a new testing approach must be adopted to insure mission success without recourse to lengthy and expensive test programs whose only purpose is the generation of reliability data.

It is the object of this paper to compare the test philosophy and the development test programs conducted for the Project Mercury environmental control system with those planned for the Projects Gemini and Apollo environmental control systems, keeping in mind the mission for which each was designed.

MERCURY PROGRAM

The Mercury system design requirements were for a 28-hour earth-orbit mission. To demonstrate reliability, the Mercury test plan subjected a complete system to 10 mission cycles under normal operation and 8 cycles under emergency, or simulated malfunction, conditions. A mission cycle was defined as 28 hours and included prelaunch operation, launch simulation of temperature and pressure profiles, normal orbital operation, reentry simulation including pressure and temperature profiles, and simulated postlanding operations. In addition, another system was reduced to 10 subsystems, each of which was tested for 20 normal and 16 emergency mission cycles.

Complete system test time totaled 533 hours. Subsystem or component-level tests were conducted on a time or cycle basis, depending upon the particular component. As examples, the suit-circuit compressor subsystem was tested for 1,440 hours, and the water separator, for 2,196 cycles. The total sybsystem test time approached 6,000 hours. In all the above tests, the requirement was that the system have a mean time between component failure of 500 hours, where failure was defined as the malfunction of any single component without regard for any redundancy which the system provided.

It is obvious that such an approach is impractical for missions whose length is more than an order of magnitude greater than Mercury, and comparable programs become impossible when cost and schedule constraints are imposed.

An alternate solution to this reliability dilemma may be a technique referred to as overstressed or "off-limit" testing, and it is the approach implemented in both the Gemini and Apollo Program.

GEMINI PROGRAM

The design requirement for the Gemini system is the life support of two men for 14 days in an earth-orbit mission. The reliability test program includes both overstressed testing of selected critical components and repeated simulated mission tests of a complete system.

Analyses of both system operating modes and inherent component design characteristics have indicated that the operation of certain components and subsystems is critical for mission success. These selected parts will be subjected to overstressed conditions of temperature, pressure, vibration, electrical loads, and flow rates. One system divided into its seven subsystems, or packages, will be employed for these tests. Failures will be analyzed, and redesign will be undertaken where design margins appear inadequate. To assure mission life capabilities, another complete system will be subjected to seven short (2-day) and eight long (14-day) mission cycles, each of which will include a 4-hour prelaunch and a 12-hour postlanding mode simulation. This rigorous life test is comparable to that performed in the Mercury Program. Simulated emergencies such as cabin decompression, coolant pump and suit compressor failures, and emergency oxygen-flow operation will be introduced. Total test time on this system will exceed 3,500 hours; however, no mean time to failure requirement will be imposed. Any malfunction will be examined, and modifications will be initiated where required. To supplement these planned test programs, additional reliability data will be gathered from hardware development tests on rotating machinery and pressure vessels and similar component-level tests.

APOLLO PROGRAM

The Apollo system mission requirement is the life support of three men for 14 days with provisions for recharging the portable life support system. The system requirements during an emergency, unlike the 35 minutes required for entry from an earth-orbit mission, may be 4 days for a return from a lunar-orbit rendezvous mission. The crew safety reliability goal is high. This goal, expressed in terms of test time required to demonstrate reliability for a 14-day mission, is 128 years (1,120,000 hours) between critical subsystem failures for which no redundancy exists. Therefore, the Apollo Program also employs the "off-limit" testing concept to arrive at the necessary confidence level. Twenty-three components or subsystems have been selected for exposure to overstressed testing as the result of a detailed failure-mode analysis on the system. These subsystems, in 16 cases a quantity of two each, will be subjected to increased levels of vibration, acceleration, temperature, and functional "off-limits" such as excessive flows, voltages, frequency variations, and similar tests. As an example, consider the following procedure for "off-limit" vibration testing. Each component (or subsystem) will first be subjected to an acceptance test which will verify compliance with hardware specifications. The component will then be exposed in a first-level test to the vibration spectrum defined in the Apollo environmental specification, applied in the most sensitive axes and directions, for a period of 5 minutes. The second and third levels will increase the vibration imposed on the component by factors of 1.25 and 1.5, respectively. At the completion of each level, the component will undergo a proof-cycle test to assure compliance with the specification before proceeding to the next level or group of tests. Upon completion of all "off-limit" tests, the component will be disassembled, inspected, and analyzed for incipient failure, and corrective action will be taken where indicated.

In addition to the overstressed testing, mission-life tests will be conducted on three environmental control systems during the qualification test program in the following manner: Each system will be divided into its 14 subsystems, or packages, each of which will be subjected to combined vibration-temperature and acceleration-temperature tests and then reassembled and operated as a complete system for 500 hours. Each system will then repeat this procedure once; and upon disassembly, the 14 subsystems will be subjected to shock tests. Schedules maintenance as required will be permitted upon completion of the first 500-hour cycle.

As in the Gemini Program, additional reliability information will be gathered from other phases of the system development program and integrated systems test vehicles such as Airframe 008, which will be tested in the Space Simulator Chamber at Manned Spacecraft Center in Houston, Texas. The accumulation and compilation of all data, from flight-hardware acceptance tests to boilerplate and unmanned spacecraft flights, will be utilized to strengthen continually the confidence level as the program proceeds toward the lunar landing mission.

FLIGHT-HARDWARE ACCEPTANCE PROCEDURES

Although the approach to reliability testing is similar in the Gemini and Apollo Programs, a fundamental difference exists in the acceptance procedure for flight hardware. In the Mercury program, completed hardward was subjected to a detailed predelivery acceptance test by the manufacturer before shipment. Upon receipt at the spacecraft contractor's plant, the hardware underwent another preinstallation acceptance test of comparable thoroughness before it was allocated for use in a spacecraft. It is a fact that rejection rates in this second acceptance test were high. A contributing factor to these discrepencies was the lack of integrated ground support equipment (GSE) for the Mercury system. Both the Gemini and Apollo Programs have profited from this experience by including integrated GSE, designed and manufactured by the system vendor, as part of the hardware contract. However, as a result of the Mercury experience, a duplication of acceptance testing on delivered packages will be repeated in the Gemini Program until test results demonstrate that this repetition is unnecessary. In contrast with this established procedure, no duplication of acceptance testing will be conducted by the Apollo spacecraft contractor upon delivery of hardware from the system vendor prior to installation in the spacecraft. Instead, resident engineers at the hardware vendor's plant will closely monitor the predelivery acceptance testing in an effort to eliminate the duplication of tests. Experience gained during tests of assembled spacecraft systems will determine the adequacy of this approach.

CONCLUDING REMARKS

The development testing of second generation environmental control systems has been modified both by necessity and choice. The Gemini spacecraft contractor has applied the experience gained during the Mercury Program where possible or feasible. The Apollo Program, with a new spacecraft contractor, has selected a similar approach, except in the area of acceptance testing, to the tasks involved in the development of a complex system with high reliability goals.