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Environmental Qualification Testing of the Prototype Pool Boiling Experiment

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ENVIRONMENTAL QUALIFICATION TESTING OF THE PROTOTYPE POOL BOILING EXPERIMENT

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SUMMARY

The prototype Pool Boiling Experiment (PBE) flew on the STS-47 mission in September 1992. This report describes the purpose of the experiment and the environmental qualification testing program that was used to prove the integrity of the prototype hardware. Component and box level vibration and thermal cycling tests were performed to give an early level of confidence in the hardware designs. At the system level, vibration, thermal extreme soaks, and thermal vacuum cycling tests were performed to qualify the complete design for the expected shuttle environment. The system level vibration testing included three axis sine sweeps and random inputs. The system level hot and cold soak tests demonstrated the hardware's capability to operate over a wide range of temperatures and gave the project team a wider latitude in determining which shuttle thermal attitudes were compatible with the experiment. The system level thermal vacuum cycling tests demonstrated the hardware's capability to operate in a convection free environment. A unique environmental chamber was designed and fabricated by the PBE team and allowed most of the environmental testing to be performed within the project's laboratory. The completion of the test program gave the project team high confidence in the hardware's ability to function as designed during flight.

INTRODUCTION

The Pool Boiling Experiment (PBE) is a Get Away Special (GAS) class payload designed to obtain data on nucleate pool boiling of R-113 (trichlorotriflouroethane) in an extended microgravity environment. Nucleate pool boiling is a process wherein a stagnant pool of liquid is in contact with a surface which can supply heat to the liquid. If the liquid absorbs enough heat, a vapor bubble can form. This report describes the environmental testing which the prototype PBE hardware was subjected to in order to qualify the design. Figure 1 illustrates the prototype PBE system.

Normally the prototype version of a new hardware design is subjected to qualification tests in order to qualify the design. A flight system is subsequently built and tested to lesser acceptance levels. The prototype system is not usually flown. However, an opportunity developed to fly the prototype PBE on STS-47 (SL-J) prior to the completion of the flight PBE system. Since the prototype system had been built with a high level of quality, and documentation was maintained to verify all the safety critical analyses, inspections, and tests, it was determined that the prototype PBE could be flown with a relatively high chance of success. In addition, flight of the prototype system would give the project's Principal Investigator, Dr. Herman Merte of the University of Michigan, an opportunity to verify the choice of test matrix points and further enhance the science prospects for the flight system.

QUALIFICATION TESTING PHILOSOPHY

The test program for the prototype PBE was derived from the Goddard Space Flight Center (GSFC) "General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and

Components" (GEVS-SE) (ref. 1) and "Guidelines for Standard Payload Assurance Requirements for GSFC Orbital Projects" (SPAR 3) (ref. 2). A project specific requirements document was prepared to summarize the test program plan.

The PBE project was conceived as a program that would incorporate the traditional prototype and flight hardware development concepts. Traditionally the prototype system is built to flight design specifications and then subjected to qualification testing. The qualification tests seek to "demonstrate that the test item will function within performance specifications under simulated conditions more severe than those expected from ground handling, launch, and orbital operations" (ref. 1). Typically, qualification testing seeks to uncover deficiencies in design and fabrication and to provide a high degree of confidence in the end design.

The specific test levels and durations were derived from the GEVS-SE and the SPAR-3 documents. In some cases the specifications were modified at the project's discretion to tailor the tests to the project's needs.

For some of the commercial components with little or no quality pedigree, random vibration testing was performed to give early verification of the components' design integrity. These components included a quartz halogen light, a pressure transducer, a pneumatic pressure regulator, a solenoid valve, a 16-mm film camera, and a boiling heater surface.

The project team determined that box level testing of the major electrical box assemblies would provide early verification of the designs that would otherwise be more difficult and costly to correct at a later stage of development. Box level testing was limited to three axis random vibration testing and thermal cycling at room pressure and extended temperatures (in contrast to thermal vacuum cycling).

At the system level, a wider range of testing was employed. The complete system was subjected to three axis random vibration testing, thermal extreme soak testing, thermal vacuum cycling, and an EMI signature test.

COMPONENT VIBRATION TESTING

The three axis component vibration test specification was taken from the 1986 edition of the GAS Experimenter's Handbook (ref. 3) and is summarized in table I. Testing was performed at the NASA Lewis Research Center's Structural Dynamics Laboratory.

The component test fixtures were designed to solidly mount the components to the vibration table; little attempt was made to accurately simulate the component's mounting on the experiment structure. Component level vibration testing helped provide confidence that the nonpedigreed commercial parts selected for the experiment would survive later system level vibration testing. The only component to fail during these tests was a precision pressure transducer with a 6-cm-diameter circuit board populated with discrete electrical components that were not solidly mounted to the board. One of the discrete electrical components failed during the vibration testing and caused the transducer to fail completely. A higher quality, ruggedized pressure transducer was subsequently ordered to replace the commercial item.

BOX LEVEL VIBRATION TESTING

The box level random vibration power spectral density (PSD) curve was derived from table B-3, appendix B of the GEVS-SE (ref. 1), and is reproduced as table II. This PSD curve, which is the same as that for the entire system, was used because detailed dynamic response data at the box mounting locations on the PBE structure were not yet available. Testing was performed at the NASA Lewis Research Center's Structural Dynamics Laboratory.

The test fixtures for the boxes were similar to those used for the components in that little attempt was made to simulate accurately the component's mounting on the experiment structure. As with the component level testing the desired outcome of the testing was a level of confidence. No failures occurred during the box level testing. However, when the data acquisition and control system box was tested, one of the STD-bus boards which had relatively tall capacitors was noted to be making contact with the circuit board above it. Subsequently, the capacitors were mounted differently to allow for additional clearance between the boards in the card cage.

Completion of the box level random vibration testing gave the project team high confidence that the system level random vibration testing could be accomplished with a much reduced chance of failure.

BOX LEVEL THERMAL TESTING

The GSFC GAS Eleven Node Thermal Model (GEM) (ref. 4) was used to model the overall system temperatures. The data derived from the modeling effort were used to determine the minimum and maximum expected temperatures for orbital operations. Using the guidelines set forth in the GEVS and the SPAR-3, the PBE team determined that qualification thermal test levels would be defined as 10 °C below the minimum expected on orbit temperature and 10 °C above the maximum expected on orbit temperature. This translated into a thermal test band of 0 to 49 °C.

Box level thermal testing was performed in a large environmental chamber that was capable of heating and cooling but was not capable of providing a vacuum. The boxes were subjected to five thermal cycles over the thermal test band. A 4-hour soak period was observed at each temperature extreme. The electrical components inside the various boxes were powered ON for the entire duration of the thermal cycle tests.

Some of the more power consumptive components inside the individual boxes were instrumented with thermocouples to monitor case temperatures during the testing. Heat sensitive indicator strips were applied to the electrical components expected to dissipate lessor amounts of heat.

During the hot portion of the cycling, the electrical components registered temperatures increases of no more than 5 °C. All the power consuming devices were heat sunk to the aluminum structure of the experiment; this significantly reduced heat buildup in the electrical components.

However, some problems did arise during the box level thermal cycling. Several boards performed erratically during the testing. It appeared that humidity levels inside the chamber might have been a contributing factor. Therefore, additional thermal cycling was performed with the problematic boards using a different environmental chamber which had better humidity control. The previous anomalous results did not repeat. The circuit boards did not have conformal coating (RTV) applied at the time of testing, but the coating was later applied.

SYSTEM LEVEL VIBRATION TESTING

The random vibration PSD curve obtained from table B-3, appendix B of the GEVS-SE (ref. 1) is reproduced herein as table II. The prototype system was subjected to an overall rms acceleration of 7.2 g. The GEVS-SE specification represents an overall level that is meant to take into account quasi-static, random, and acoustic induced vibration inputs. The system level random vibration testing was performed at the NASA Lewis Research Center's Structural Dynamics Laboratory and at the Loral System facilities in Akron, Ohio.

The initial attempt to perform the random vibration test had to be aborted. The PBE has a number of pneumatic lines which are routed to various places on the experiment. Several of the stainless steel tubing runs were not adequately supported. During the initial random vibration test, several pneumatic components went into resonance, and this caused fittings to back off and parts to hit one another. In addition, the vibration test fixture was found to have its own natural frequencies which, when coupled with the experiment, were providing significant resonant couplings that ultimately caused the vibration table control system to shut down after a predetermined structure response limit was reached. The pneumatic system problems were solved by adding additional support brackets and altering some of the pneumatic component brackets.

Solving the fixture/experiment coupling problem was more difficult. The vibration test fixture, illustrated with the experiment assembly in figure 2, had a cantilever resonant mode which effectively caused more energy to be coupled into the top portion of the experiment than to the base. To eliminate this, the vibration table control accelerometers were placed on the top plate of the experiment and on the vibration table itself. The response signals from these accelerometers were averaged for use in the vibration table control feedback loop.

SYSTEM LEVEL THERMAL SOAK TESTING

The prototype system was subjected to system level hot and cold thermal soak tests in order to verify the system's capability to start and perform a complete mission simulation at the qualification level temperature extremes of 0 °C and 49 °C. In addition, it was felt that a level of confidence could be obtained for the system's ability to withstand temperature extremes during shipment from Cleveland, Ohio, to Kennedy Space Center, Florida. In addition to verifying the system's ability to perform at the temperature extremes, the thermal soak tests also helped put operating time on all the components so that infant mortality failures could be weeded out (no failures occurred).

The project-unique environmental test chamber designed and fabricated by the project team is illustrated in figure 3. The test chamber has internal dimensions identical to those of a GAS canister. The chamber is equipped with external cooling/heating fluid loops on the top and bottom of the chamber as well as around the cylinder side walls. These loops, used in conjunction with a constant temperature bath unit equipped with a small fluid pump, allowed varying the test chamber temperature from -5 to over 60 °C. In addition, the chamber was designed to allow vacuum operations to be performed inside it. A variety of gas-tight electrical feedthroughs were provided on the test chamber end plate to facilitate control and monitoring of the hardware in the chamber.

The system level thermal soaks were performed with a 10-psia pressure inside the environmental chamber to simulate the PBE's on-orbit operation. (The project requested a nonstandard 10-psi pressure relief to be fitted to the GAS canister for flight.)

The length of the thermal soak, or the time required for the hardware to achieve the desired temperature, was based on the interior temperature of the experiment's two batteries. The system was allowed to cool or heat as needed until the battery internal temperatures reached the desired level, at which time a full mission simulation test was performed using software resident in the experiment's computer.

During the cold soak test, the battery voltages dropped significantly, from 34 to 25 V dc. It was initially thought that the cold soak test might need to be aborted to avoid bringing the silver-zinc battery voltages too low. However, as the batteries were discharged, they released heat which in turn warmed the batteries and helped to bring the battery voltages back to an acceptable level of about 27 V dc.

SYSTEM LEVEL THERMAL VACUUM CYCLE TESTING

In addition to the thermal soak tests, thermal vacuum cycling was performed to simulate the convection free environment for on-orbit operations. The environmental test chamber was fitted with a vacuum pump that could provide a chamber vacuum of about 10^{-2} Torr. Since the experiment's pneumatic system was not designed to function properly in a vacuum environment, Performance Acceptance Tests (PAT's) were performed at the temperature extremes to verify the experiment's health. The PAT's exercised each of the experiment's subsystems to an extent that verified functional capability.

The thermal vacuum cycles were performed over the temperature range of 0 to 49 °C. Sixteen-hour soak periods were observed at each temperature extreme. Two full cycles were completed. The experiment remained powered ON during the entire test.

SYSTEM LEVEL EMI SIGNATURE TEST

A radiated E-field test was performed at the EMI/RFI Laboratory at Lewis. The test followed the requirements of MIL-STD-462 except that the frequency step rate was increased to facilitate making quicker measurements to reduce the operational time for the PBE hardware. The test results showed that the bare PBE system exceeded the MIL-STD-461A, RE02 specification by 20 dB at 80 MHz. However, the GAS canister flight enclosure provides 60 dB of attenuation, thus making the overall system (PBE and the GAS canister) compliant with the MIL-STD-461A, RE02 specification.

EFFORT REQUIRED FOR THE TEST PROGRAM

The initial component and box level tests occurred over the course of approximately 1 year. Typically, one or two engineers and a technician would spend a week writing procedures, developing test fixtures, and performing the tests.

The system level testing was performed over a 4-month period during which the tests were conducted in a serial fashion. Preparation for most of the system level tests often occupied three or more engineers and a technician for 1 to 2 weeks. Preparing for the system level random vibration tests required even more team involvement.

CONCLUSIONS

A number of lessons were learned from the environmental qualification testing program that was used to prove the integrity of the prototype hardware:

1. Testing of candidate components early in the design process can uncover design problems which force the use of a different component. Such testing also saves much time and money when compared to fixing problems at a later stage of hardware development.

2. Box level environmental testing helps the project team develop confidence in the box level design. Also, problems found at this stage can be more readily fixed than at later stages in the project development.

3. System level testing uncovers many problems not found at the box level. The dynamic interactions of the various subsystems are difficult to completely determine ahead of time.

4. The amount of data that needed to be reduced and analyzed after the system level tests was significant. Analyzing the experiment data was just as time consuming as preparing for and performing the test itself.

5. The design of the vibration test fixture is critical to accurately simulating the GAS canister vibration environment. Although the project had access to a vibration test fixture, it was not clear that the GAS canister vibration environment was simulated properly.

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2. Guidelines for Standard Payload Assurance Requirements for GSFC Orbital Projects. GSFC Designation: SPAR-3. NASA Goddard Space Flight Center, Greenbelt, MD, Mar. 1990.

3. GAS Small Self Contained Payloads Experimenter Handbook. NASA Goddard Space Flight Center, Greenbelt, MD, 1986, p. 57.

4. Butler, D.: GAS Eleven Node Thermal Model (GEM). The 1987 Get Away Special Experimenter's Symposium, NASA CP-2500, N. Barthelme and F.L. Mosier, eds., 1987, pp. 153-169.

TABLE I.—COMPONENT RANDOM VIBRATION SPECIFICATION

[Overall rms acceleration, 12.9 g; test time per axis, 2 min.]

Frequency, Hz	Power spectral density, g^2/Hz	Slope, dB/octave
20	0.003	-----
20 to 80	------	6.0
80 to 1000	.125	-----
1000 to 2000	------	-6.0
2000	.25	-----

TABLE II.—BOX AND SYSTEM RANDOM VIBRATION SPECIFICATION

[Overall rms acceleration, 7.2 g; test time per axis, 2 min.]

Frequency, Hz	Power spectral density, g^2/Hz	Slope, dB/octave
20	0.01	-----
20 to 50	--------	4.77
50 to 600	.0428	-----
600 to 2000	--------	-3.64
2000	.01	-----

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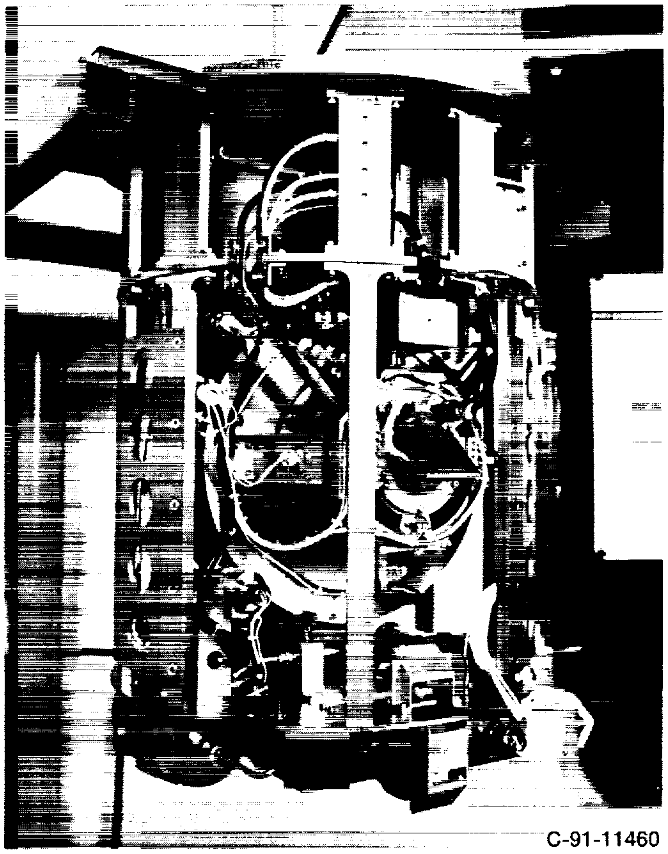
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Figure 1.—Prototype pool boiling experiment (PBE) system.

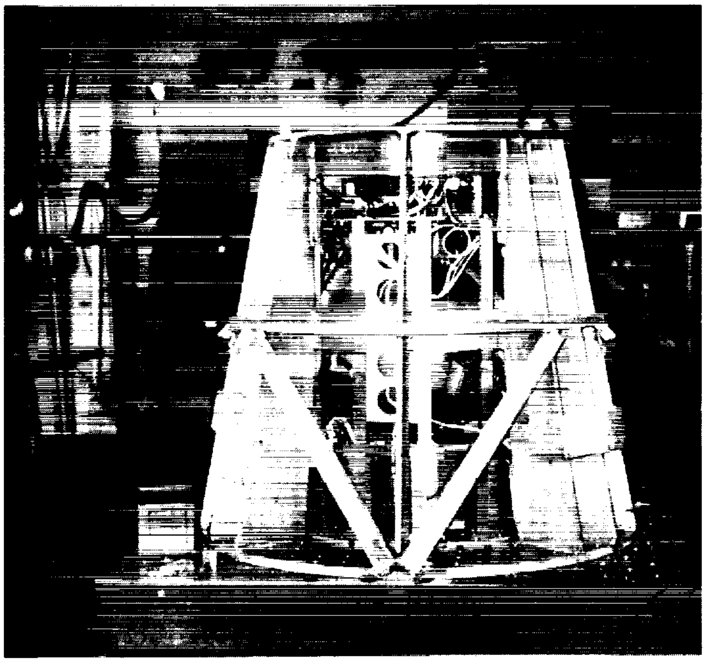

Figure 2.—System vibration test fixture (with experiment).

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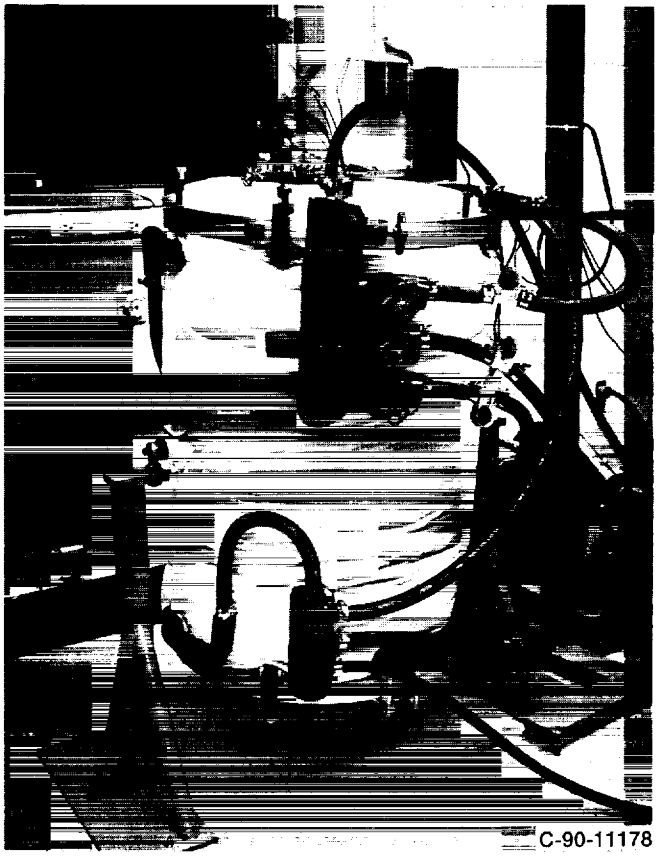

Figure 3.—Pool boiling experiment (PBE) environmental test chamber.

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