HANDS ON TESTING

One Small Test for Man, One Giant Leap for Software Quality: Adopting Apollo's Testing Principles

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28th of August 2024

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NASA SP-287

WHAT MADE APOLLO A SUCCESS?

A series of eight articles reprinted by permission from the March 1970 issue of Astronautics & Aeronautics, *a publication of the American Institute of Aeronautics and Astronautics*

Scientific and Technical Information Office 1971
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

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SPACECRAFT DEVELOPMENT

Four aspects of spacecraft development stand out: design, test, control of changes, and interpretation of discrepancies. We can begin with them.

Spacecraft Design

The principles of manned spacecraft design involve a combination of aircraft-design practice and elements of missile-design technology: Build it simple and then double up on many components or systems so that if one fails the other will take over.

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The concept of inflight maintenance was discarded entirely as being impractical for flights with the specific purpose and duration of Apollo. In its place, more telemetry was added and full advantage was taken of the ground's ability to assess system performance, predict trends, and compare data with preflight test experience.

Apollo Test Activities

The single most important factor leading to the high degree of reliability of the Apollo spacecraft was the tremendous depth and breadth of the test activity.

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- 4104 hours
- 513 workdays (8h/day)
- 2.33 years for one person (220 workdays/year)

TABLE 1-I. - DEVELOPMENT AND QUALIFICATION TESTS

[Full-scale spacecraft testing]

Escape motor flight tests	7
Parachute drop tests	40
Command module land impact tests	48
Command module water impact tests	52
Lunar module structural drop tests	16
Lunar module complete drop tests	5
Command and service module acoustic/vibration tests, hr	15.5
Lunar module acoustic/vibration tests, hr	3.5
Command and service module modal survey testing, hr	277.6
Lunar module modal survey testing, hr	351.4
Command and service module thermal vacuum tests, hr	773
Lunar module thermal vacuum tests, hr	2652
Service module propulsion-system tests, min	1474.5
Ascent-stage propulsion-system tests, min	153
Descent-stage propulsion-system tests, min	220

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Most important of all, the tests gave us a tremendous amount of time and experience on the spacecraft and their systems. Such experience — together with a detailed analysis of all previous failures, discrepancies, and anomalies — led us to the conclusion that we were ready to fly a lunar orbit with Apollo 8 and that we were ready to make a lunar landing with Apollo 11.

Acceptance testing played an equally important role. This testing starts with piece parts. Although Apollo was late in applying this rule, I believe that screened and burned-in electronic parts must be made a firm requirement. Next, each component, or black box, is tested before it is delivered, and again before it is installed in the spacecraft. Then, factory testing of the complete spacecraft begins. First, the wiring is wrung out, and individual subsystems are tested as installed. Then, groups of systems are jointly tested. Finally, the complete spacecraft, with all of its systems functioning, is run in an integrated test. All normal, emergency, and redundant modes are verified.

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A most important facet of acceptance testing is environmental acceptance testing. The primary purpose of acceptance vibration testing and acceptance thermal testing is to find workmanship errors. To do this, the environment has to be severe enough to find the fault (e.g., a cold-solder joint), yet not so severe as to weaken or fatigue the component. Figures 1-1 and 1-2 show the levels selected for these tests in Apollo. These levels were picked on the basis of experience in Gemini and other programs. Each component type, of course, had to pass qualification tests under even more severe environments. Nevertheless, our environmental acceptance tests sometimes uncovered design faults (as opposed to workmanship faults) that had been missed in the qualification tests. The reason was that a single qualification test may have missed a marginal condition, which the large number of acceptance tests could catch.

Flight missions (Page 18)

The flight-test program shown in figure 1-7 was then evolved through an iterative and flexible process that was changed as time went on to take the best advantage of knowledge about mission operations and hardware availability at any given time. The basic principle in planning these flights was to gain the maximum new experience (toward the goal of a lunar landing) on each flight without stretching either the equipment or the people beyond their ability to absorb the next step.

Concluding remarks (Page 23)

Spacecraft development, mission operations, and flight crew activities — in reviewing these areas of Apollo, I see one overriding consideration that stands out above all the others: Attention to detail. Painstaking attention to detail, coupled with a dedication to get the job done well, by all people, at all levels, on every element of Apollo led to the success of what must be one of the greatest engineering achievements of all time — man's first landing on the moon. The reports which follow amplify this observation.

Excerpt from ISTQB Certified Tester Foundation Level v4.0 Syllabus:

1.5.1. Generic Skills Required for Testing

While being generic, the following skills are particularly relevant for testers:

- Testing knowledge (to increase effectiveness of testing, e.g., by using test techniques)
- Thoroughness, carefulness, curiosity, attention to details, being methodical (to identify defects, especially the ones that are difficult to find)

Testing to ensure mission success (Page 31)

Theoretically, one no longer needs to test hardware or software, after developing a new concept, except occasionally to gather empirical data needed to operate the equipment. Unfortunately, designs are not perfect, materials and processes often do not work as the designers expect, manufacturing techniques sometimes inadvertently alter the design, assembly procedures leave room for mistakes, engineering and development tests do not necessarily provide all the required data, and, finally, substandard workmanship and human error creep in.

All of these factors require attention at the outset of a program. Some factors, such as human error, demand vigilance until delivery of the last item. Experience has shown that only a well-balanced test program can instill confidence in the delivered hardware and software for a space vehicle.

Testing to ensure mission success (Page 32)

After the spacecraft fire, NASA launched an extensive review of the Apollo acceptance test practices. Subcontractors and vendors for 33 Apollo spacecraft assemblies, representing a cross section of electrical, electronic, and electromechanical equipment throughout the spacecraft, received 79 detailed questions concerning their individual acceptance test plans and objectives. This survey revealed the inadequacy of environmental acceptance tests or, in many cases, the nonexistence of acceptance tests.

Testing to ensure mission success (Pages 36-38)

In retrospect, several recommendations and points of interest stand out from the test experience gained during this nation's three major manned spacecraft programs over the past 10 years.

1. Design and development testing plays an important part in the overall test plan. Perform it as early as possible. Document the results well, and hold the data for future reference. Pay particular attention to what seem minor details, especially for substitute parts and "explained" failures.

5. Make qualification tests rigorous and complete, yet realistic. A strong tendency exists to qualify equipment to the designer's desires rather than to the actual requirements.

Excerpt from "1.3 Testing Principles" in ISTQB Certified Tester Foundation Level v4.0 Syllabus:

3. Early testing saves time and money. Defects that are removed early in the process will not cause subsequent defects in derived work products.

Testing to ensure mission success (Pages 36-38)

6. Carefully document, track, explain, and take necessary corrective action on test failures encountered on all production hardware. Qualification test hardware, by definition and from bitter experience, must count as production hardware. No suspected failure encountered during any test on production hardware should escape from this rule, no matter how insignificant or unrelated the failure may seem at the time. Experience has shown that major failures always receive adequate attention. The minor unreported failure is the one that slips by and shows up late in the vehicle test cycle or, worst of all, in flight.

15. Always retest after changes to the hardware or software have been made. Set up rigorous controls to assure it.

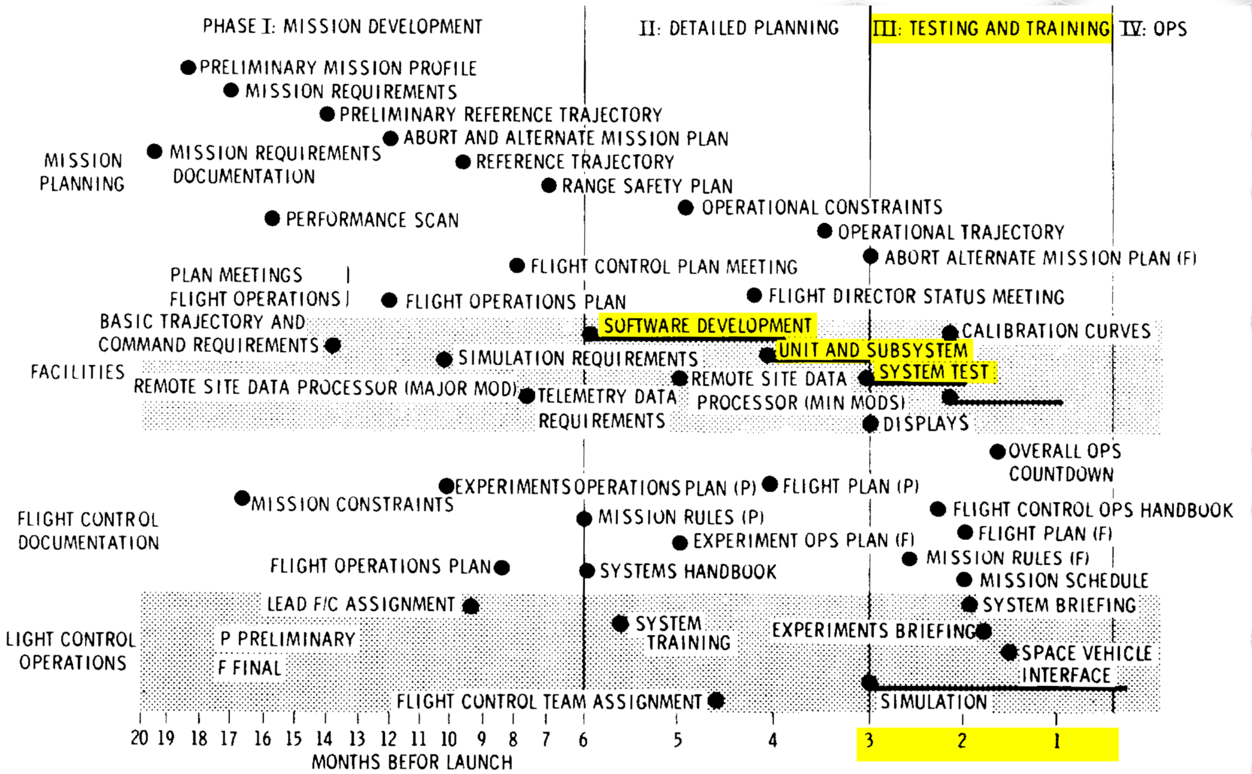
16. When possible, test all functions and paths on the installed systems at least once prior to delivery to the launch site. As a general rule, when changes or replacements require retesting, do it at the factory. Prelaunch testing at the launch site should demonstrate total space-vehicle and launch-complex compatibility and readiness. They should not simply prove the adequacy of a given component or single system.

Testing to ensure mission success (Page 39)

We believe these measures have proved themselves in the Apollo Program. By calculating from the design and workmanship failure rates during reacceptance tests, the program corrected or removed before launch approximately 65 potential spacecraft pilot-safety or mission-critical hardware failures per flight. Some faults remained. Each of the first 10 vehicles flown on the first six manned Apollo missions experienced approximately eight hardware failures. But fewer than two failures per vehicle stemmed from workmanship or quality. Of the total flight failures from these two causes, better or more thorough acceptance testing could conceivably have revealed only five. Also, no evidence in the flight-failure history indicates a failure caused by too much testing.

The real effectiveness of the test program comes out in examining the results of hardware failures during the first six manned Apollo flights. None of the flight failures affected pilot safety or mission success.

Figure 5-2. – Mission-development time line (Page 53)



Action on mission evaluation and flight anomalies (Page 66)

System anomalies caused by design deficiencies can generally be traced to insufficient design criteria. Consequently, the deficiency can pass development and qualification testing without being detected, but will appear during flight under the actual operational environment.

Slides:

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