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ENVIRONMENTAL TESTING PHILOSOPHY FOR A SANDIA NATIONAL LABORATORIES SMALL SATELLITE PROJECT*

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BIOGRAPHIES

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ABSTRACT

Sandia National Laboratories is the system integrator on a small satellite project. Following the intent of the NASA GEVS [1] document, an integrated test philosophy was formulated to certify the satellite for flight. The purpose of this paper is to present that philosophy.

KEYWORDS

Environmental, Satellite, Testing

INTRODUCTION

A Sandia National Laboratories small satellite project has defined its environmental test requirements. This satellite is a one-time venture and few of the subsystem designs will have spare hardware available for testing. Therefore, a mixture of protoqual and protoflight testing schemes will be used to certify hardware for flight.

This paper is divided into two sections. The first section presents the environmental testing philosophy. The second section identifies the methodology used to validate and refine the testing requirements throughout the life of the project.

Definitions

For the purpose of this paper the following definitions will be used:

Testing - Assumed to refer only to environmental testing.

Test Series - The complete set of environmental tests (random vibration, pyroshock, acoustic, etc.) used to account for all conditions encountered during flight.

Component - A self-contained package that will be integrated into a larger assembly.

Subsystem - A grouping of components that are physically combined into a single assembly for the purpose of performing a specific functional task, but that will still be integrated into a larger assembly.

System - The complete satellite.

Acceptance Test Requirement - The level to which flight hardware is tested in order to identify any manufacturing defects prior to flight. The testing of flight hardware to acceptance levels requires that a non-flight (qualification) unit of the same design be tested at protoqual levels to establish design margin.

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Protoqual Test Requirement - The level to which non-flight hardware is tested in order to establish design margin for the corresponding flight hardware. Protoqual is defined in GEVS as 3 dB above acceptance with longer test durations.

Protoflight Test Requirement - The level to which flight hardware is tested if there is no qualification hardware available with which to establish design margin. Protoflight is defined in GEVS as 3 dB above acceptance with the same test durations. The philosophy behind protoflight testing is to establish design margin without "wearing out" the unit.

System Definition

The Sandia small satellite system assembly consists of the bus subsystem and the Payload subsystem. Each subsystem consists of components and subsystems that perform specific functions.

Derivation of Test Environments

At the present time the launch vehicle selection has not been made. Therefore, the environments have been based on a combination of the inputs from the prospective launch vehicle payload user's guides [2,3] and the NASA GEVS document.

Since the launch vehicles under consideration are still relatively unproven, the project test plan will provide for the possibility that recommended test levels might change.

TESTING PHILOSOPHY

The emphasis for the satellite test plan is to ensure that hardware designs are validated early in the project. In addition, since a major portion of the hardware being built is the actual flight hardware, it will be important to avoid overtesting both in duration and level.

Two testing options have been defined to certify flight hardware designs (a Protoflight test option and a Protoqual test option). Designers may choose whichever plan best suits their specific method of operation. The primary difference between the two plans is the method used to certify components. However, both plans are designed to produce the least amount of overtesting if all components within a given subsystem follow the same plan.

Protoflight Testing Option

The protoflight testing option is applied when no qualification hardware is available. The goal is to subject each item to no less than 2 test series (a component level or a subsystem level protoflight test and a system level acceptance test) and no more than 3 test series (a component level protoflight test, a subsystem level protoflight test, and a system level acceptance test). The integration of this testing scheme into the overall assembly plan is shown in Figure 1.

Protoqual Testing Option

The protoqual testing option is applied when qualification hardware is available. A spare of the same construction as the flight hardware is subjected to a protoqual level test. The flight hardware is then subjected to no less than 2 test series (a component level or a subsystem level acceptance test and a system level acceptance test) and no more than 3 test series (acceptance tests at the component, subsystem, and system levels). The integration of this testing scheme into the overall assembly plan is shown in Figure 2.

IMPLEMENTATION OF TESTING SCHEME

This section discusses how the testing configurations were chosen and how we intend to refine the test levels used for the test program.

Test Setup

Due to differences in boundary conditions, it is virtually impossible to perform a subassembly test in a manner that produces the same overall response as the next assembly test. Even the full-up system test is not an exact match for the actual flight conditions. However, we believe that we have the best chance of producing the most realistic test responses if the testing is performed at the highest level of assembly.

Therefore, the current plan is to test the major subsystems in the full-up assembled system configuration (i.e., the bus subsystem test will be conducted with mockup payload hardware, and conversely, the payload subsystem test will be conducted with mockup bus hardware). The mockup hardware will simulate the actual weight, cg, and structural rigidity of the flight unit, but hopefully at a much lower cost than what is needed to build a true qualification unit.

Mockup Hardware Tests

An important requirement for the implementation of the desired testing techniques will be a dry run system test using both the bus and payload mockup hardware identified above. Such a test will be used to perfect the test control and input levels for the system test. In addition, responses measured at key points on the structure will be used to verify/update the component and subassembly test levels.

Refinement of Test Levels

The test philosophy calls for implementing several improvements over the cookbook approach of testing to generic test levels in the manner of GEVS. These improvements are admittedly more complex and costly to implement, but they will improve the reality of the test by reducing unquantified over-conservatism. These improvements will be implemented as deemed necessary.

Since the current test levels are based on a combination of the GEVS document and several payload user's guides, they are considered to be conservative. A series of analytical model predictions and mockup hardware system tests will be used to refine the test requirements culminating in the final system flight certification tests. The decision points where these refinements can be implemented into the overall testing program are shown in Figures 1 and 2.

Refinement of Baseline Test Levels

Once a launch vehicle is selected, it will be possible to implement the system level tests recommended in the corresponding payload user's guide. This will significantly reduce some of the current test levels.

Refinement of Low Frequency Vibration / Ignition Shock Test Levels

Testing hardware using a rigid shaker table and a single point motion controlled vibration test based on a straight line Power Spectral Density (PSD) profile has been shown to produce significant overtests of the item that are directly related to the overdriving of its fixed base resonances. The current philosophy for dealing with this issue is to manually notch the PSD profile at the first fixed base resonance of the test item [4]. The notch is made deep enough to restrict the resulting stress levels to less than or equal to the stress state generated by the equivalent static load factors.

This procedure is considered somewhat arbitrary and depends heavily on knowing exactly where the 1st fixed base resonant frequency occurs and whether or not it moves with excitation level. In addition, it does not account for the overtesting of secondary resonances associated with subsystem responses.

We believe that this method can be improved upon by the implementation of a force limited vibration test [5]. Such a test uses extremal control of both the input acceleration and force spectrums to limit the overconservatism that may occur in a test that relies on controlling only the input acceleration spectrum.

A force limited vibration test is based on fundamental physical properties of the test item and its next assembly. This eliminates the guesswork associated with how deep to make the notch. In addition, the vibration controller can automatically track all test assembly resonances and notch accordingly, thereby providing protection for subassemblies as well as for the primary structure.

Therefore, when deemed appropriate, force limiting may be invoked in order to minimize the over-conservatism associated with shaker table tests. Measurements of the driving point impedances for both the item and its attachment structure are necessary for force limiting. Until hardware is available, Finite Element Analysis (FEA) models may be used to predict the driving point impedances.

In a manner that is analogous to the force limiting of vibration test levels [6], we will also limit the over-conservatism of any low frequency shaker shock tests used to simulate the ignition shock environment.

Refinement of High Frequency Vibroacoustic Test Levels

It is also desirable to understand the response of the structure to high frequency vibroacoustics. The mockup hardware system test identified in Figures 1 and 2 will be used to obtain improved estimates of the component test inputs for various regions of the structure. However, since this will not happen for quite some time it may be useful to perform a vibroacoustic analysis of the structure using Statistical Energy Analysis (SEA) to establish better estimates of the actual vibration environment at various locations on the structure [7]. An SEA model is good for predicting the response of the structure for frequencies beyond the first few modes of the structure. Therefore, such an analysis would compliment an FEA analysis. The SEA predictions would be refined using experimental results when the mockup structural hardware is available.

Refinement of Pyroshock Test Levels

Since the pyroshock inputs for the Sandia small satellite are defined as base inputs, there is a need to predict or measure the response of the satellite structure to these shock inputs. The ideal situation would be to measure all critical component inputs during a series of system level functional pyroshock tests. However, a live pyroshock test may not be practical. Therefore, it may be useful to predict the component responses to the pyroshock event(s) using analytical models.

FEA models are not practical for predicting the response of the satellite to high frequency transients such as pyroshock. At this time there are two analytical techniques available at Sandia for predicting high frequency shock levels: 1) semi-empirical scaling laws [8], and 2) the shock transmission code MANTA, which was developed by Teledyne Brown Engineering [9].

The scaling laws require only a knowledge of the path lengths and the number of joints in the structure, and will be applied at this time for lack of any better information. However, these scaling laws are based on a simple cylindrical structure and may not produce a very accurate estimation of the shock mitigation within the satellite.

MANTA requires either an SEA model or experimentally derived Frequency

Response Functions as an input along with a description of the force generated by the separation event so some preparation is required before it can be used. However, it is believed that MANTA will produce far more reliable answers than the scaling laws and will be invoked once an SEA model is generated. The MANTA predictions will be refined using experimental results when the mockup structural hardware is available.

CONCLUSIONS

It is believed that the testing philosophy presented in this paper will produce a straight forward, reliable, and cost effective method for certifying the Sandia National Laboratories small satellite for flight.

REFERENCES

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4) MIL-STD-1540C; issued 9/15/94; "Test Requirements for Launch, Upper-Stage, and Space Vehicles."
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Figure 1: Flow Chart for the Protoflight Environmental Test Plan

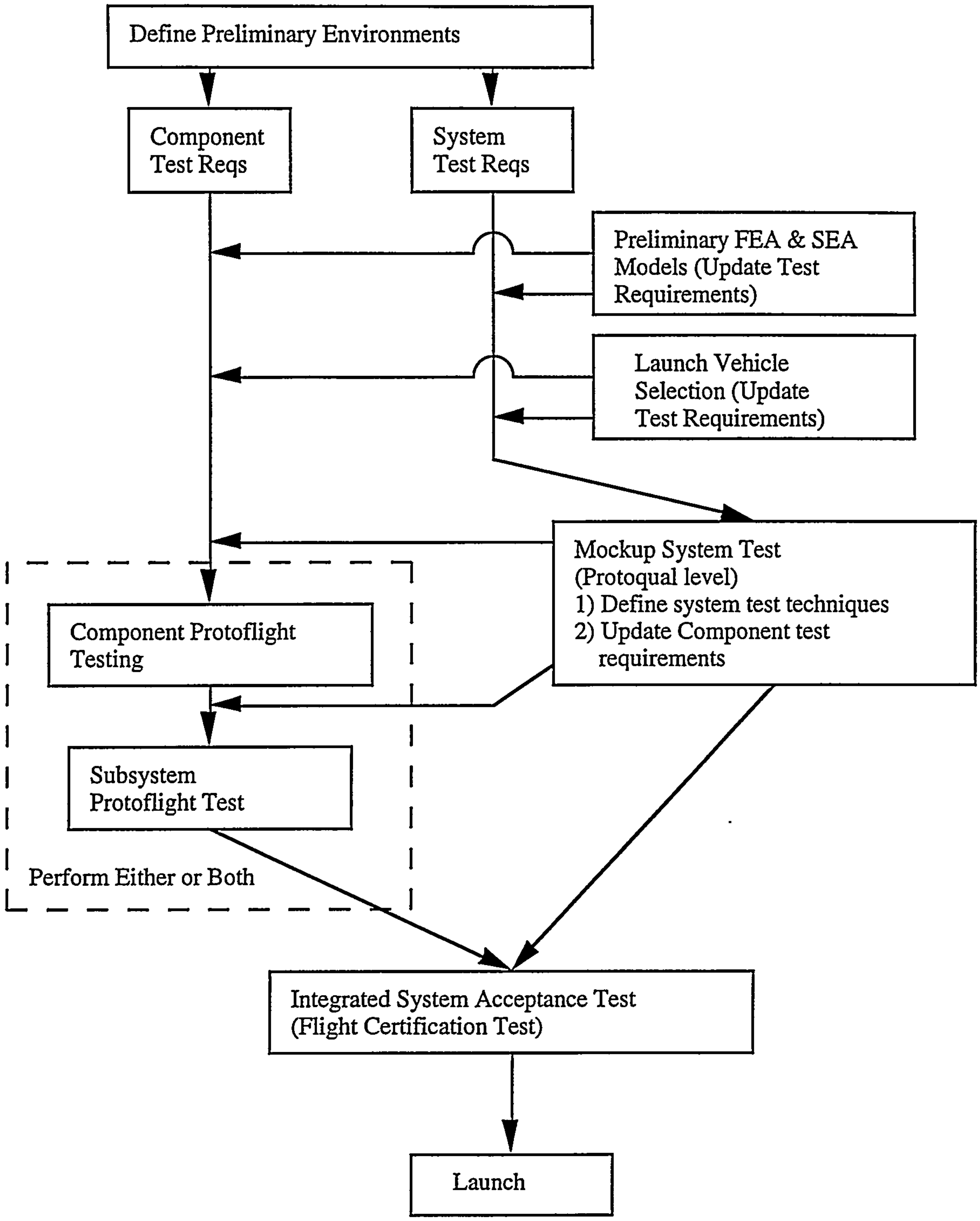

Figure 2: Flow Chart for the Protoqual Environmental Test Plan