THERMAL-VACUUM VERSUS THERMAL-ATMOSPHERIC TESTS OF ELECTRONIC ASSEMBLIES

Practice:

Perform all thermal environmental tests on electronic spaceflight hardware in a flight-like thermal vacuum environment (i.e., do not substitute an atmospheric pressure thermal test for the thermal/vacuum test). Moreover, if a compromise is thought to be necessary for nontechnical reasons, then an analysis is required to quantify the reduction in test demonstrated reliability.

Benefit:

Assembly-level thermal vacuum testing is the most perceptive test for uncovering design deficiencies and workmanship flaws in spaceflight hardware. The margin beyond flight conditions is demonstrated, as is reliability. However, substituting an atmospheric pressure thermal test for the thermal/vacuum test can effectively reduce electronic piece part temperatures by 20°C or more, even for low power density designs. The net result of this is that the effective test temperatures may be reduced to the point where there is zero or negative margin over the flight thermal environment.

Programs That Certified Usage:

Ranger, Mariners, Viking, Voyager, Magellan.

Center to Contact for Information:

Jet Propulsion Laboratory (JPL).

Implementation Method:

Establish a policy for spaceflight electronic hardware that requires all assembly-level thermal testing to be performed in a thermal/vacuum environment. Moreover, deviation from this policy should require a waiver, supported by *quantitative* analysis that considers the effect on test demonstrated reliability.

Technical Rationale:

Vacuum effects:

A thermal/vacuum (T/V) test simulates the flight condition. Two different physical phenomena occur when a thermal/atmospheric pressure (T/A) test is performed in lieu of a T/V test. They are "pure vacuum" effects and temperature level/gradient effects.

The "pure vacuum" phenomena include corona and multipacting. Corona is of concern in the pressure region from about 0.1 to 0.001 torr. Multipacting can

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occur starting from the middle of the corona region all the way to near hard vacuum conditions. Pure vacuum problems most often are associated with radio frequency (RF) or high voltage circuits and devices.

The addition of an ambient pressure gas alters key temperature levels and gradients. For a unit that is designed to be conductively coupled to the spacecraft structure (shear plate), the prime thermal path from the piece parts to the shear plate is via the boards and the housing. The introduction of a gas into the "simulated" flight environment results in two significant thermal alterations. First, the dominant thermal paths from key elements of the assembly (piece parts and solder joints, etc.) are altered because the gas creates a parallel path from these elements to the chamber ambient via the total housing skin. Secondly, artificial parallel paths between the key elements to the flight heat sinking surface are added. These additional parallel paths short out any of the high thermal resistance paths that may be present in the design. The net result of this is a reduction in the temperature of the key elements at *both* test temperature extremes. This test temperature reduction is referred to as the ΔT effect.

A reduction in gradients between circuit elements also occurs, which can lead to circuit performance that is not typical of flight. For example, a timing circuit may show adequate performance due to the reduced gradients, whereas the performance in a flight-like vacuum condition could be unacceptable.

JPL Study Results:

Analyses and testing have been specifically performed at JPL since 1985 to quantify the effects of performing T/A testing in lieu of T/V testing. The results of these efforts are summarized in Table 1. Performing T/A testing in lieu of T/V testing reduces the temperature rise from the thermal control surface to key elements (boards, solder joints, parts, etc.) internal to the assembly. Note that this effect reduces the operating temperatures of the key elements over the whole temperature range (i.e., hot testing becomes less severe, while "cold" testing becomes colder). Reductions in the temperature rises can be on the order of 15ºC to 20ºC or more. Commonly, T/A testing reduces temperature rises by a factor of 2 to 4.

Such reductions lead to margin demonstrations dramatically lower than desired, and can easily cause negative test margin demonstrations.

An electronic assembly is manufactured by a series of chemical and mechanical processes. Design and workmanship failures related to the chemical processes are best described by the Arrhenius reaction rate equation. Mechanical design and workmanship failures are most often a result of thermal fatigue and, to a lesser degree, vibration. Both the chemical and thermal fatigue failure mechanisms are a function of temperature. Tables 2 and 3 quantify the temperature influence on these failure mechanisms.

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Table 1. Summary of Analysis and Test Results for the ΔT Effect Associated with Performing T/A Testing in Lieu of T/V Testing

ASSEMBLY	TYPE	POWER DENSITY W/cm^2	ΔT effect (Deg. C)	
			Analysis	Test
Radar Transmitter	RF	0.04	16	(1)
Radar Transmitter	Power Supply	0.04	9	
Radio Receiver	RF	0.10	< 9	
Power Distribution	Analog	0.01	< 5	
Data Formatter	Digital/analog	0.15	10	10 (2)
Range Dispersion	Digital/analog	0.19	10	
Command Data Bay 3	Digital/analog	0.02	21	
Command Data Bay 4	Digital	0.01	16	18
Science Instrument	Digital/analog	0.03	22	20
Output Network	RF	0.01	3	

Notes: (1) Unit not blanketed during initial T/V test. Estimates for the effect of this indicated that the load on the heat exchanger was approximately twice that dissipated by the unit.

(2) Test performed for the ΔT effect part case-to-housing. Full ΔT effect shown is a combination of test and analysis.

Table 2. Arrhenius Reaction Rate Reduction Factors for Various ΔT Effects and Activation Energies.

ΔT effect Deg. C	Activation Energy (eV) (*)		
	0.6	1.0	1.4
20	2.7	5.3	10.3
10	1.6	2.3	3.1
5	1.3	1.5	1.8

*Assuming a 75ºC shear plate plus a 35ºC rise shear plate-to-part junction. Lower test levels lead to greater reduction ratios.

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Table 3. Screening Strength Reduction Factor ("X" Factors) for Various ΔT Effects and Shear Plate Temperatures.

Shear plate Temperature Deg. C	ΔT Effect Degrees C (*)		
	5	10	20
45	1.5	2.2	4.1
55	1.4	1.8	3.0
65	1.3	1.6	2.5
75	1.2	1.5	2.2

*For compliant solder joints and cold test temperatures above the glass transition temperature for all materials involved.

Also presented in Table 1 are various rationales generally in use in industry today for choosing a T/A test in lieu of a T/V test. The most common of these rationales are either based on the power density of the unit or type of hardware (i.e. power supply, digital, RF, etc.) undergoing testing. The JPL study results clearly show that these two rationales are not valid. The current rationale in use at JPL today is that if analysis shows that the ΔT effect is less than 5°C on *all piece parts, solder joints*, etc., *and* there are no known pure vacuum effects, then performing a T/A test in lieu of a T/V test might be allowed depending of the criticality of the unit under test. The safest and simplest course of action is to T/V test everything.

Impact of Nonpractice:

Performing an atmospheric pressure thermal (T/A) test in lieu of thermal/vacuum (T/V) test reduces the hot temperature margin, screening strength, and test demonstrated reliability. Hot temperature margins can be compromised to the point where there is a zero or negative margin between environmental test levels and the allowable flight level (e.g., a test with only a planned 10°C margin and a T/A reduction effect of 15 to 20°C would result in a negative test margin). Screening strengths can be reduced by factors of 2 to 4 or more. Test demonstrated reliability can be reduced by factors of 2 to 10 or more.

Related Practices:

"Part Electrical Stress Analysis," PD-AP-1303.
"Solder Joint Fatigue Cycles," *to be published.*
"Environmental Factors," PT-EC-1101.
"Thermal Analysis of Electronic Assemblies to the Piece Part Level," PD-AP-1306.

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References:

1. Mark Gibbel, "Thermal/Vacuum Versus Thermal Atmospheric Testing of Space Flight Electronic Assemblies," NASA Conference Publication 3096, from the 16th Space Simulation conference, Albuquerque, New Mexico, November 5-8, 1990.