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A COST-EFFECTIVE LOOK AT SPACECRAFT COMPONENT TESTING

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Summary

The trend towards fixed price programs accompanied by stringent schedule requirements, has forced RCA to make a critical reassessment of the traditional methods for testing spacecraft and spacecraft components. The assessment consisted of a detailed review of the rationale for vacuum testing at the component level and a concomitant review of the failure history on several successful spacecraft programs. As a result, certain conclusions were drawn:

- Vacuum testing is only required on vacuum sensitive items;
- The sensitivity of these items could be predicted; and
- A thermal cycle test would be more protective.

These conclusions have now been implemented successfully in a major classified spacecraft program.

Introduction

It has been an act of faith in spacecraft testing to subject all spacecraft components to vacuum thermal testing prior to their integration on the spacecraft. With the emphasis on fixed-price contracts and stringent scheduling, a detailed reassessment was made of this philosophy. As a result, it was concluded that many components did not require vacuum testing. Additionally, the components which will require vacuum testing can be predicted in advance. The remainder of this paper delineates the rationale and analyses which resulted in this decision.

The purpose of vacuum testing at the component level is to (1) provide confidence in its ability to perform in vacuum at the spacecraft test level and ultimately in orbit; (2) determine the suitability of the design for vacuum operation; and (3) detect vacuum-sensitive anomalies.

For the program under consideration, the specified component test plan was carefully analyzed. It required all components to be tested in vacuum for 12 hours at each of three temperature levels with the temperature-time rate of change (dT/dt) unspecified. This program had been in existence for several years at RCA, and the test philosophy was thoroughly embedded.

An initial review of the failure history showed that the component tests were not as effective as they should have been in protecting against system failures. It appeared that the reason for this deficiency lay in the limited number of temperature cycles and the specified dT/dt which permitted gradual temperature transitions. Based on other program experience, it appeared that a

more effective test for weeding out incipient problems would consist of several thermal cycles with a dT/dt of approximately 0.5°C per minute. It also became apparent that it would be desirable for test facility, and schedule reasons that the test be performed with a temperature box. To ascertain whether this was possible, a systematic review of the merits of vacuum testing was conducted. This took the form of an analysis of the failure history of several RCA programs (for example, Relay, Lunar Orbiter, RAE, and a classified program). A review of the effects of vacuum on the materials and parts in the articles and on the articles' actual function was conducted.

Effects of Vacuum Operation

When designing for vacuum operation, consideration must be given to:

- Temperature — in a vacuum, convection is no longer present as a heat transfer process.
- Outgassing — materials with high vapor pressure will change state from a solid to a gas. Additionally, some gas may be absorbed or trapped in the conformal coating, etc.
- Sublimation — certain metals and other materials will vaporize in vacuum and deposit on the nearest cold surface.
- Breakdown — in vacuum, effects such as Paschen's law, multipactor, electrical arcing and other phenomena become a serious consideration.
- Dimensional anomalies — the loss of atmospheric pressure can cause dimensional distortion in housings, boards and parts.
- Migration of lubricating materials — certain lubricants tend to migrate or otherwise disappear in vacuum.
- Cold welding — rotating or sliding metal parts may stick or cold-weld in vacuum under certain conditions.

It became clear that not performing vacuum testing might permit deficiencies in the areas cited to go undetected and prevent verification at the component test level. To determine whether this was a real possibility, each component was reviewed in terms of its materials, parts, application and history for possible problems. The results are summarized in the following paragraphs.

Thermal

To compensate for the addition of convection as a thermal heat transfer process, 5° C was added to the top end of the temperature. Thus, components subjected to thermal cycling underwent temperature level tests which were 5° C higher than those required in vacuum. This was considered by the thermal group to be more than adequate compensation.

Outgassing

All parts and materials were reviewed to provide assurance that they will not outgas. For example, all RCA components utilize printed circuit board construction, employing 2-ounce G-11 glass epoxy with electrolytic copper traces coated with reflowed, electro-deposited Sn-Pb (60 to 40 percent). These boards and the process for their fabrication have been successfully employed by RCA for the past five years on such programs as TIROS, Lunar Orbiter, RAE-AAAS, Ranger, etc.

The conformal coatings used were originally developed for TIROS and Lunar Orbiter and then used on other programs. Precautions against gas entrapment and incomplete coatings formulation are provided by de-aerating such materials (pulling a vacuum) when mixing, and a high temperature bake after application. Again, these formulations have been thoroughly qualified for use in vacuum by virtue of extensive testing prior to their adoption. Verification of the success of these methods is provided by the successful performance in the cited programs.

The housings are made of 6061-T6 aluminum (0.040-inch thick typical and the tape recorders 0.100 inch; all components are painted with a polyamine epoxy paint which is space-qualified). The harness wire, internal to the components, is made of Teflon-coated copper wire; the connectors are all gold-plated brass. Thus, there is nothing employed which can outgas significantly. There still remained the possibility that improper materials might be inadvertently employed or the process might not be properly implemented. Since this possibility existed on previous programs, an extensive review of RCA malfunctions and test discrepancy history was made to determine what the frequency of occurrence of this type of problem had been. Not one vacuum malfunction in over 10,000 analyzed could be attributed to improper materials or an incorrectly implemented process in applying these materials.

Sublimation

Every part and material was and is reviewed by knowledgeable personnel prior to its acceptance for use in a spacecraft program to ensure that it does not contain material which could sublimate. For example, zinc and cadmium platings and was-impregnated lacing tape are not permitted.

The effectiveness of these controls has been verified by reviewing the failure history. Again no failures were attributed to sublimation.

Breakdown Effects

The factors which can initiate electrical breakdown in vacuum are well known. These are:

- Voltages present in excess of 200 volts.
- Presence of substantial amounts of RF power.
- High voltage gradients (volts/mil) resulting from sharp edges, etc.

The spacecraft components were reviewed as delineated in the attached table. The only components liable to have problems in this area are transmitters.

Momentum wheel assemblies, despite their low voltage application, were tested in vacuum to provide a reference for motor current and assure adequate lubrication throughout the system.

Tape Recorders. Since the recorders are hermetically sealed, pressurized and helium-leak tested after each environmental exposure, it was decided that it would be safe to forego the vacuum portion of the test.

DC-DC Converters. Although there are no high voltages present, it was decided to subject the prototype units to thermal vacuum because of the newness of the design.

Dimensional Stability. The design precautions required to obviate problems in this area are well known and have been taken on the program. These precautions include:

- Adequate numbers of vent holes.
- Structurally-sound design (that is, covers are dimpled; materials have adequate safety factors).

Assurance that these measures are more than adequate is provided by the previous performance of RCA hardware. Additionally, a series of tests was conducted on Lunar Orbiter. The rapid ascent of the launch vehicle introduced the possibility of distortions. A series of tests was conducted which required each component to be pressurized to two atmospheres. The chamber was then opened, resulting in a rapid decompression. There was no evidence of any distortion.

Lubrication Migration

This is a significant problem, as evidenced by several shutter problems experienced on certain programs. The use of a properly qualified space grease, Verslube (G-300), obviated the condition. However, to avoid problems, all shutters and open switches were exposed to vacuum as part of the acceptance test procedure.

Cold Welding

This is a recognized phenomenon in vacuum. The safest course is to pressurize and to expose all such components to vacuum testing.

The following paragraphs summarize the RCA failure history on several recent spacecraft programs. The conclusions are that components which will be vacuum-sensitive can be successfully anticipated.

Relay I. On the Relay I program, there were a total of 141 malfunctions at the component, subsystem and spacecraft levels. Of these, 79 (56 percent) were associated with the wideband systems (receiver, beacon and transmitter); 25 (17.8 percent) occurred in thermal vacuum, and 4 of these (3 percent of the total number of malfunctions) required vacuum to evidence themselves. All of these were in the TWT and associated power supply. This could have been anticipated because of high voltages ($E_H - 1200$ V, $E_{coll} - 600$ V) and high RF power (10 watts at 1600 MHz).

Relay II. A total of 78 malfunctions were reported at all levels of testing, 60 in component level and 18 on the spacecraft level. Exactly 9 (11.5 percent) occurred in vacuum; of these, two required vacuum to occur. Not unexpectedly, these involved the TWT and associated high voltage supply.

It is also interesting to note that the percentage of thermal vacuum failures is higher at the spacecraft level than at the component level. This would seem to indicate that the spacecraft test, because of the additional handling, longer test times, and more careful data review, is more effective in detecting failures.

Lunar Orbiter. There were a total of 1130 test discrepancies at all levels of test; that is, board, component, subassembly and spacecraft. These break down into:

196 board level malfunctions
931 component and subassembly
<u>3 spacecraft</u>
1130 total malfunctions

Of these, 260 (or 23 percent) occurred in thermal vacuum. Four required vacuum to evidence the failure. These included:

- A breakdown of the TWTA (12 watts at S-band) bandpass power monitor filter at critical pressure.
- A breakdown of Teflon-insulated wire in the TWT power supply. The supply was required to put out a helix voltage (E_H) of 1200 volts and a collector voltage of 600 volts. The fix was to put in silicone rubber wire.
- A breakdown of a capacitor in the TWT power supply in spacecraft test. The failure was attributed to an accidental crease of an aluminum sheet in the capacitor stack causing a voltage stress. The unit had passed FAT in vacuum at the power supply and TWTA level.
- A breakdown of flex wiring in the TWTA in vacuum. Again this was corrected by using silicone-insulated wire.

All of these failures could have been anticipated in light of the criteria cited previously.

Antenna Aspect Subsystem of the Radio Astronomy Explorer Satellite. There were a total of 54 failures at all levels of test. Of these, four occurred in vacuum, of which two required vacuum to manifest themselves.

- A failure of the dc-dc converter, which was required to produce 400 volts from a 24 volt bus in vacuum. The problem was anticipated, tests conducted and a fix, better venting, was implemented.
- A failure of a shutter blade in vacuum. In this case, the addition of Versilube G-300 eliminated the condition. Again, the problem could have been anticipated on the basis of the ground rules cited.

Classified Program, Phase A. On this program, there were a total of 114 malfunctions and discrepancies reported. Of these, 18 occurred in vacuum and 18 in thermal tests. One required vacuum to manifest itself; this was the magnetic stepper switch where the lubrication was found to have disappeared, and the use of Versilube G-300 corrected the problem. The transmitters were chronic problems, passing the supplier's vacuum but failing in the spacecraft vacuum. They subsequently failed in thermal testing at the supplier after extensive temperature cycling.

Classified Program, Phase B. As a whole, there were a total of 117 test discrepancies at the component level on this program. This broke down into 32 in thermal vacuum and 23 in thermal tests. Considering the longer exposure time in vacuum, it would appear that the thermal test is equally good at detecting problems at the article level. None of the vacuum failures would have required the vacuum test to manifest themselves.

Conclusions

The following conclusions were made as a result of this study:

- RCA is convinced, based on its experience, that thermal test is equally as efficient as thermal vacuum in detecting incipient defects on certain nonvacuum-sensitive components.
- The thermal cycle is more effective than temperature-vacuum storage tests in vacuum.
- Certain articles are vacuum-sensitive. These can be identified in advance in terms of their performance, parameters, construction, function or parts.
- Thermal vacuum, as performed on previous programs, has not been particularly protective in spacecraft tests.