2009 WORKSHOP
Thermal Fluids & Analysis

TFAWS 2009

CONSTELLATION

ARES – ORION – ALTAIR

CEQATR Thermal Test Overview

CxP 70036, Constellation Environmental Qualification and Acceptance Test Requirements Document

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CEQATR Thermal Test Overview

- Overview/Scope
  - Establish uniform baseline environmental qualification and acceptance test requirements for all CxP flight (not applicable to GSE and ground systems) hardware.
    - CEQATR does not provide test requirements for all environments
      - Some controlled by other documents
      - Some verified via M&P requirements or analysis
    - CEQATR does not apply all types of hardware

CEQATR Thermal Test Overview (cont)

- Environments covered by CEQATR
  - Dynamics (shock, random and acoustic vibration, sinusoidal vibration, high force vibration)
  - Acceleration
  - Thermal (cycle, vacuum, gradient, balance)
  - Depress/repress
  - Climatics (rain; salt fog; sand, dust and regolith; humidity; explosive atmosphere)
  - Oxygen Compatibility

CEQATR Thermal Test Overview (cont)

- Environments covered by CEQATR (cont)
  - Life
  - Functional/Performance
  - Leak (considered part of performance but separate paragraph in CEQATR due to uniqueness)

CxP Environments

- See CEQATR Table 1.2-1 for list of all environments and applicable program source documents for associated verification requirements

CEQATR Table 1.2-1

Environment	Verification Requirements
Acoustic Noise	CxP 70024
Acoustic Vibration	CxP 70036
Atomic Oxygen	NASA-STD-6016
Corona/Arcing (1)	CxP 70080
Depress/Repress	CxP 70036
EMC	CxP 70080
Explosive Atmosphere	CxP 70036
Functional Performance	CxP 70036
Fungus	NASA-STD-6016
Gravity (Earth, Lunar, Martian)	Analysis
Humidity	CxP 70036
Ice/Snow/Hail	Analysis
Ionizing Radiation	CxP 70144
Leak	CxP 70036
Low Earth Orbit (LEO)	CxP 70036/NASA-STD-4005
Life	CxP 70036
Micrometeoroid/Orbital Debris	Analysis
Modal Survey	CxP 70135

Environment	Verification Requirements
Multipaction (1)	CxP 70080
Offgas	NASA-STD-6016/CxP 70024
Outgas (1)	NASA-STD-6016
Oxygen Compatibility	CxP 70036/NASA-STD-6016
Ozone	Not Applicabe
Plasma	CxP 70036
Pressure	CxP 70135
Rain	CxP 70036 /NASA-STD-6016
Random Vibration	CxP 70036
Run-In	NASA-STD-5017
Salt Fog	CxP 70036
Sand/Dust	CxP 70036
Shock	CxP 70036
Sinusoidal Vibration	CxP 70036
Solar Radiation	CxP 70036
Static load	CxP 70135
Thermal Cycle	CxP 70036
Thermal Vacuum	CxP 70036

Levels of Assembly

- CEQATR requirements begin at the unit level of assembly and progress through the "major assembly" level. Included are "multi-unit modules" (MUMs) that are subject to the same requirements as units.

Definitions for Levels of Assembly

- Unit: A unit is a functional item (hardware and, if applicable, software) that is viewed as a complete and separate entity for purposes of manufacturing, maintenance, and record keeping. Examples: hydraulic actuator, valve, battery, transmitter, heat exchanger, "black box." Specifically excluded are instrumentation and sensors such as strain gauges, strip and patch heaters, thermocouples, wiring, cables, tube runs, etc., although these items are required to undergo environmental qualification and acceptance testing as part of their higher levels of assembly. Also excluded from definition as a unit are primary and secondary structure (as defined in CxP 70135) and Thermal Protection System (TPS).

Definitions for Levels of Assembly (cont)

- Multi-Unit Module : A Multi-Unit Module (MUM) is an intermediate level-of-assembly between the lowest level unit (as defined in this document) and the system level-of-assembly referred to in this document as a major assembly. It is comprised of units connected through common support structure, wiring harnesses, electrical cables, or fiber optic cables. Examples are a docking ring or an electronic box consisting of a large chassis in which are housed smaller electronic units (i.e., a "superbox"). MUMs have their own requirement specifications and are qualified and acceptance tested at the MUM level-of-assembly. They are also to be tested as "units" in accordance with this document.

Definitions for Levels of Assembly (cont)

- Major Assembly: A physical entity that has functional capabilities allocated to it necessary to satisfy system-level mission objectives within the Cx Architecture. A major assembly can typically perform all system functions within a mission phase (e.g., launch, ascent, on-orbit, reentry), or through mated operations with other Cx major assemblies (e.g., Orion, Earth Departure Stage [EDS], and Altair). Major assemblies will fall into one of the following four categories:

  a. Elements, such as the Crew Module (CM)

  b. Systems, such as the Orion

  c. Combined systems, such as the Orion/Ares I integrated vehicle

  d. Any large, complex hardware article that is determined by the Project to require qualification or acceptance testing prior to integration at the element level

Hardware Applicabilty

WHAT TYPES OF EQUIPMENT DOES CEQATR APPLY TO?

- Units
  - Electrical/Electronic
  - Antenna
  - Mechanism
  - Solar Panel
  - Battery
  - Fluid Equipment
  - Pressure Vessel
  - Thermal Equipment
  - Optical
- Major Assemblies
  - Earth Launch Assembly
  - Lunar/Mars Surface Assembly
  - Space Assembly

Hardware Applicability (cont)

WHAT TYPE OF EQUIPMENT DOES CEQATR NOT APPLY TO?

- Liquid rocket engines and thruster assemblies*
- Solid and hybrid propellant rocket motors*
- Pyrotechnics and Pyro-actuated devices (CxP 70199)
- Parachutes and parafoils and associated harnesses
- Ground facilities and equipment
- Stowable items not providing functionality to CxP flight systems (e.g., ISS payloads, food, crew personal items)
- Subunits/Parts (CCAs, EEE parts, roller bearings, solar cells, etc.)

* Units comprising these assemblies, such as valves, electronic boxes, and mechanical assemblies, are required to meet the unit-level requirements of this document. The integrated propulsion subsystems feeding liquid rocket engines or thrusters are required to undergo systems-level testing in accordance with this document. This document does not address unit- or system-level propulsion hot firings; these tests are mainly functional and not environmental in nature.

CEQATR Thermal-Related Definitions

- Nonoperating Maximum/Minimum Temperature: The maximum (or minimum) temperature to which an item may be exposed in a nonoperational state as documented in the applicable development specification or as derived analytically from the thermal environments specified in the applicable development specification. The item is usually required to meet all specification requirements at operational environmental extremes after exposure to the required nonoperational environments.

- Operational Maximum/Minimum Temperature: The maximum (or minimum) temperature to which an item may be exposed in an operational state as documented in the applicable development specification. The item may be required to meet all or only some of the functional/performance requirements while exposed to the temperature extremes.

CEQATR Thermal-Related Definitions (cont)

- Thermal Dwell: Thermal dwell of a unit at the hot or cold temperature extreme is the time required to ensure that internal parts and subassemblies have achieved thermal equilibrium.

- Thermal Equilibrium: Thermal equilibrium is achieved when the unit internal part with the largest temperature constant is within 3 °C (5.4 °F) of its equilibrium temperature, as determined by extrapolation of test temperatures and/or previous analysis/test data, and its rate of change is less than 3 °C (5.4 °F) per hr.

Requirements for unit-level thermal testing

Qualification									
Test	Electrical/ Electronic	Antenna	Mechanism	Solar Panel	Battery	Fluid Equipment	Pressure Vessel	Thermal Equipment	Optical Equipment
Thermal Cycle	R	ER	ER	ER	ER	R	ER	ER	ER
Thermal Vacuum	R(11)	R	R(4)	R	R	R	R	R	R(4)
Thermal Gradient	-	-	ER	ER	-	-	-	ER	ER

(4) Required for units external to pressurized volumes and units internal to normally pressurized volumes but which are required to operate under vacuum conditions
(11) Hermetically-sealed units shall be oriented in thermal vacuum testing to minimize the effect of natural convection (i.e., the effect of gravity).

Acceptance									
Test	Electrical/ Electronic	Antenna	Mechanism	Solar Panel	Battery	Fluid Equipment	Pressure Vessel	Thermal Equipment	Optical Equipment
Thermal Cycle	R	ER	ER	ER	ER	ER	ER	ER	ER
Thermal Vacuum	R(4)	R	R(5)	R	R	-	R	R	R(4)
Thermal Gradient	-	-	ER	ER	-	-	-	ER	ER

(4Hermetically-sealed units shall be oriented in thermal vacuum testing to minimize the effect of natural convection (i.e., the effect of gravity).
(5) Required for units external to pressurized volumes and units internal to normally pressurized volumes but which are required to operate under vacuum conditions

Requirements for major assembly level thermal testing

Qualification			
Test	Earth Launch Assembly	Lunar/Mars Surface Assembly	Space Assembly
Thermal Vacuum	-	ER*	R
Thermal Balance	-	ER*	R

Acceptance			
Test	Earth Launch Assembly	Lunar/Mars Surface Assembly	Space Assembly
Thermal Vacuum	ER	ER*	ER*

General thermal testing requirements

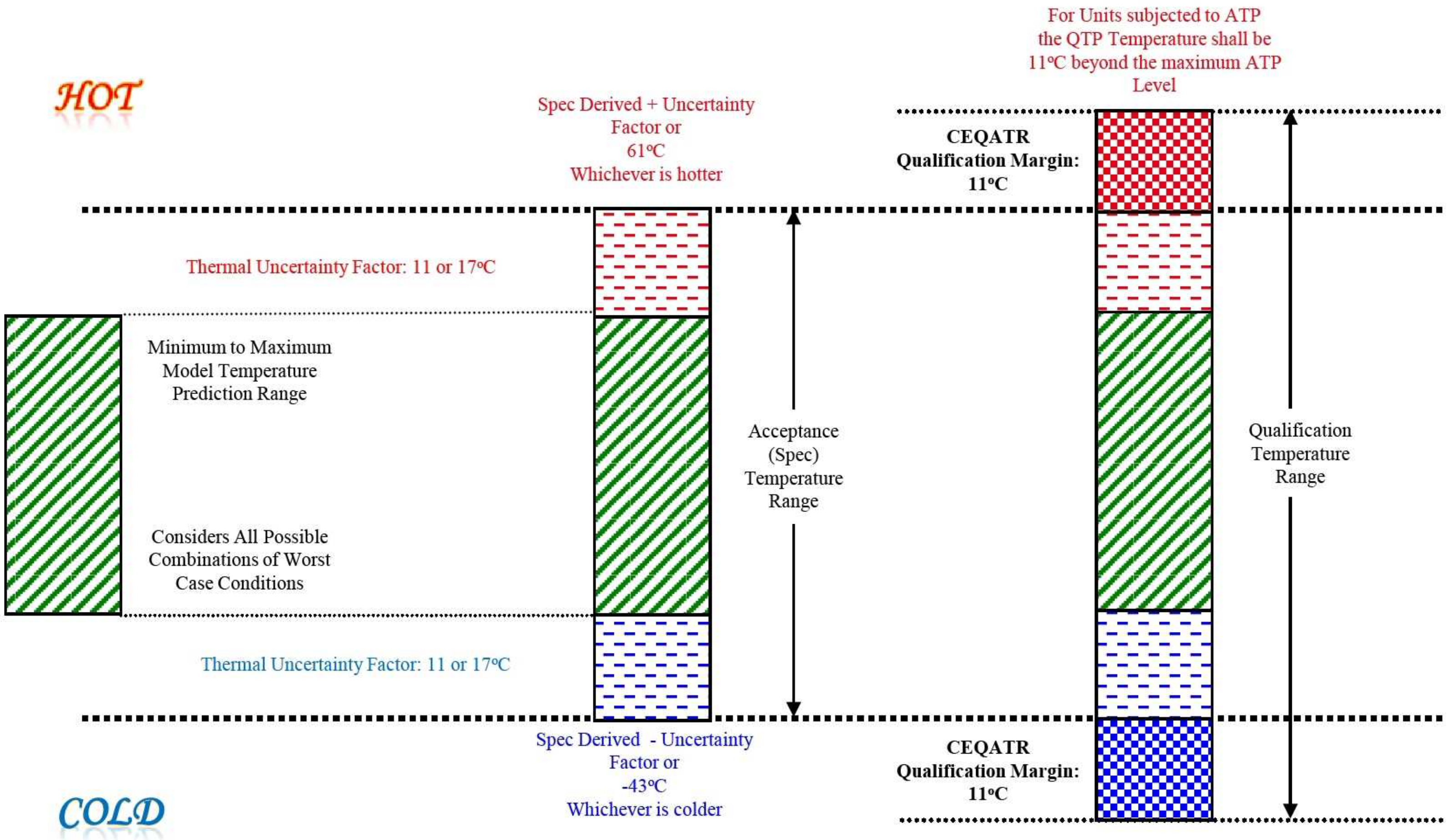
- Rationale/Purpose of cycling:
  - Establish confidence in hardware's ability to withstand multiple excursions to min/max temperature conditions and sufficiently cyclically stress hardware to precipitate design and workmanship flaws.

	Thermal Cycle		Thermal Vacuum	
	Qual	Accept	Qual	Accept
Electrical/Electronic Units	20	10	8	4
Non-Electrical/Electronic Units	8	4	8	4
Major Assemblies	NA	NA	8	4

General thermal testing requirements (cont)

- Temperature levels (all h/w, all levels of assembly)
  - For acceptance:
    - Spec min/max if spec gives explicit unit temperatures (presumed to incorporate appropriate uncertainty factor)
    - If spec gives environments:
      - 11° C beyond model predicted temps if model has been or will be validated by system-level thermal balance test
      - 17° C beyond model predicted temps if model has not been and will not be validated by system-level thermal balance test
    - Electrical/electronic units subject to at least -43° C +60° C for workmanship screening purposes if either is more severe than the above
  - For qualification
    - Acceptance +/- 11° C if thermal acceptance test required or (if thermal acceptance test not required):
    - 11° C beyond spec min/max if spec gives explicit unit temperatures (presumed to incorporate appropriate uncertainty factor)
    - If spec gives environments:
      - 22° C beyond model predicted temps if model has been or will be validated by system-level thermal balance test
      - 28° C beyond model predicted temps if model has not been and will not be validated by system-level thermal balance test

General thermal testing requirements (cont)



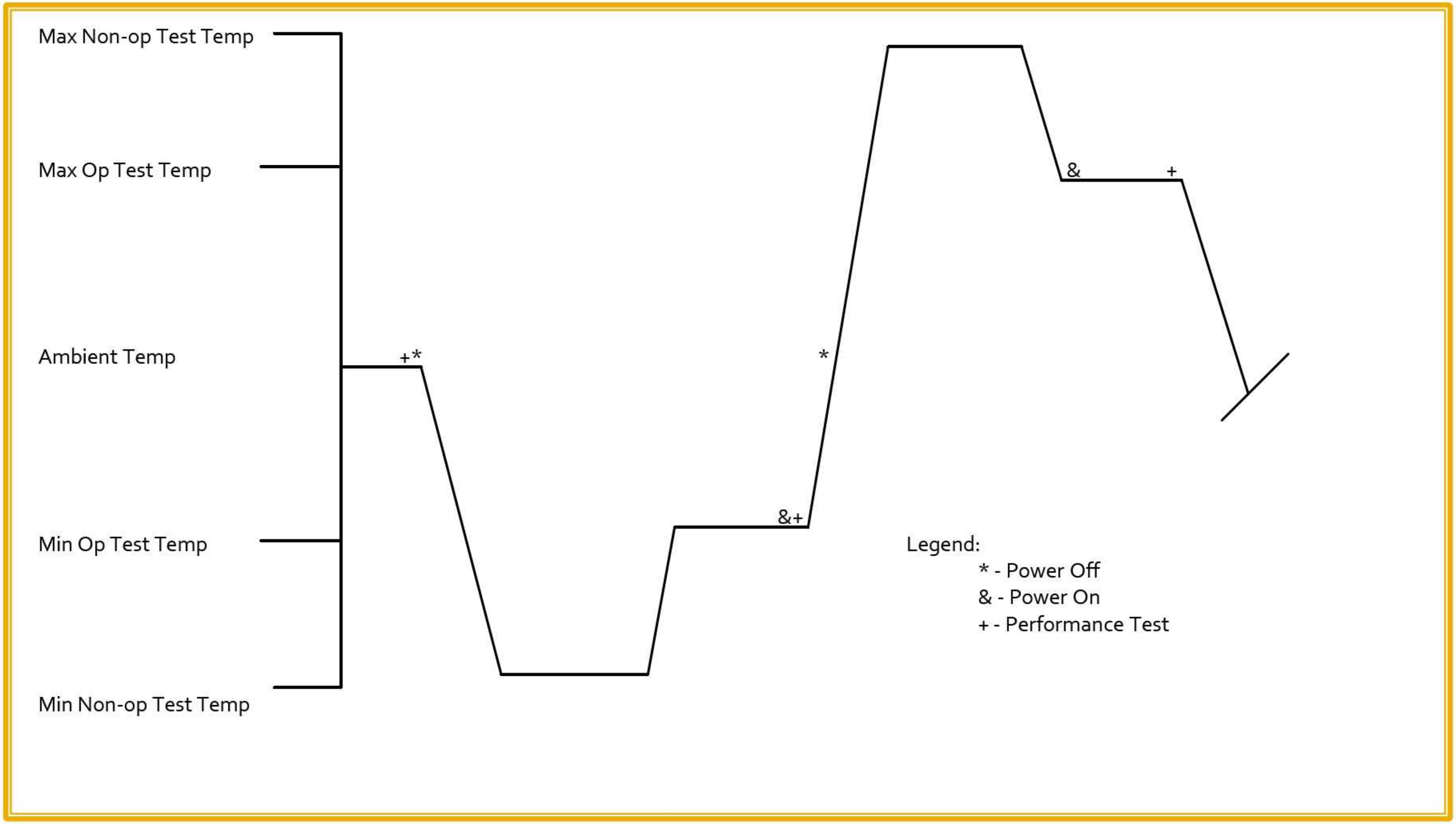
General thermal testing requirements (cont)

- Ramp Rates
  - For unit thermal cycle, average of 3° to 5° C per minute
  - For unit thermal vacuum, no less than max predicted rate if specified in the spec
  - For major assemblies, duplicate max predicted rate in critical areas to greatest extent practical.
- Dwell periods
  - For units, sufficient to achieve internal thermal equilibrium but not less than one hour for thermal cycle and thermal vacuum at hot and cold on each cycle
  - For unit thermal gradient, condition sufficiently long to achieve thermal equilibrium for each half for mating tests
  - For major assembly thermal vacuum, soak at hot and cold on first and last cycle for 8 hours minimum; one hour soaks minimum at hot and cold on intermediate cycles

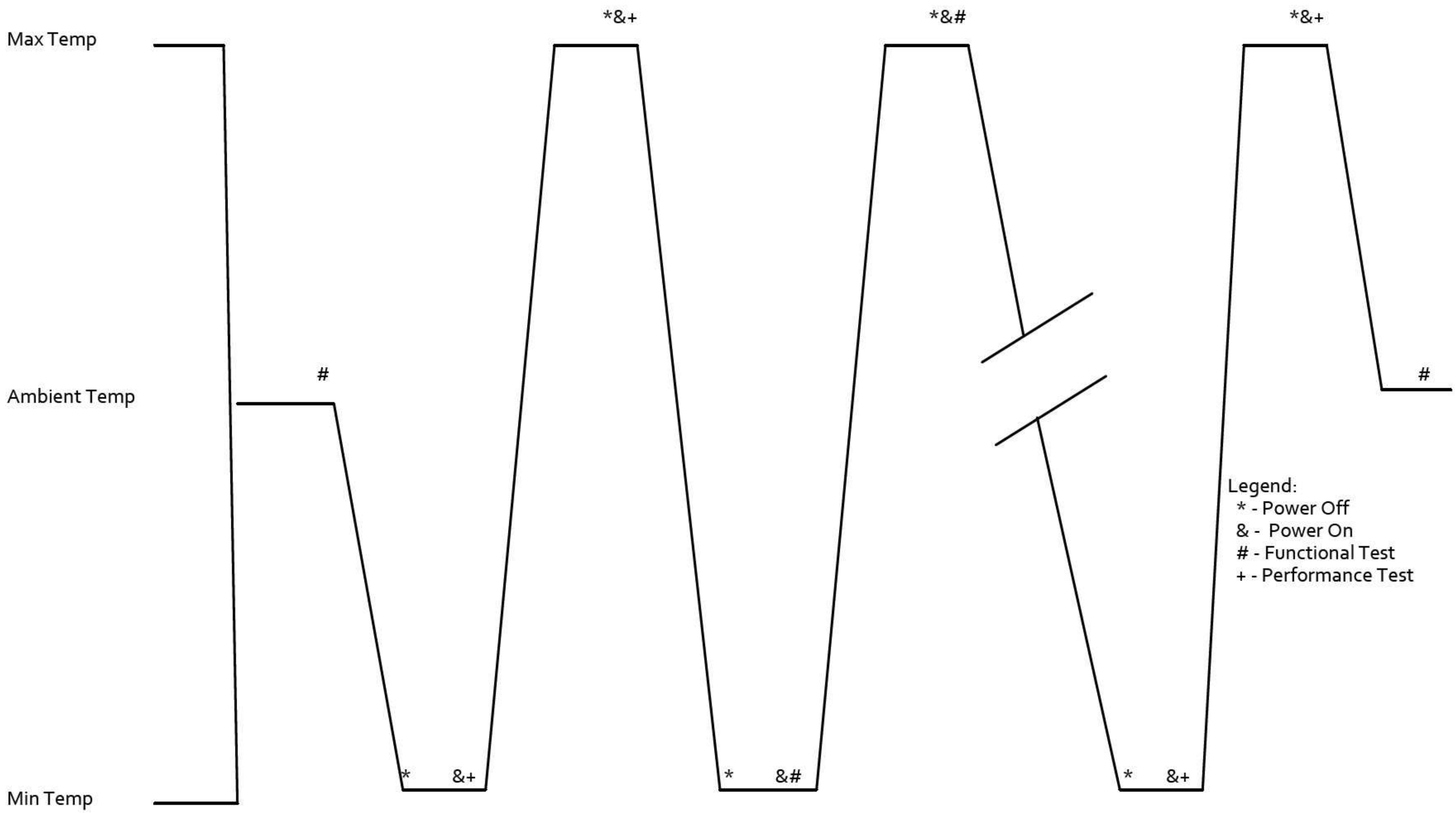
General thermal testing requirements (cont)

- Non-operational temperatures
  - If unit non-operational temperatures are beyond the operational temperatures on either or both hot and cold ends, one acceptance non-op cycle (2 for qual) are required
    - Non-op cycle(s) required to be performed prior to or in conjunction with first operational temperature cycle

General thermal cycle, thermal vacuum profiles



General thermal cycle, thermal vacuum profiles



Test Tolerances

- For hot side: -0/+3° C
- For cold side: -3/+0° C

OR

For both sides, +/- 3 ° C provided that 50% or more of the time during functional/performance testing at each temperature extreme is at or beyond the target test temperature.*

* Upcoming update

Vacuum vs Ambient

- Particularly important for electronics with unsealed chassis as temperature of internal electronics can be significantly higher under vacuum than at ambient pressure!!

Thermal Gradient

- Thermal gradient testing may be required for units which:
  - Are required to mate when one half may be at a low temperature condition and the other half is at a hot temperature condition
  - Large units (most likely mechanisms) with tight tolernaces and/or precision performance requirements that may be sensitive to thermal gradients across the unit.
- The need to perform thermal gradient testing needs to be evaluated on case-by-case basis
- In general, thermal test requirements are based on specified delta-T and number of mate/demates or other operational characteristics (e.g., start/stop) to cover anticipated service conditions.

Sequence of Testing

- CEQATR does not specify a required sequence of testing to be followed* – it does recommend one for units and major assemblies (see tables 4.1-2, 4.1-4, 5-2, and 5-4)

- Except in select cases such as:
  - Functional and performance testing before and after environments.
  - Leak testing after proof pressure testing
  - Others as stated in the requirements

Table 4.1-4

Test	Suggested Sequence	Requirement Document	Document Section
Run-in (4)	1	NASA-STD-5017	
Functional/Performance (1)	2,10	CxP 70036	4.2
Proof Pressure	3	CxP 70135	
Leak (2)	4	CxP 70036	4.4
Random Vibration	5	CxP 70036	4.6
Acoustic Vibration	5	CxP 70036	4.7
Thermal Cycle	6	CxP 70036	4.10
Thermal Vacuum (3)	7	CxP 70036	4.11
Thermal Gradient (3)	7	CxP 70036	4.12
Corona/Arcing (3)	7	CxP 70080	
Depress/Repress (3)	7	CxP 70036	4.15
EMC (5)	8	CxP 70080	
Explosive Atmosphere	9	CxP 70036	4.16.5
Oxygen Compatibility	10	CxP 70036	4.17

Alternative Stategies

- Two alternative strategies to baseline full qualification/acceptance test program
  - Protoflight
  - Highly Accelerated Life Testing/Highly Accelerated Stress Screening (HALT/HASS)
- Use of either approach requires approval by the CxSECB

Protoflight

- Used when there is no test-dedicated qualification article and all production builds are intended for flight usage
  - In general, test at qualification amplitudes for acceptance duration
    - When no acceptance test performed, test is baselined qualification test except modify duration if necessary to eliminate unnecessary wear or life comsumption
  - All S/Ns tested identically except those tests required to verify design only (e.g., salt fog) not required for all units
  - Not subjected to tests intended to demonstrate life or ultimate strength capability (e.g., ultimate load, burst pressure, pressure cycle)
- Protoflight NOT permitted for the following:
  - Crit 1, 1R, 2, or 2R hardware
  - Hardware with more than 5 production articles to be built
  - Hardware/system required to perform more than one mission

HALT/HASS

- Employed on case-by-case basis with CxSECB approval
- Test conditions/specifics developed on case-by-case basis

Humidity

- New humidity test developed for CxP believed to be more representative of CxP's needs
- Consists of three basic tests (not all are necessarily required for all hardware)
  - Consider the following for humidity test specifics:
    - Type of unit (electrical/electronic with vented chassis, electrical/electronic with sealed chassis, non-electrical/electronic)
    - Thermal control (passive, forced air, cold-plate)
    - Installation environment (internal-controlled, sheltered-controlled, external-uncontrolled)
    - Service life phase (mission –unpowered, mission – powered, nonoperational (storage, transportation))
  - Two basic tests (constant temperature/humidity/bias (THB) and cyclic THB
- Test needs to be rewritten to put in "requirement-ese"

Humidity (cont)

- Two basic tests to consider:
  - Constant Temperature/Humidity/Bias (THB)
  - Cyclic THB

Tailoring

- CEQATR requirements always intended to be tailorable
  - Based on technical appropriateness in a given case
  - Was not intended to be tailored because "that's the way we've always done it"
  - Tailoring approval authority based on risk assessment (5X5) performed by:
    - Hardware developer
    - Responsible NASA project office
    - Responsible center engineering technical authority subsystem manager
    - "Expert practitioner" of environmental test discipline ("CEQATR technical expert")
    - SR&QA representative

Tailoring (cont)

- Risk assessment documented in Test Requirement Evaluation Report (TRER) and should address, as a minimum:
  - The physical response or lack of response of the equipment to the environment in question. (The response may be categorized as changes to material properties or performance variability due to the environmental exposure.)
  - The severity of environmental exposure of the equipment to the environment in question. (The severity of the environment and the duration of exposure throughout the total equipment service life with potential impacts on hardware performance and life expectancy must be considered.)
  - The fidelity of the predictive modeling associated with the environment and hardware history.
  - The criticality of the equipment (i.e., the consequence of failure of the equipment to perform in the manner required) during or after exposure to the environment, especially as it affects safety of flight.

Tailoring (cont)

- The ability to identify and respond in a timely manner to any environmentally-induced failures.
- The ability to mitigate all hazards of equipment failure including levels of redundancy, hardware redundancy, and operational backups.
- Assessment of whether any redundant equipment is like the failed unit or of unlike design.
- Review of in-flight maintenance or replacement capability and associated risks.
- The effectiveness of the environment to precipitate latent manufacturing defects in the equipment to failure that cannot otherwise be precipitated through application of other environmental acceptance tests.
- The cost and schedule impacts associated with conducting the test versus cost of failure manifesting at later points in the mission preparation and operational flow.

Tailoring (cont)