TESTING FOR RELIABILITY IN SPACE SYSTEMS

INTRODUCTION

Testing is a pivotal phase in the development of space systems. Although it is an ongoing process, which actually begins with the development of test plans early in the design phase, the most crucial time is the period of full-up operation of the integrated system. A barrage of tests, often as many as a program can afford, is applied to the final product in an all-out effort to eliminate defects undetected in earlier inspections and operations.

Improving the process of testing has broad implications for risk reduction in space systems. Better test procedures affect not only the ability to build more reliable spacecraft but also the launch and the ground control systems that deploy and operate them. Since change in this area has such far-reaching implications, efforts to improve testing are very important.

Traditional methods of testing spacecraft are undergoing a period of change, however. This appendix will review the factors driving change within the test community, highlight NASA's response, and assess the impact on space systems.

FACTORS DRIVING CHANGE IN THE TEST COMMUNITY

The process of testing spacecraft, much like the process of designing them, is being significantly restructured. Three factors are driving this restructuring: a policy decision to deemphasize the role of military specifications; new data that are challenging traditional test methods; and the emergence of small spacecraft that demand new, less costly approaches.

Moving Away from Military Specifications and Standards

Change within the test community intensified in the summer of 1994 when then–Secretary of Defense Perry issued a memorandum restricting the use of military specifications and standards (milspecs and milstds) in DoD procurement practices:

> Performance specifications shall be used when purchasing new systems, major modifications, upgrades to current systems, and non-developmental and commercial items, for programs in any acquisition category. If it is not practicable to use a performance specification, a non-government standard shall be used. (Perry, 1994.)

Secretary Perry's decision allows the use of milspec only "as a last resort." Although the decision focused on the procurement of military systems and not on the use of milspecs for design and test, it nevertheless sent shock waves through the PA community, which relied heavily on milspecs for source material. (Coppola, 1995.) In principle, the announcement signaled a movement away from tradition and, over the long term, the possibility that the milspec backbone of the test community would dissolve.

The spacecraft community makes extensive use of milspecs for design, test, and inspection. Through decades of use, they have become embedded in the PA processes of both the government and the aerospace industry. The Perry decision was viewed with some disappointment within the PA community, since more recent milspecs were created to perform a dual-use function and had been significantly streamlined. New standards for quality and reliability, such as ISO-9000 and the proposed program management standard, ISO-14300, are viewed by many spacecraft developers more as guidelines than specifications and are not, therefore, seen as a replacement for traditional milspecs.

New Insights into Traditional Test Practices

The physics-of-failure approach, outlined in Appendix B, is beginning to illuminate deficiencies in traditional test practices and inspire new approaches to testing. It appears that some tried-and-true test practices can be ineffective when applied to new technologies, possibly even inducing failures. There is some evidence, for example, that burn-in tests, the principal means of identifying infant mortality in new parts and electronic components, can actually lead to premature system failure. (Jordan et al., 1996, p. 18.)

Another example is thermal testing. Repetitive thermal cycling, where systems are alternately heated and cooled inside a chamber, is used extensively in spacecraft programs. Analysis of thermal-cycle testing now suggests that a single thermal excursion is sufficient to identify most defects and that additional variations can induce failure. (JPL, 1994, p. 14.) The traditional practice of derating components (operating well below the stated performance limit of a part or component or, conversely, selecting a component with performance well above expected stress levels) in an effort to increase reliability, has been shown to be ineffective in some cases. (Pecht et al., 1992, p. 1163; Coppola, 1995.) The PA community must rapidly respond to these developments and provide guidance to ongoing programs.

Simulation-based design (discussed in greater detail in Appendix E) is also significantly changing the type and level of testing being contemplated for future programs. The ability to simulate the performance of a proposed design with ever-increasing fidelity changes the manner and extent of testing of the final item. It does not, however, replace it.

Small Spacecraft Test Requirements

Although similar to traditional spacecraft, the new generation of smaller ones places additional requirements on the test community by

- Placing a greater emphasis on the cost-effectiveness of testing.
- Elevating the criticality of testing.
- Utilizing new technology to a greater extent than previous missions.

Small spacecraft demand a cost-effective test program. The cost of time in test facilities has not shrunk in proportion to the size of the spacecraft. The equipment used to test a small spacecraft, such as a thermal-vacuum chamber, is often the same equipment as used for larger spacecraft. Designing an affordable test program is, therefore, a challenge for small spacecraft program managers.

Testing, to a significant degree, is a "seat-of-the-pants" affair in small spacecraft programs, and approaches vary widely. As shown in Figure A.1, the test-and-integration phase of NASA small spacecraft reviewed in this study accounts for an average 3 percent of TMC. But this value ranges from 1.3 to 5.5 percent, possibly reflecting the variation in approaches taken to testing. The process of creating a test plan, tailored to both the mission and available funds, relies heavily on the experience of the senior team members. Many of the data validating test procedures are empirical and anecdotal, complicating the task of preparing the most cost-effective solution to the test requirements of a given mission. Since the test phase occurs late in the development cycle, even a carefully crafted test plan can be stressed by cost overruns in other areas.

Testing is more critical in small spacecraft programs, since, in many cases, redundancy is available only partially or not at all. In these situations, testing becomes the most important means of evaluating the design and preventing defects that now have a higher potential for causing failure later in the mission.

To achieve higher performance, small spacecraft rely on technology more than did past missions. Designers employing new technology require performance estimates and projections of risk. New parts and components with little or no space heritage are particularly vexing in terms of test and validation. The closest analog often serves as the only model for designing the test plan.

Additionally, this new technology increasingly takes the form of commercial-grade electronics that are proving to be at least as good as their military-grade equivalents in terms of quality.[1] Their use, however, adds additional complexity in that established methods may be wholly inappropriate to their handling, processing, and test. The screening of electronic parts is a case in point. Screening is a process of accelerated testing designed to eliminate infant mortality. The process helps to ensure that, once in space, parts fail only due to the inevitable degradation of the space environment. Because past component quality was low and the cost of failure high, NASA screened nearly 100 percent of the electronic components used in spacecraft. Detailed procedures for inspection and test were outlined in milspecs and NASA handbooks. For the reasons cited above, however, new test methods are needed.

DEVELOPING NEW APPROACHES TO TESTING SPACECRAFT SYSTEMS

Under the sponsorship of NASA's OSMA, research on test effectiveness has been under way since 1992. Similar efforts are being supported by the Air Force. The advent of small spacecraft has accelerated these efforts, however, and given emphasis to reducing the cost of implementing test procedures.

Figure C.1 portrays the spacecraft testing process. As illustrated in the figure, the goal of each test is to halt defects that have "escaped" detection in prior tests. Occasionally, the test process fails to detect a certain mode of failure, and a defect may make it through the entire test process. Of course undetected defects do not automatically lead to a mission failure; robust designs and redundant systems can protect spacecraft from serious, often compounding, failures.

The width of the rectangles in Figure C.1 implies that some tests are highly effective at detecting certain types of defects; others are more broadly able to find flaws and errors. Additionally, Figure C.1 suggests diminishing utility of additional testing if prior evaluations have already eliminated defects.

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[1]The use of commercial components in spacecraft is complex and controversial. Appendix D covers this issue in greater depth.

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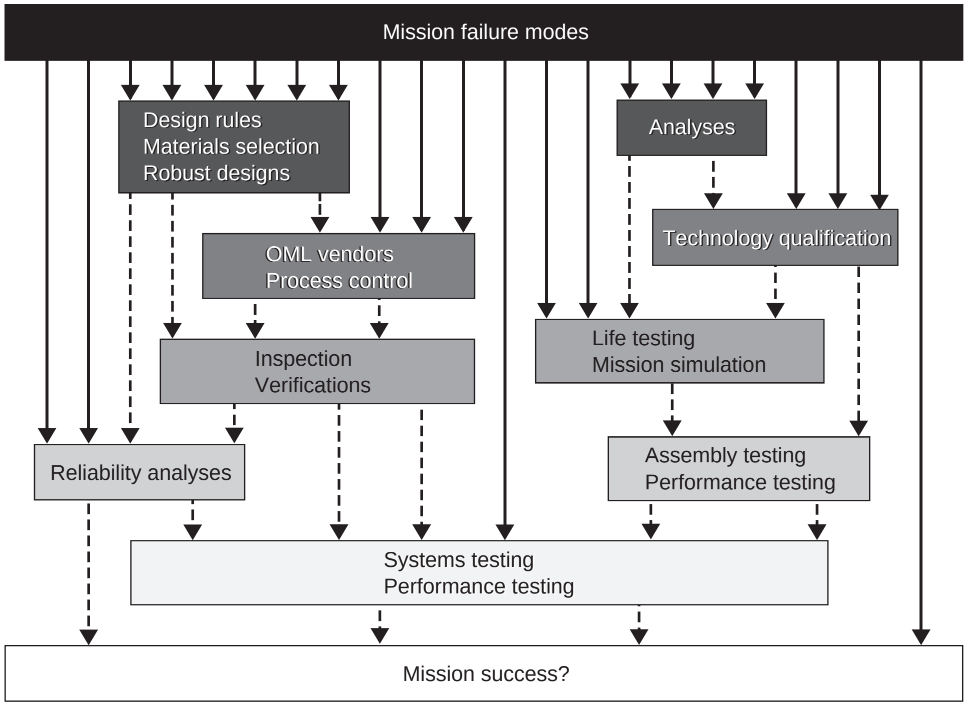

NOTES: Each box represents a collection of Preventions, Analyses, Controls, and Tests (PACTs). Dotted lines represent "escapes"—undetected/unprevented failure modes.

SOURCE: JPL (Cornford, 1996a, p.4).

Figure C.1—Defect Propagation Model

The goal of NASA's test effectiveness program is to provide improved test procedures that cost less to run and that have a greater probability of eliminating defects. To achieve this goal PA engineers are conducting controlled experiments on current test procedures to evaluate how well they identify defects. This analytical approach has the added benefit of removing past empiricism and providing a better characterization of any given test. Spacecraft builders will have an improved awareness of the impact of specific tests and their limitations.

IMPLICATIONS FOR FUTURE SPACECRAFT

Better characterization of tests allows builders of space systems to tailor a test plan more precisely to the type of spacecraft and mission. A mission that would, for example, place a spacecraft in a high or unique radiation environment should be able to select tests most likely to identify deficiencies in the spacecraft's ability to withstand such conditions. More effective test procedures should also provide spacecraft builders greater assurance in relation to the reliability of new technology components and subsystems. Additionally, improved test procedures influence other aspects of building space systems. For example, some in-process tests and inspections, conducted at key points during fabrication, could be eliminated if testing at a higher level of integration can be shown to be less costly and more effective. Finally, providing scientific data on the effectiveness of specific test procedures should reduce variability among spacecraft programs.

The importance of improving test effectiveness has resulted in this being a major focus within the PA community. More-refined test procedures will likely be a significant contributor to continuing improvement in the reliability of space systems.

SUMMARY

Despite its broad-scale importance, testing has long been an empirical process, with a great deal of variation in how the builders of space systems approach the test phase of a project. Change within the test community has begun as new insights into how components and systems fail illuminate deficiencies in traditional practices. The inherent quality and reliability of new components has also spurred a reexamination of test procedures. This review was accelerated by the government's decision to emphasize performance specifications in DoD procurement over long-standing military specifications and standards. Within the PA community, this decision was viewed with alarm in that milspecs form the backbone of traditional test procedures. Finally, the arrival of smaller spacecraft placed unique demands on test procedures: Testing had to remain effective yet be responsive to a smaller, tightly constrained budget; its criticality was increased, since many small spacecraft were proceeding with little or no redundancy; and a greater amount of new technology was being incorporated.

The response from the PA community has been a fresh look at test procedures aimed at replacing empiricism with experimental evaluations of the effectiveness of specific tests. Both NASA and the Air Force plan to establish refined test procedures that both cost less to implement and are more effective in preventing defect propagation. The net effect of these improvements is expected to be a significant improvement in the reliability of all space systems.