Introduction & Application of SSC-S-016: Thermal Environmental Testing

John W. Welch
The Aerospace Corporation

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Learning Objectives

Thermal Test Requirements

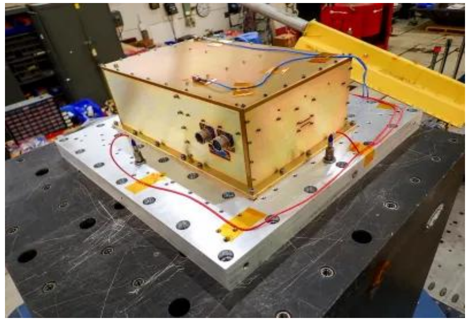
- Understand purpose of environmental testing
  - *SSC-S-016 history and philosophy*
- Understand and articulate the sources of the thermal environment
  - *Mission events*
- Understand the implications of environments on
  - *Margin demonstration*
  - *Workmanship/Stress Screening*
- Understand the analytical derivation of test specifications for units, subsystems and vehicles
- Understand basis for thermal uncertainty margin
- Understand test configurations and test profiles
- Understand test effectiveness and test parameter rationale

What is Environmental Testing?

- Environmental testing is the process of subjecting hardware to environmental stresses for the purpose of
  - *Increasing confidence is mission success*
  - *Demonstration flightworthiness*
  - *Verification of unit/subsystem performance in flight-like environments*
  - *Verification or demonstration of:*
    - Design requirements
    - Design margins to ATP requirements
    - Operation and performance to mission specifications
    - Mission and life capabilities
    - Workmanship integrity

- Environmental testing generally includes
  - *Dynamic testing (random vibration, acoustic, shock, ejection/deployment)*
  - *Thermal testing (thermal cycle, thermal vacuum, burn-in)*
  - *EMI/EMC*

- Environmental testing can occur with non-flight hardware, flight hardware, and engineering simulations of flight hardware
  - *Qualification units are flight representative units*
  - *Flight software and/or test equipment are not subjected to environmental testing*



Photos courtesy of NASA

What is SSC-S-016?

- "Test Requirements for Launch, Upper-Stage, and Space Vehicles"
  - *Standard establishing environmental ground testing requirements for the procurement of U.S. military launch vehicles and space systems*

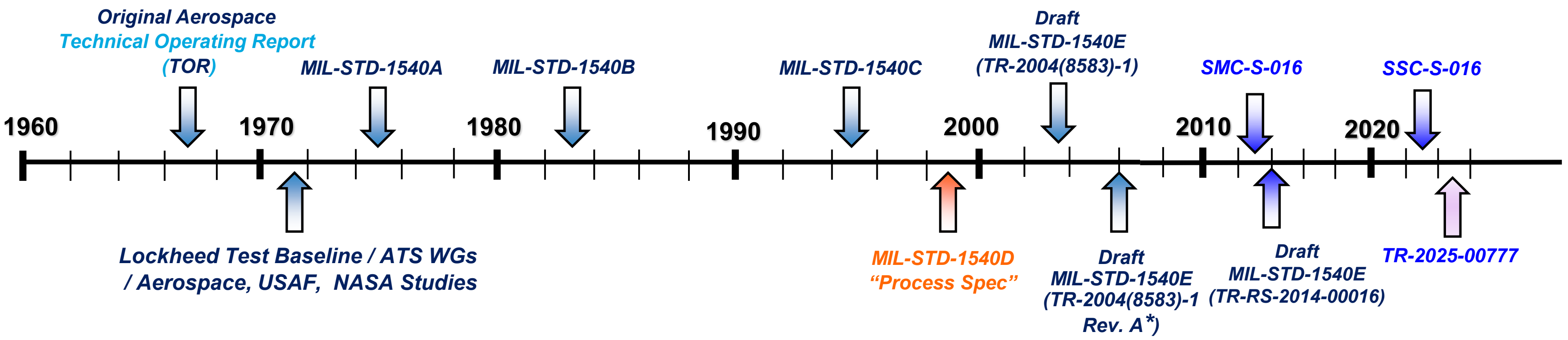
- Aerospace Corporation technical report TR-RS-2014-00016
  - *Same requirements as SSC-S-016*
  - *Designed to verify robustness of launch and space vehicle design and workmanship*
    - *Ensure the vehicle survives launch and operating environments and performs its mission*
    - *Find latent functional and performance defects at the lowest possible level of assembly where test perceptivity is better, and program impacts associated with repairing defects are lesser*
    - *Verify that flight hardware will operate in the presence of, and following, exposure to test environments*

- Follows historical precedent of MIL-STD-1540A, B, and C
  - *Updated to reflect current data and practices*

- Conservative and generic - intended to be tailored

- Tailored document used as a mission assurance compliance document
  - *Provides uniform definitions and environmental ground testing requirements*
  - *Used as source of contractual compliance requirements*
  - *Provides baseline for the development of tailored, program specific, test requirements*

Timeline of MIL-STD-1540 & SSC-S-016 Publish Dates



- SSC-S-016 is the next revision of the MIL-STD-1540 line
  – With each revision updating requirements with industry experience
  – The baseline for SMC-S-016 was MIL-STD-1540B due to its wide acceptance by testing community
- SSC-S-016 replaced SMC-S-016 when SMC became SSC (no differences in content)
  – A revision to SSC-S-016 is expected soon
    - The revision has been published as Technical Report (TR)-2025-00777
  – As compared to SMC-S-016, the revision has requirements that are generally less stressing but still maintain baseline test effectiveness goals

SSC-S-016 Environment Test Requirements

- Environmental ground testing requirements at
  - *Units*
  - *Subsystems*
  - *Vehicles*

Environment	Unit	Subsystem	Vehicle
Pre-, During, & Post-Environmental Tests	Inspection Performance	Inspection Performance	Inspection Performance
Propulsion / Pressure	Leakage Pressure Burst Pressure [1]	Leakage / Pressure	Leakage / Pressure
Dynamics	Shock Vibration Acoustic Acceleration Static Load [2]	Shock Random Vibration Acoustic Static Load Mode Survey [3]	Shock Random Vibration Acoustic Mode Survey [3]
Mechanical		Separation and Deployment [3]	Separation and Deployment [3]
Thermal	Thermal Cycle Burn-In Thermal Vacuum	Thermal Vacuum Thermal Balance [3]	Thermal Vacuum Thermal Balance [3]
Climatic	Climatic		
EMC	EMC	EMC	EMC
Life	Life		

[1] Burst pressure testing also verified proof pressure
[2] Static load testing also includes proof load verification
[3] Performed at either subsystem or vehicle levels, not both

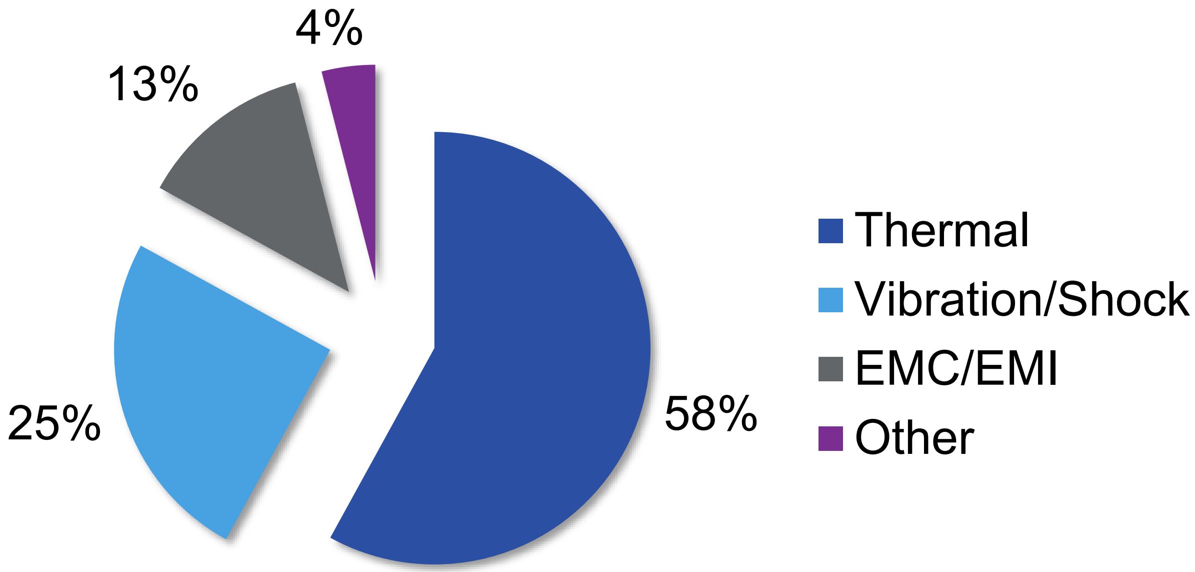
Unit Acceptance Tests – SSC-S-016

Test	Reference paragraph	Suggested Sequence	Electrical and Electronic	Antenna	MMA	Solar Array (Panel)	Battery[12]	Pressure Component	Pressure Vessel	Thruster	Thermal	Optical	Structural Components
Inspection	4.6	1, 15	R	R	R	--	R	R	R	R	R	R	R
Wear-In	6.3.1	2	--	--	R	-	ER	R	--	R	--	--	--
Specification Performance[1]	6.3.2	3, 14	R	R	R	R	R	R	R	R	R	R	ER
Leakage	6.3.3	4, 7, 12	ER	--	R[11]	--	R	R	R	R	ER[4]	--	--
Shock	6.3.4	5	ER	--	ER	--	ER	ER	--	ER	-	ER	--
Vibration or Acoustic[2]	6.3.5 6.3.6	6	R[8]	R	R	R	R[6]	R[6]	ER	R	ER[3]	R	ER
Thermal Cycle	6.3.8	8	R[7][8]	ER	ER	ER	ER	ER	ER	ER	ER	ER	ER[3]
Thermal Vacuum[7]	6.3.9	9	R	R	R	R[10]	R[6]	R[6]	ER	R	R	R	--
Proof Pressure	6.3.12	10	ER	--	ER	--	R	R	R	R	ER[4]	--	--
Proof Load	6.3.11	11	--	ER	ER	--	ER	ER	ER	--	--	--	R[3]
EMC[5]	6.3.13	13	ER	ER	--	ER	ER	ER	--	--	--	--	--

R Required
ER Evaluation required (see 6.3).
(1) Performance tests shall be conducted prior to, during, and after each environmental test, as appropriate.
(2) Vibration or acoustic required, with the other discretionary.
(3) Required only on composite and/or bonded structures.
(4) Required for sealed or pressurized units (such as heat pipes).
(5) Required when there is less than 12 dB margin.
(6) Evaluation required for silver-zinc batteries
(7) See 4.10.2 for exemptions.
(8) Burn-in required.
(9) Thruster thermal vacuum requirement may be satisfied with hot fire testing.
(10) Thermal vacuum testing of solar panels may be performed on solar arrays.
(11) Required only for pressurized or hermetically sealed units.
(12) Safety device testing required for lithium-ion batteries.

Unit Level Environmental Testing

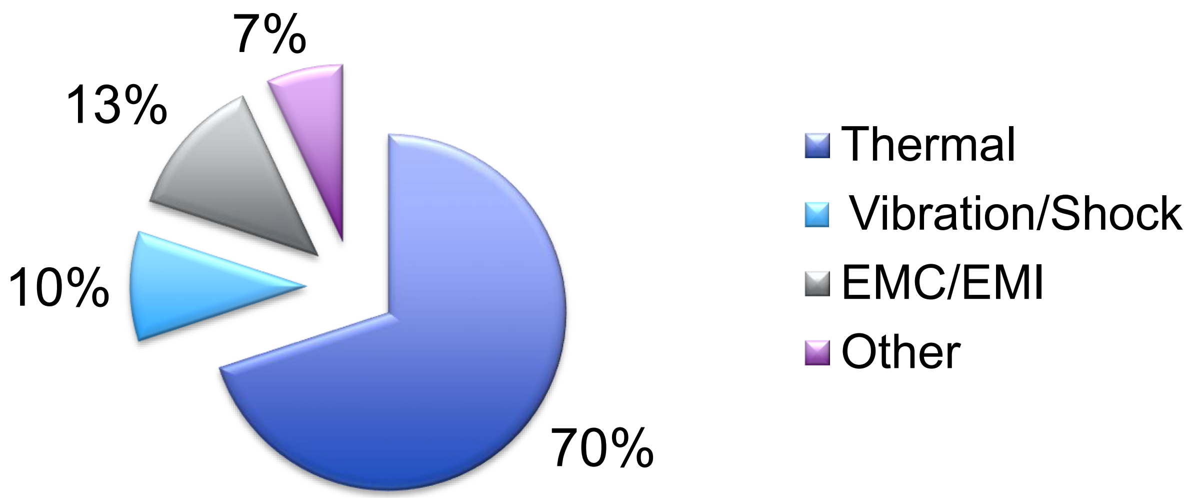
Typical *Distribution of Failures*



- All tests are important and required, regardless of the number of failures found in each test
- Each test can identify unique failures not found in other tests
  - *Hard to justify an operational failure that was missed because a test was weakened or omitted*

Vehicle Level Environmental Testing

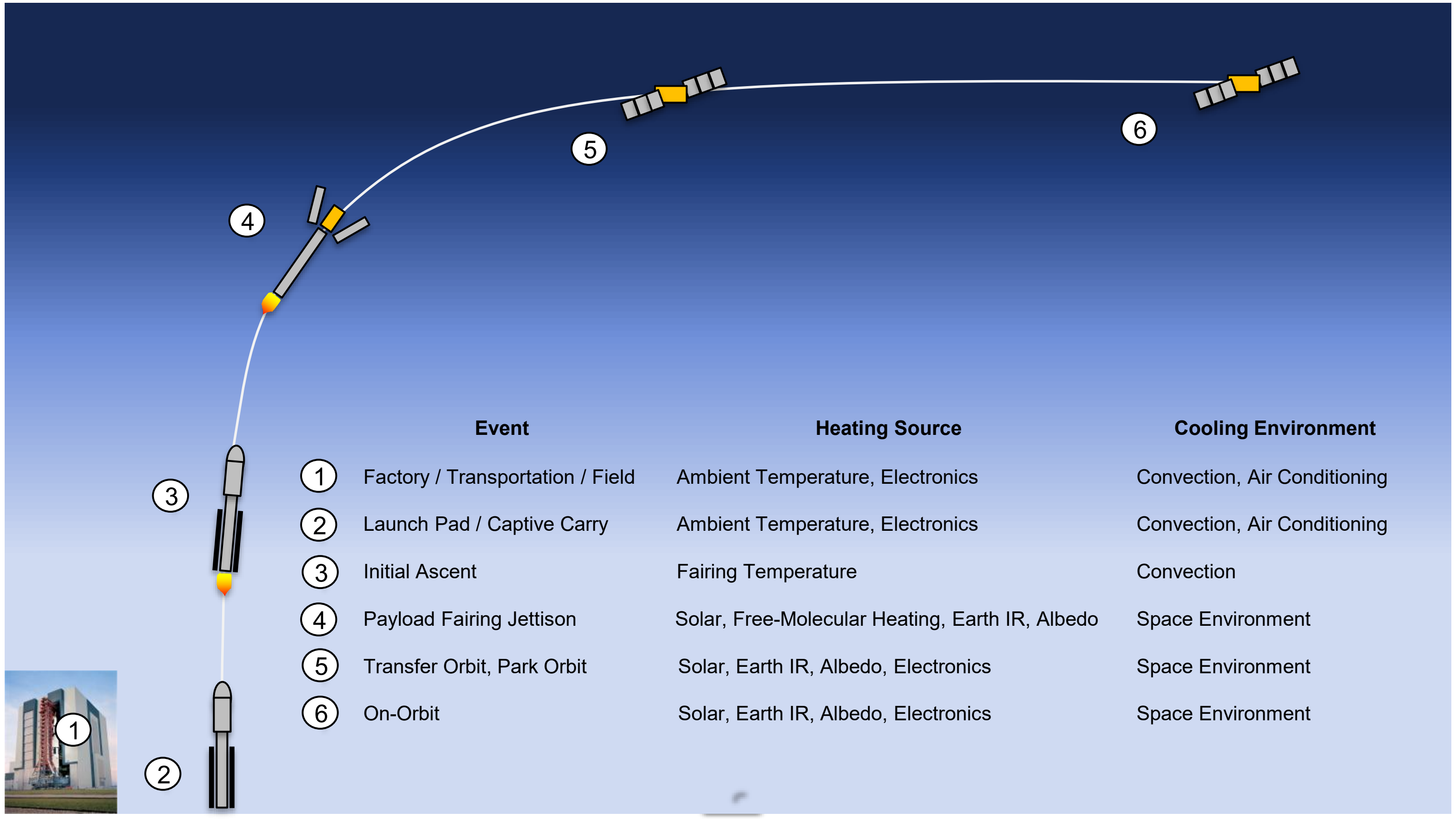
Typical Distribution of Failures



- Vehicle level testing last opportunity to identify defects before flight
- Several categories of failures found during vehicle test
  - *Escapes from lower levels of testing*
    - Even with the rigor of an SSC-S-016 compliant program, escapes from lower levels of testing occur
  - *Failures due to design errors and workmanship defects*

Source of Thermal Environments

Where Do The Environments Come From?



	Event	Heating Source	Cooling Environment
1	Factory / Transportation / Field	Ambient Temperature, Electronics	Convection, Air Conditioning
2	Launch Pad / Captive Carry	Ambient Temperature, Electronics	Convection, Air Conditioning
3	Initial Ascent	Fairing Temperature	Convection
4	Payload Fairing Jettison	Solar, Free-Molecular Heating, Earth IR, Albedo	Space Environment
5	Transfer Orbit, Park Orbit	Solar, Earth IR, Albedo, Electronics	Space Environment
6	On-Orbit	Solar, Earth IR, Albedo, Electronics	Space Environment

https://www.nasa.gov/sites/default/files/s70-54121.jpg

Fundamental Design Requirement for Thermal

Thermal Design Approach

- Design hardware to withstand qualification margins regardless of test strategy to show
  - *Manufacturer's limits envelope junction temperatures*
  - *Temperature limits are maintained with expected material degradation over life*
  - *Thermal gradients do not cause adverse performance*
    - Delamination, debonding, etc.
    - Unacceptable coefficient of thermal expansion mismatches
    - Significant flight deployment failures
  - *Heat transfer paths with ample capabilities*

- Provide analytical margin for possible multiple retests

SSC-S-016 Thermal Test Practices and Requirements

Objectives of Thermal Testing

- Environmental Stress Screening (ESS)
  - *Subjects hardware to physical stresses and forces flaws that are not ordinarily apparent into observable failures*
    - Flaws are latent defects which could cause premature component failure
    - Repaired or replaced prior to usage in flight
  - *Involves environments that will be more severe than expected in usage*

- Performance Verification
  - *Demonstration that a unit, subsystem or space vehicle operates within specifications within a flight-like environment*
    - Accomplished during functional tests in which equipment is exercised over operational scenarios
  - *Realistic environment is achieved during the test*

Objectives of Thermal Testing (continued)

- Turn-on capability
  - *Demonstration that a unit can be activated within a severe thermal environment*
    - Under severe temperatures, changing temperatures and thermal gradients

- Survival demonstration
  - *Survival temperatures*
    - Those temperatures over which a unit is expected to survive
      - *Most severe, but realistic temperature range*
    - The unit must demonstrate that it can be turned on at these temperatures, and although performance does not need to meet specification at these temperatures, the unit must not show any performance degradation when the environment or unit temperatures are returned to the operational temperature range of the unit

- Thermal model correlation
  - *Thermal data obtained in test to be compared with thermal model predictions*
  - *Verification of thermal model capabilities for predicting flight temperatures*

Test Levels

- Acceptance testing
  - *Demonstrate the acceptability of each deliverable item*
  - *Emphasis of acceptance testing is on verification of workmanship and demonstration of flight-worthiness*

- Qualification testing
  - *Demonstrate the design, manufacturing process, and acceptance program*
  - *Emphasis of qualification testing is on verification of the design and not the workmanship*
  - *Testing is performed at environmental conditions more severe than expected in flight*
    - Performed prior to acceptance testing
    - Performed on non-flight equipment

- Protoqualification testing
  - *Reduced qualification testing of flight hardware*
    - Reduces costs of building qualification hardware and schedule time
  - *Also known as protoqual testing or flight-proof testing*
  - *Thermal environment is typically between that specified for acceptance testing and qualification testing*

- Development testing
  - *Engineering tests used to gain information about the design*
  - *Can occur at any point in the test sequence, but typically before formal qualification testing and before unit level testing*

Thermal Environmental Tests specified in SSC-S-016

- Thermal tests have different purposes
  - *Environmental stress screening (ESS) forcing latent defects into observable failures*
  - *Performance verification*
  - *Survival and turn-on demonstration*
  - *Thermal control subsystem (TCS) verification*

	Thermal Cycle (TC)	Burn-In (BI)	Thermal Vacuum (TV)	Thermal Balance (TB)
Test Environment	Hot/Cold cycling in ambient air or gaseous Nitrogen	Hot/cold cycling or steady hot in air or gaseous Nitrogen	Hot/Cold cycling in vacuum	Hot/cold simulations in vacuum
Test Distinction	Enhanced convection so transitions can be rapid	Continuation of TC	Realistic simulation of flight thermal environments	Part of TV with simulated flight conditions
Primary Purpose	ESS	ESS	Performance Verification, Survival/Turn-On	Verification of TCS, TCS Model Correlation
Test Level				
Unit	Primary Test	Primary Test	Primary Test (Vac-Sensitive)	-
Subsystem	Optional	-	Primary Test	Some subsystems
Vehicle	Optional	-	Primary Test	Primary Test
Test Hardware				
Qualification	Yes	No	Yes	Yes
Protoqual	Yes	Yes	Yes	Yes
Acceptance	Yes	Yes	Yes	No

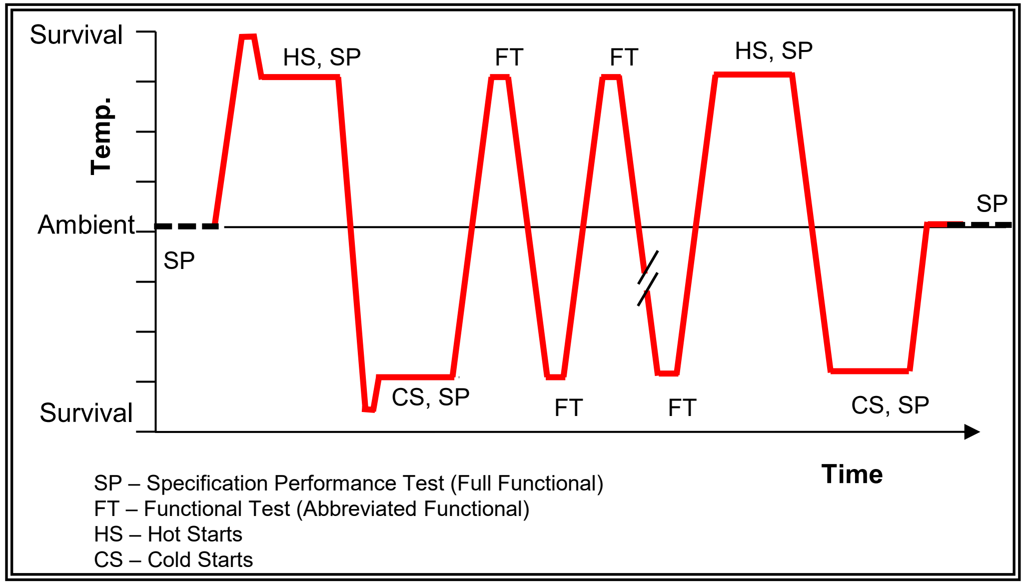
Thermal Test Purposes

- Demonstrates capability to perform within the specified thermal environments and screens for quality of workmanship
- Thermal cycling and thermal vacuum tests are not interchangeable
  - *Different physics of failure*
  - *Different test objectives*

Test Verification	Thermal Cycle	Thermal Vacuum
Flight-like performance	Not Perceptive	Very Perceptive
Thermal control – Thermal balance	Not Perceptive	Perceptive
Arcing	Not Perceptive	Perceptive
Multipaction & Corona	Not Perceptive	Perceptive
Material outgassing	Not Perceptive	Perceptive
Latent defects & Failure propagation	Perceptive	Perceptive
Thermal stress effects	Very Perceptive	Perceptive
Hardware & Integration	Perceptive	Perceptive
Electrical intermittences	Perceptive	Perceptive

Important Unit Thermal Test Parameters

Thermal Profile



- Test temperature range
- Number of test cycles
- Temperature transition rate
- Thermal dwell
  - *Time spent initially at each temperature level before functional testing*
  - *Ensures all areas are at the test temperature before functional testing*
- Thermal soak to ensure adequate performance/functional test durations
- Operation of the unit during all test phases
- Hot and cold starts to demonstrate turn-on capabilities
- Performance testing on first/last hot/cold cycles and functional testing hot/cold on intermediate cycles

Temperature range and number of cycles are the most important test parameters for establishing screening effectiveness (detecting failures)

Thermal Chambers for Unit Testing

- Thermal cycle chambers
  - *Internal fans circulate environment for rapid rates of temperature change*
  - *Walls thermally heated and cooled*
    - Testing capabilities over wide temperature ranges with humidity-controlled air or gaseous Nitrogen (GN_2)
    - Temperature and humidity measurements are provided in the chamber wall

- Thermal vacuum chambers
  - *Roughing pumps and cryopumps / turbomolecular pumps achieve 10^{-7} Torr*
  - *Temperatures range from LN_2 (-190°C) to typically +150°C*
  - *2 to 8 feet in diameter typically*

Thermal Cycle Chambers

JPL Thermal Chamber "T-1"

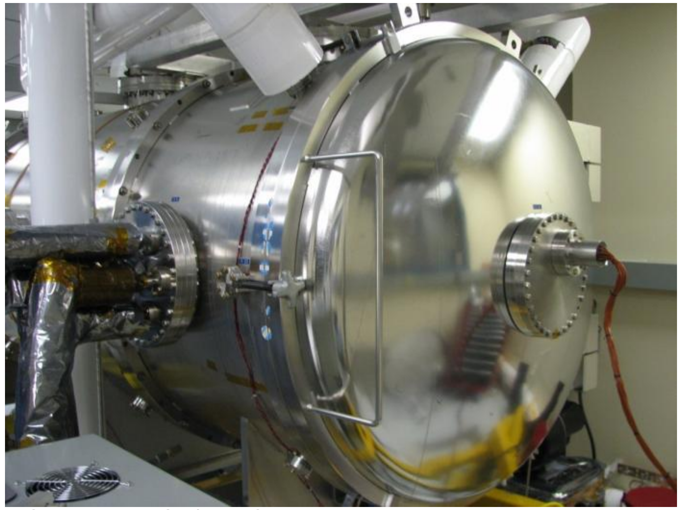
Courtesy NASA/JPL-Caltech

Courtesy NASA/JPL-Caltech

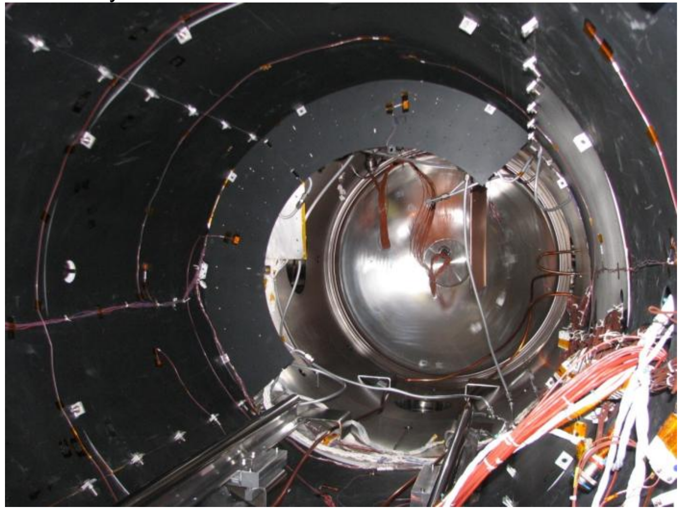
Thermal cycle or thermal conditioning chambers are typically commercial items

Thermal Vacuum Chamber

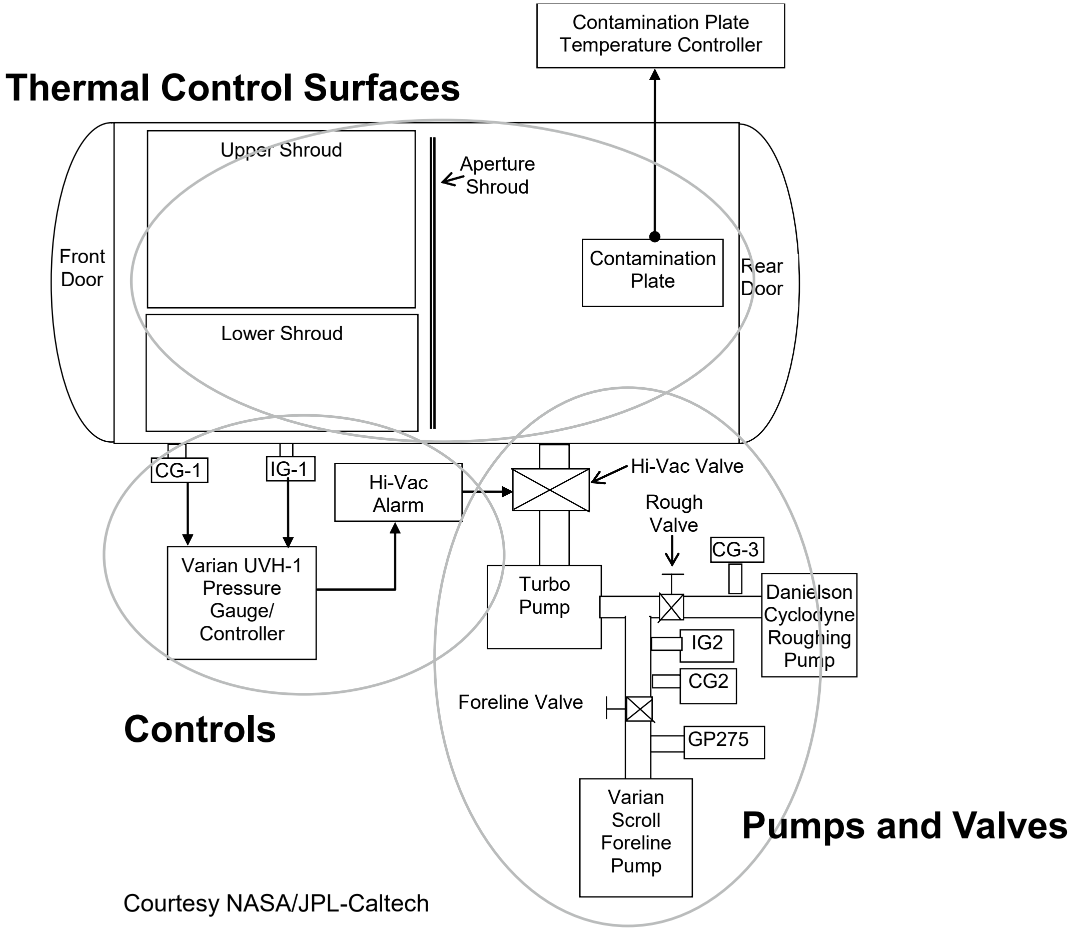
JPL 4 Foot Vacuum Chamber “TV-24”



Courtesy NASA/JPL-Caltech



Courtesy NASA/JPL-Caltech



Courtesy NASA/JPL-Caltech

Thermal vacuum chambers employ COTS technology but are often custom designs

Unit Thermal Cycling in Ambient or Vacuum

- Physics of failure
  - *Plastic strain/thermal expansion mismatch/fatigue expressed by Coffin Manson/Miner's rule/Temperature (low cycle fatigue) – time related degradation*
  - *Failure Detection is significant for first 20 cycles over the design temperature range of electronic units*

- Test parameters
  - *Temperature extremes and range/number of cycles*
  - *Temperature transition rate*
  - *Operation/non-operation profile*
  - *Dwell at temperature extremes (Burn-In)*
  - *Ambient pressure or vacuum*

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- Perform after vibration
  - *Latent vibration defects may precipitate in the thermal tests*
  - *Thermal testing allows more time to operate the unit while exposed to the test environment and optimizes flaw detection*

Thermal Failure Mechanisms in Electronic Parts

Part Type	Thermal Trigger	Failure
Semiconductor Devices and ICs	Temperature cycling	Cracking of die, delamination at chip-resin interface, Hillock formation
	Temperature cycling, thermal shock	Die-bond defect, package-seal defect, CTE mismatch, substrate defect
	Thermal shock	Cracking of resin
	High Temperature, thermal shock,	Cracking of encapsulation
	High storage temperature	Metallization defect, corrosion, bulk-silicon defects
	High temperature in accelerating test	Electromigration
	Low temperature	Increase in leakage current, hot-electron effects
PW Boards	High temperature, thermal shock	Discoloration, warping, delamination, measling
Conformal Coatings	High temperature, thermal shock	Cracking of coating (lack of protecting)
Resistors	Temperature cycling, thermal shock, high temperature	Discoloration, charring, change in resistance, open circuit, melting
Inductors/Transformers	Temperature cycling, thermal shock, high temperature	Open circuit
Capacitors	Elevated temperature life test	Change in capacitance, dielectric strength, insulation resistance; surface cracking
Electrolytic Capacitors	Thermal shock, high temperature	Damage to hermetic seal, drying or leakage of electrolyte
Chip Capacitors	Temperature cycling	Cracks in body/attachment joints
Crystal Oscillators	Temperature change	Drift in oscillation frequency
All electronic parts (and cables/connectors)	Thermal shock, high temperature	Damage to mechanical joints, loosening of terminations, softening of insulation, opening of solder seals, change in electrical characteristics

Basis for Unit Level Temperature Levels

- Unit test temperatures use worst case prediction range with appropriate ±11C thermal uncertainty margin, or (whichever is more severe)
  - *Default temperature levels for minimum environmental stress screening (ESS) of electronic units*
    - Acceptance -24°C to +61°C (85°C range) (-11°F to +142°F)
    - Protoqualification -29°C to +66°C (95°C range) (-20°F to +151°F)
    - Qualification -34°C to +71°C (105°C range) (-29°F to +160°F)

- Temperature range well understood and accepted by industry

- Source of -24°C to +61°C acceptance temperature range originates from position that an 85°C operating range is
  - *Characteristic of well-built electronic parts*
  - *Verified by the Coffin-Manson[1] equation calculations*

- Typically, only occasion for tailoring is when thermal limits prevent performance over these ranges
  - *Cycles can be increased to maintain screening strength*
  - *Commonly associated with payloads, rather than bus units*

Reference: 1 "Failure Modes And Mechanisms In Electronic Packages" By P. Singh, Puligandla Viswanadham

Hot and Cold Temperature Design Limits

- Hot temperature design limits
  - *Manufacturing Specification for part junctions: 150°C to 175°C (typical)*
    - Recommended Operating Conditions (ROC): 140°C to 150°C (typical)
    - Derated limits to improve reliability: 105°C to 125°C (MIL-STD-1547)
  - *Hot temperatures are a primary reason for electronic failures*
    - Cracking of part casing, solder joints, coatings, wiring

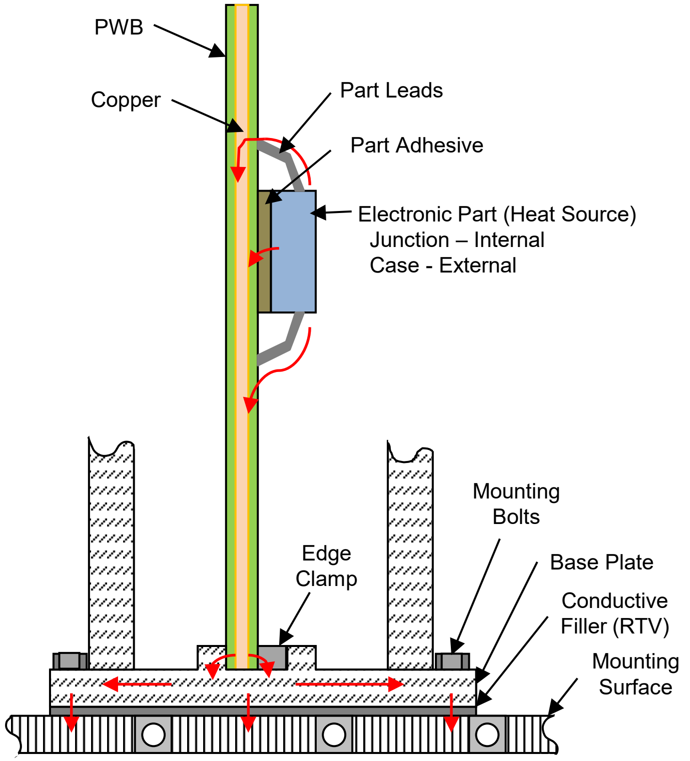
- Cold temperature design limits
  - *Result of applying screening ranges to hot temperature limits*
    - Common qualification temperature design range: -40°C to +70°C
    - SSC-S-016 adopted a 105°C qualification screening range (85°C acceptance screening range)
  - *Excessive cold temperatures can result in electronic failures*
    - Cracking in bonds and wires
    - Coefficient of thermal expansion mismatch in materials
    - Glass transition temperature - deformation and hardening of materials

Thermal Design Based on Design Limits

- Unit thermal control subsystem to
  - *Keep parts below derated temperature limit under worst case operating conditions*

- Design board and mountings to minimize the temperature increase from unit base plate to the hottest part location
  - *Part interface materials, adhesives and leads*
  - *Copper traces and vias*
  - *Wedgelock and edge clamps*

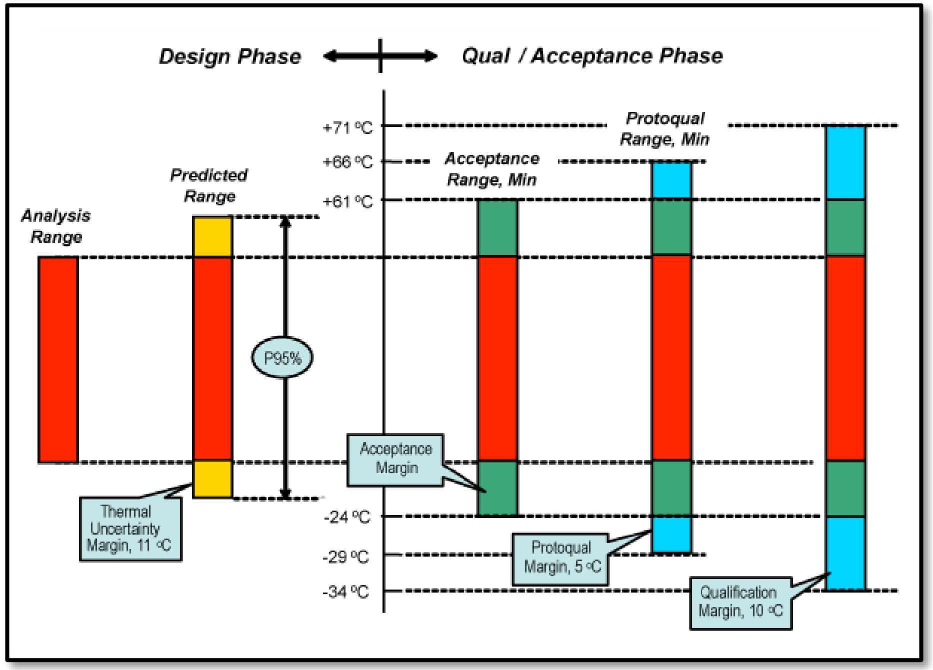
- Results in maximum temperature range (cold to hot) for effective ground testing/screening
  - *If maximum base plate temperature is ~70°C, then ground screening can be performed with commonly used screening temperature ranges*
    - 85°C for acceptance hardware
    - 105°C for qualification hardware



Establishing Thermal Test Parameters

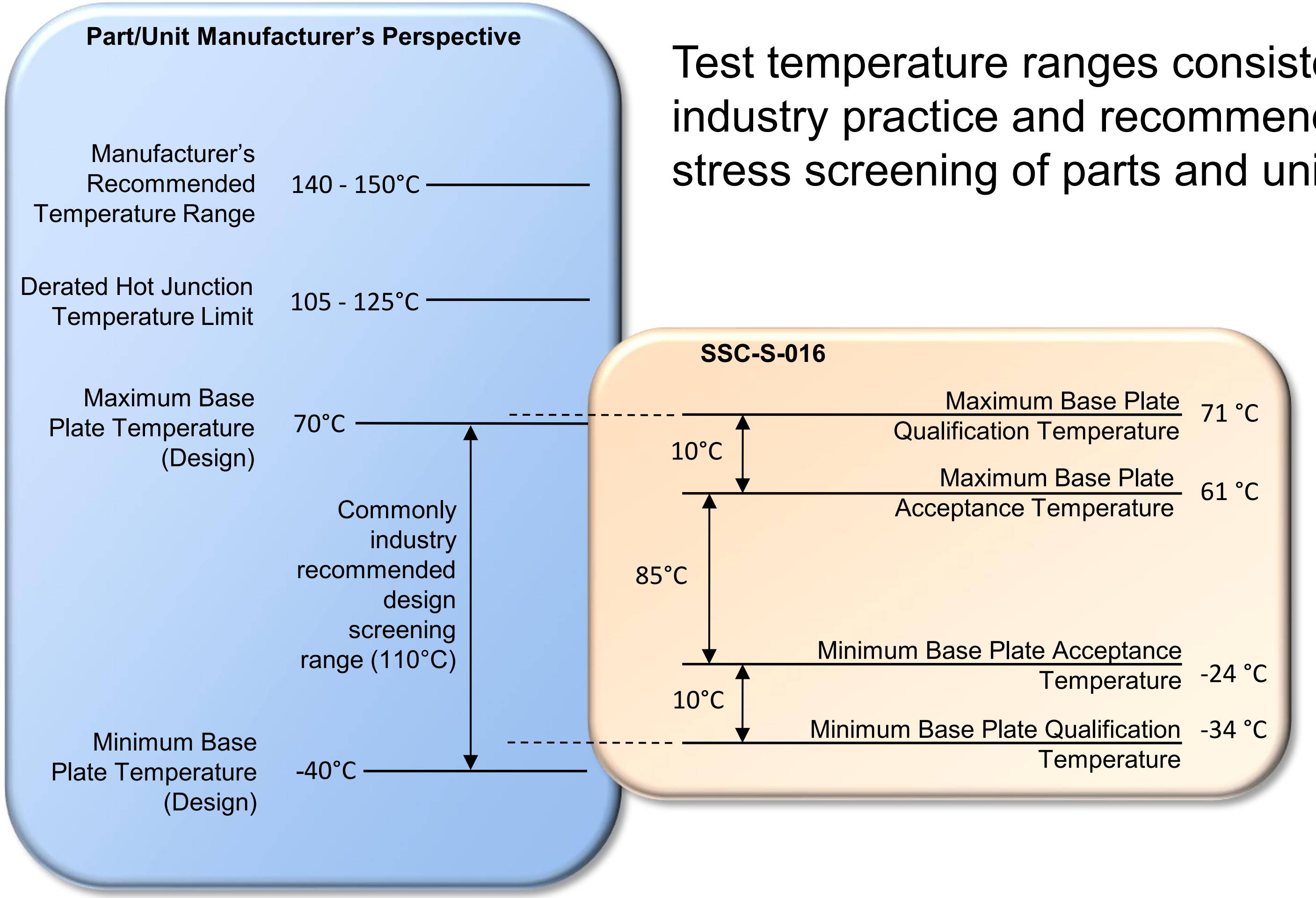
Temperature Levels

- Temperature Ranges and Levels
  - *Basis of the SSC-S-016 acceptance temperature range and levels is the goal of having 95 percent of flight temperatures within ±11°C of thermal model predictions*
    - Flight data over the past three decades has demonstrated that the ±11°C thermal uncertainty margin necessary to maintain units within acceptance ranges
      - *Basis of the* SSC-S-016 ±*10°C qualification margin was a general agreement by contractors as to additional temperature range needed to further stress flight hardware without incurring damage or significant reductions in life or performance*
      - *Protoqualification margin was established by reducing the qualification in half*



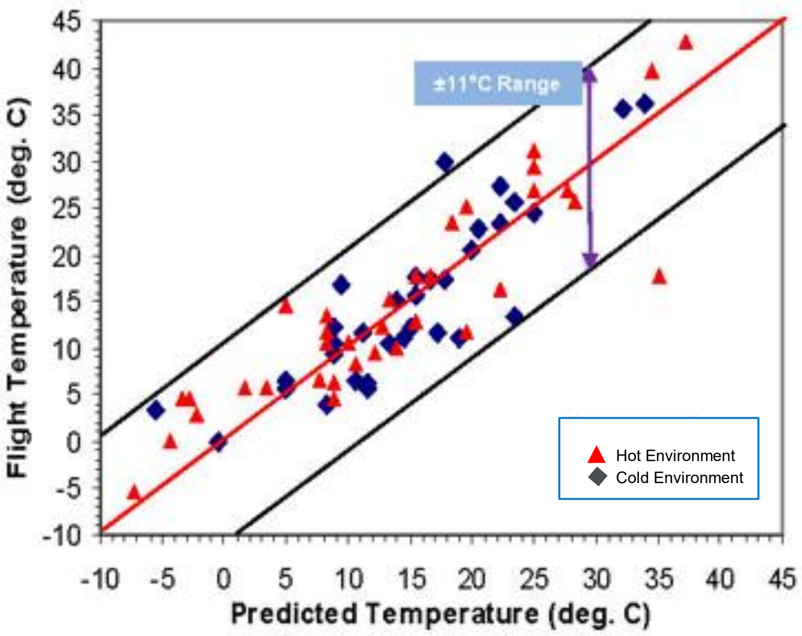
Tying SSC-S-016 Test Temperature Levels to Industry Practice

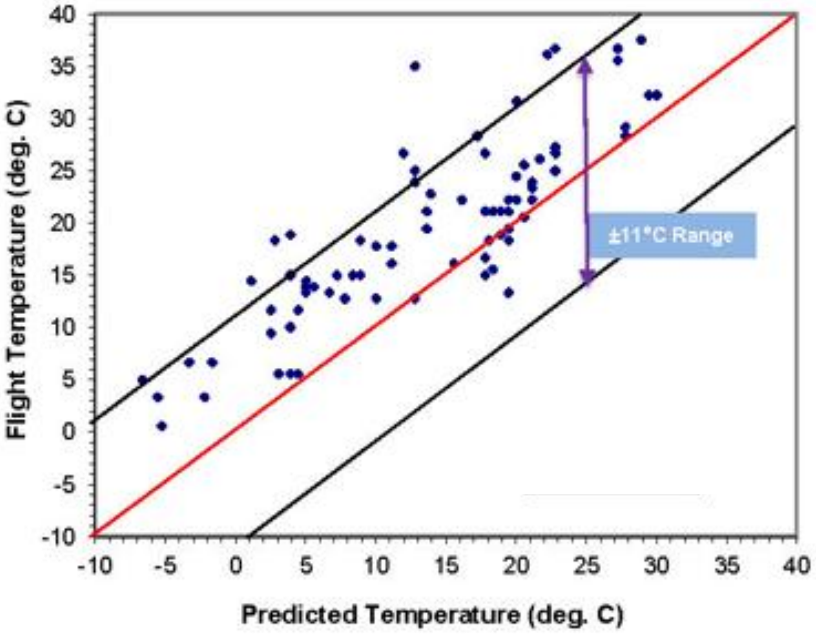
Test temperature ranges consistent with industry practice and recommendations for stress screening of parts and units



Basis of Unit Thermal Uncertainty Margin

- Comparisons made between flight data and BOL model predictions show need for ±11°C (±20°F) thermal uncertainty margin (±11°C gives 2 sigma screening)
- Wide variety of programs; consistent with ESA and JAXA data over 30 years
  - *Fundamental thermal solution approaches have not changed*
  - *Power density (W/m^2) on current vehicles is significantly higher than on vehicles 30 years ago*
- For Class A/B missions, thermal analysis predictions should include ±11°C uncertainty



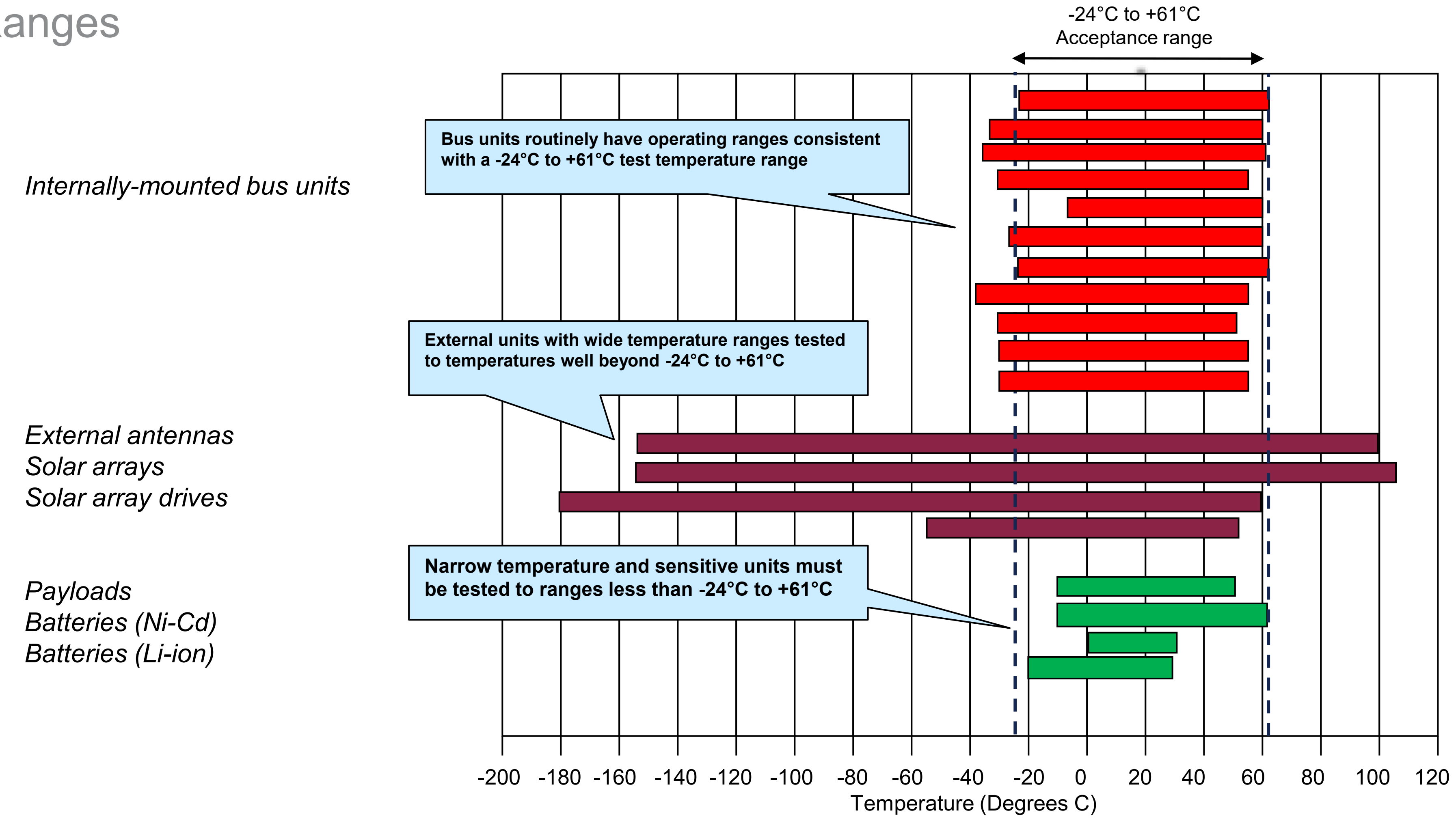


J. Welch, *Assessment of Thermal Uncertainty Margin from Flight Data Comparison with Thermal Model Predictions,* 24th Aerospace Testing Seminar, USAF/The Aerospace Corp., Manhattan Beach, CA ,8 April 2008

Satellite data over 30 years indicates consistent uncertainty in predictions vs. flight of ±11°C

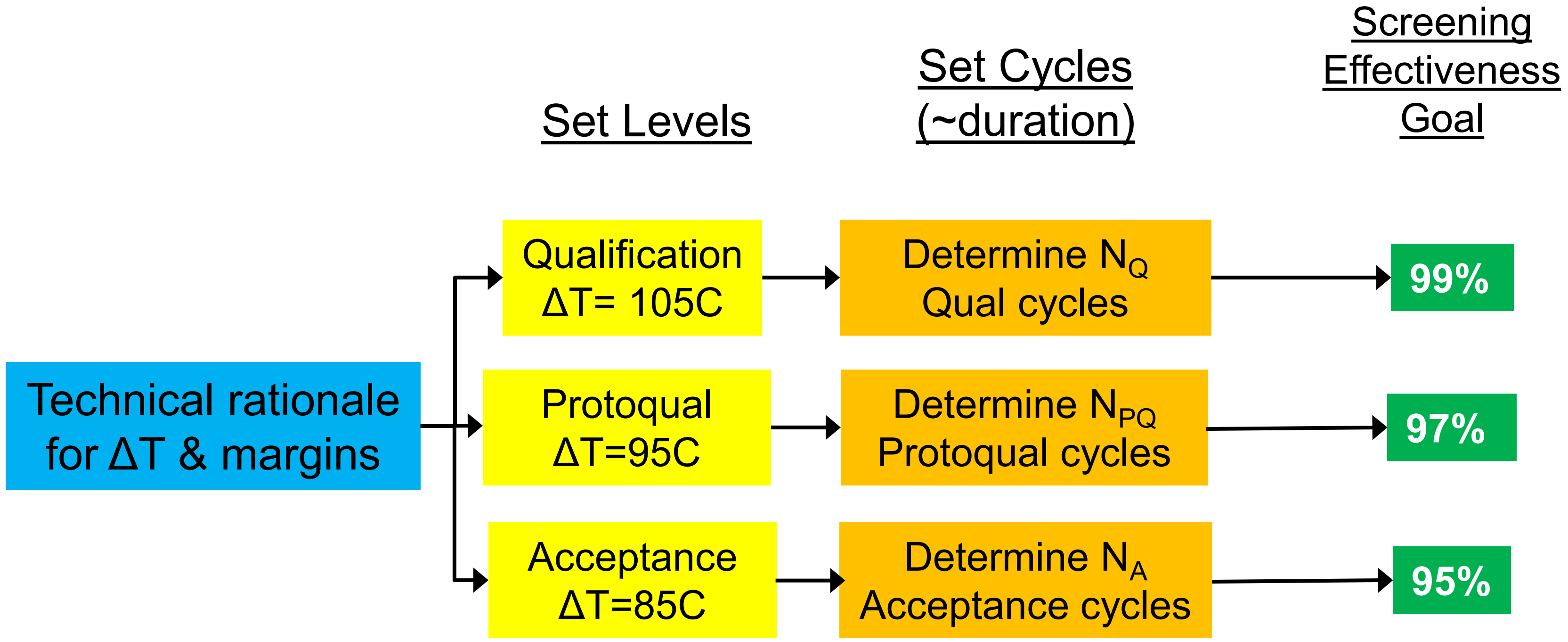
Temperature Ranges for Unit Thermal Testing

Typical Ranges



Many electronic units have operating temperature limits consistent with a -24°C to +61°C test temperature range

Tying Thermal Cycling Range to Number of Cycles



Task is to determine the number of cycles over a prescribed test temperature range to achieve screening goals

Thermal History

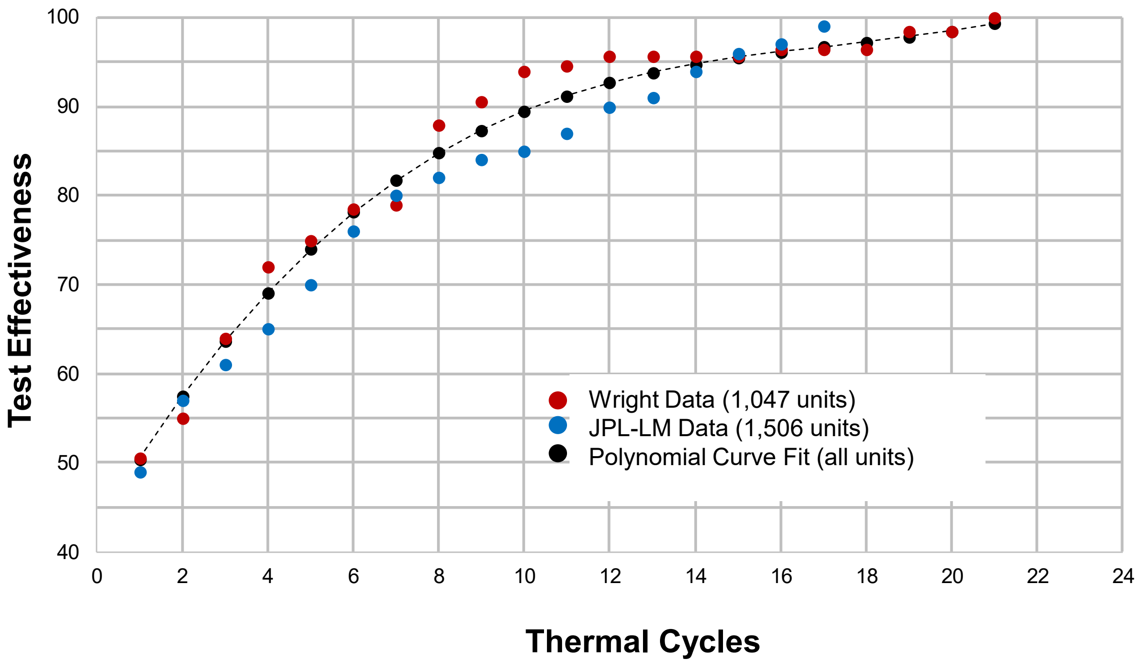
Unit Thermal Testing – Test Duration

- Unlike the test temperature range, the minimum number of test cycles is often debated. The number of cycles required in thermal testing has changed between versions of MIL-STD-1540 or SSC-S-016
  - *SSC-S-016 test durations*
    - For acceptance testing, fewer cycles required
    - Burn-In (BI) hours (accrued during unit thermal cycling and thermal vacuum) reduced
  - *Duration requirements have been reduced when technical data can justify the change*

Test	1540A	1540B	SSC-S-016 2023	SSC-S-016 2026
Acceptance	8 TC + 1 TV + 9 BI (18 Total Cycles) (300 Hr BI)	8 TC + 1 TV + 9 BI (18 Total Cycles) (300 Hr BI)	10 TC + 4 TV (14 Total Cycles) (200 Hr BI)	10 TC + 4 TV (14 Total Cycles) (150-175 Hr BI)
Protoqualification	N/A	24 TC + 3 TC (27 Total Cycles) (300 Hr BI)	16 TC + 4 TV (20 Total Cycles) (200 Hr BI)	16 TC + 4 TV (20 Total Cycles) (150-175 Hr BI)
Qualification	24 TC + 3 TV (27 Total Cycles)	24 TC + 3 TC (27 Total Cycles)	23 TC + 4 TV (27 Total Cycles)	23 TC + 4 TV (27 Total Cycles)

Rationale for Unit Thermal Cycles

Unit test data from Wright and JPL-LM study



Wright, C. P, *Test Effectiveness of SMC-S-016 Unit Acceptance Thermal Testing*, 26th Aerospace Testing Seminar, March 2011.

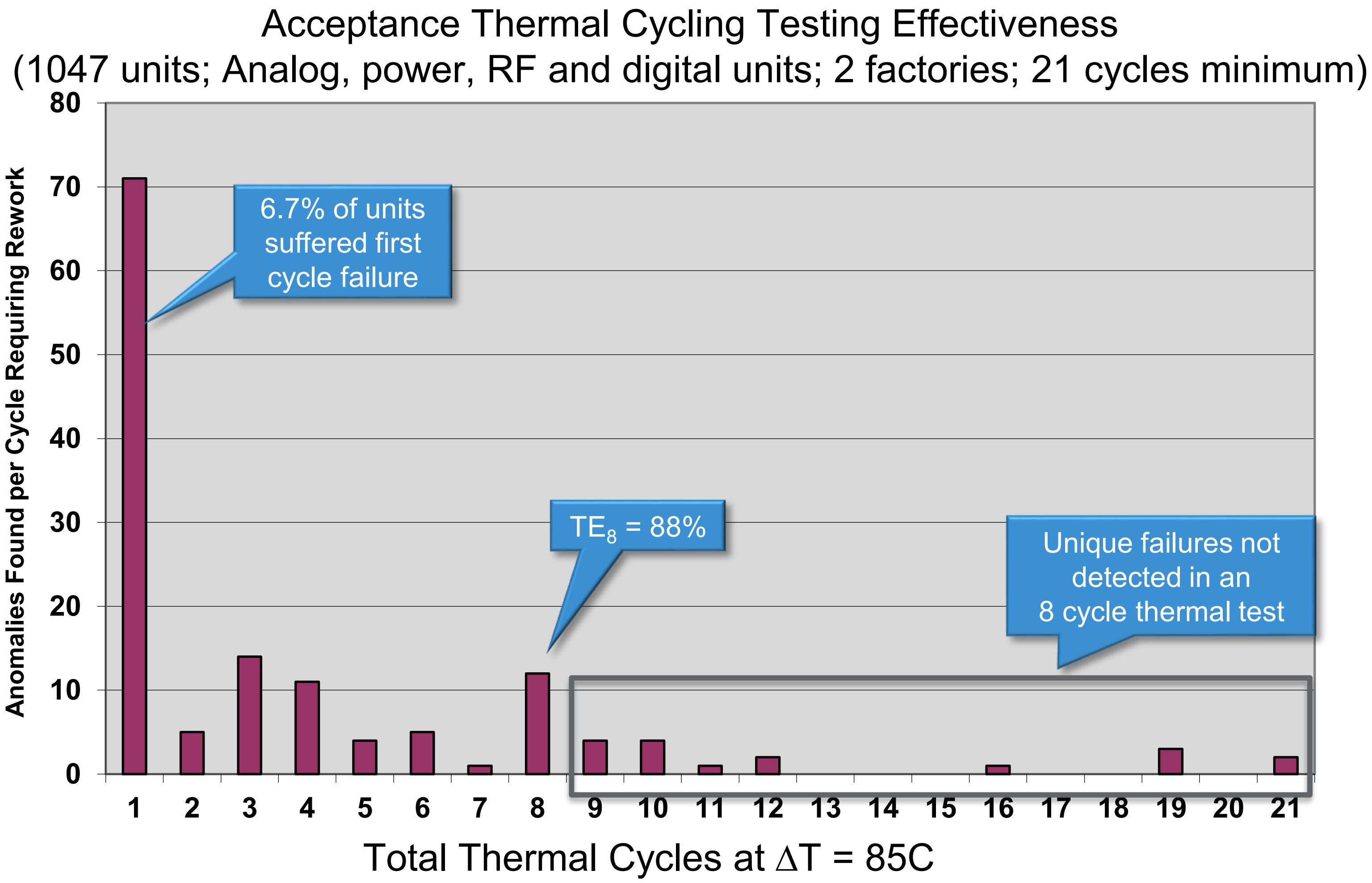
Cornford, S. and Plumb, P., Thermal Testing Study Report, Jet Propulsion Laboratory Report R-11958, October 1994.

- Half of failures are found on first cycle
- 95% test effectiveness at 14 cycles consistency
- “Knee-in-the curve” at about 10 cycles separates levels on uncertainty
  - *Higher uncertainty in test effectiveness below 10 cycles*

Unit thermal test to <10 cycles carries higher uncertainty in test effectiveness

Unit Thermal Cycling Failures

Aerospace Study Of 1,047 Units – Unique Failures Only

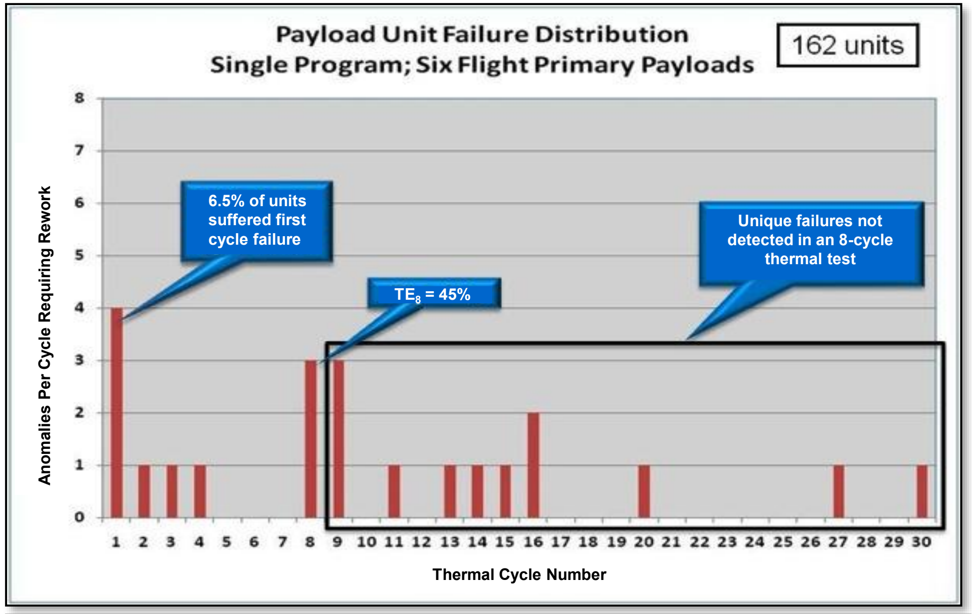


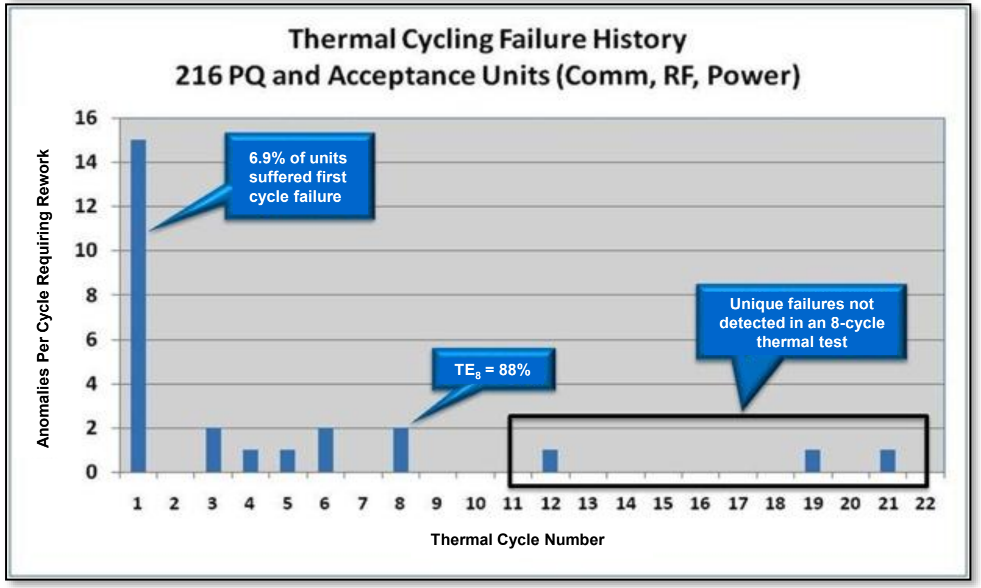
Wright, C. P, *Test Effectiveness of SMC-S-016 Unit Acceptance Thermal Testing*, 26th Aerospace Testing Seminar, March 2011.

Consistent Unit Thermal Test Anomaly Behavior

- Across different unit types from difference sources, data is consistent showing a significant number of failures are detected after 8 cycles

- 8 cycles is simply not enough to achieve 95% test effectiveness

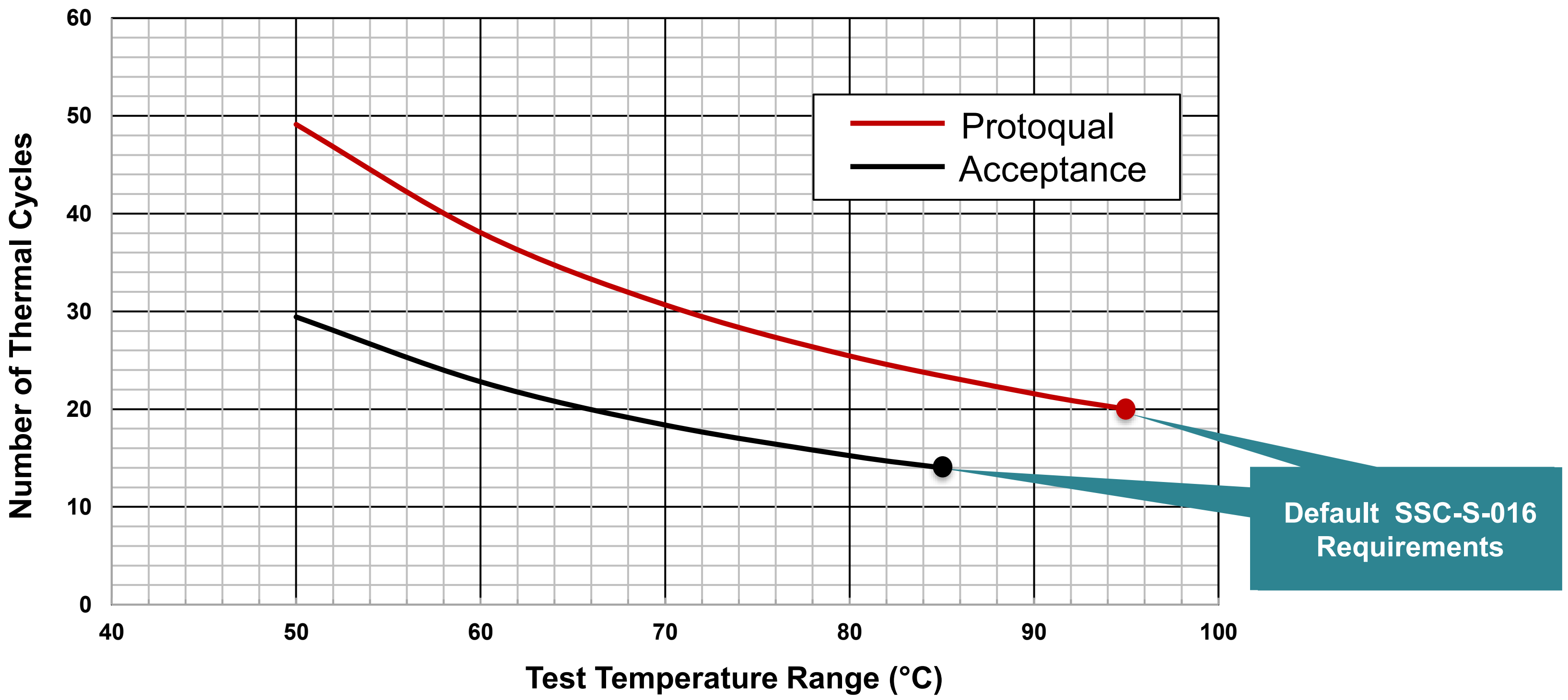




Equivalent Thermal Stress Screening

Mitigation Options for Acceptance and Protoqual

- When unit test temperature ranges are less than SSC-S-016 requirements, the number of cycles is increased to achieve the same screening/fatigue exposure (based on exponent of 1.4 in SSC-S-016 equations)



Proposed Tailoring You May See

Unit Thermal: Fewer Acceptance Thermal Cycles at Unit Level

- Tailoring Suggestion
  - *Perform fewer acceptance thermal cycles. Eight cycles often suggested. "Are eight cycles good enough?"*

- Baseline Rationale
  - *Historical data show SSC-S-016 compliant, 14 cycle, 85°C thermal cycling provides 95% (2 sigma) test effectiveness after protoqualification*
  - *Data show 8 cycle, 85°C thermal cycling range provides 85% test effectiveness; additional latent defects escape to vehicle level*
  - *8 cycle thermal testing allows 2-4 additional latent defects to escape to AI&T*
  - *Latent defects may not be detected at vehicle level due to decreased thermal test effectiveness of TV test*
  - *Additional 1-3 defect escapes from 8 cycle tests likely to fly*
  - *Impact to flight not knowable a priori*
  - *Card/Slice thermal preconditioning does not satisfy unit cycle requirements*

- Baseline Recommendation
  - *Perform SSC-S-016 compliant 14 cycle, 85°C acceptance thermal testing*
  - *Reduce cycles only if hardware specific data show needed reliability achieved with fewer cycles*

Other SSC-S-016 Thermal Test Requirements

Parameter	Requirement
Operation	Unit operating at temperature plateaus and during transitions Plateaus: performance testing, hot and cold starts, turn-on demonstration Transitions: monitor perceptive parameters for failures and intermittents
Thermal Dwell Time	TC: 1 hour on all cycles TV: 2 hours on first and last cycle, 1 hour on intermediate cycles
Temperature Rate of Change	TC: 3-5°C/minute TV: on average, greater than 1°C/minute (if possible)
Thermal Soak	Total time at each temperature plateau: TC and TV: 4 hours on first and last cycle, 1 hour on intermediate cycles
Failure-Free Performance	Last 3 cycles of TC (or last 3 cycles of TV is no TC is performed)
Burn In	Acceptance and protoqualification of electronic units Total duration of thermal cycle, thermal vacuum, and <u>elevated-temperature</u> operation: at least 200 hrs (at least 100 hrs per redundancy)

SSC-S-016 (2026) will reduce the burn-in duration requirement to 175 hours for internally-redundant units and 150 hours for non-internally-redundant units

Survival and Turn-on

- Performance demonstration function
  - *Demonstrates unit can survive extreme environments and operating conditions, and subsequently perform within specification over a narrower environmental range – flight critical requirement*
  - *Verifies survival and turn-on capabilities for anticipated and contingent flight conditions and environments*
    - Cold conditions following transfer orbit or hot conditions following sun-stare environment
    - Cold safe mode conditions
    - Satellite damage or loss of attitude control or communication during ascent or transfer orbit
    - Failed on/off heater or inadvertent operational mode
  - *Provides performance margin beyond expected flight conditions*

- Stress screening process function
  - *Demonstrates unit is well-designed, has good parts and materials, and is properly manufactured*

- Required for all acceptance units

- Crucial requirement for any unit affecting fault recovery

Proposed Tailoring You May See

Thermal: Dwell Times

- Tailoring Suggestion
  - *Cut back on thermal dwell times at unit and/or SV level to speed up testing*

- Baseline Rationale
  - *Dwell time requirement intended to ensure that all areas of the test article are at the test temperature before functional testing begins*
  - *Temperature sensors are mounted on base-plates or mounting panels away from internal locations. Thermal mass of unit causes internal locations to lag behind external locations in reaching test temperature*
  - *Beginning functional testing when parts are still transitioning results in an under-test situation and possible test anomalies that are unrealistic of flight conditions. These types of failures are nearly impossible to duplicate.*

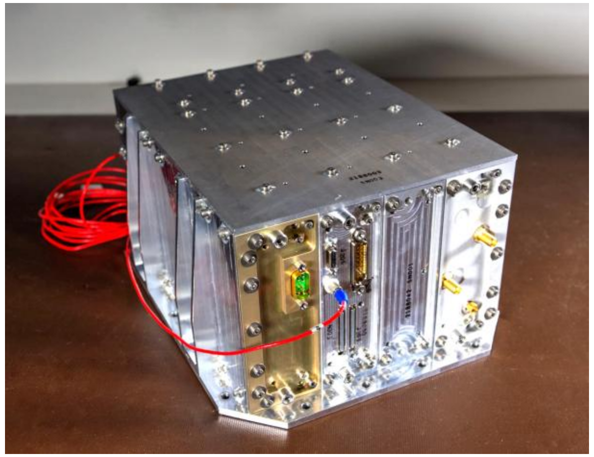
- Baseline Recommendation
  - *Maintain requirement to ensure that test temperatures are properly demonstrated and prevent unrealistic test situations.*
  - *Allow dwell time reduction when data or analysis demonstrate that significantly less time is required to get all areas of test article to test temperature*

Slice/Board Level Test Consideration

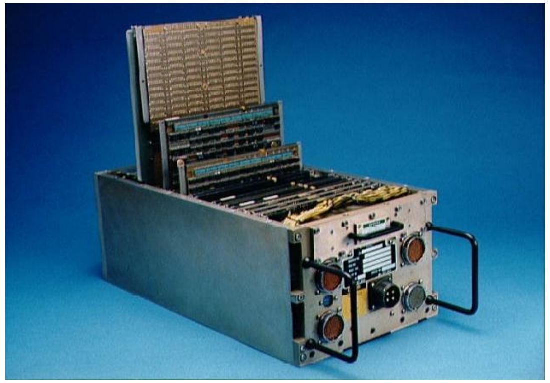
Unit Thermal: Counting Pre-Unit-Level Testing Toward Unit Requirements

- Slice/Board Level Thermal Testing
  - *Performing TC testing on individual slices or boards prior to formal unit-level TC testing*
    - Detect problems early
    - Testing over a very wide temperature range

- Baseline Assessment
  - *As part of tailoring the number of unit cycle requirements, SSC-S-016 will give consideration for slice/board level testing*
    - All slices/boards in the unit are tested
    - Slices/boards are powered on
    - Functional testing performed in a manner consistent with unit testing
    - Anomalies and defects are reported
  - *Credit may be given for an equivalent screening environment up to half the required unit cycle count*
    - Applicable for qual, PQ and acceptance hardware



Electronic Box
[Image courtesy of NASA]



Slices/boards in Electronic Box
[Image courtesy of NASA]

Alternative Approach to Vacuum Testing Electronic Units

- SSC-S-016 thermal test requirements for electronic units

Hardware	TC Test	Burn-In Test	TV Test
Qualification Unit	Required	-	Required
Protoqualification Unit	Required	Required	Required
Acceptance Unit	Required	Required	Required

- Recognized that not all electronics units are sensitive to vacuum environment
  - *Low power units, units with robust heat transfer paths (conductive transfer dominates)*
  - *Temperature gradients and part temperature nearly the same in TV as in TC*

- SSC-S-016 (Paragraph 4.10.2) allows acceptance electronic units to waive the TV test and combine the cycles into the less expensive TC test
  - *When it can be <u>demonstrated</u> that unit design is insensitive to vacuum conditions*
    - Temperatures are nearly identical between vacuum and air environment
    - Performance is unaffected by vacuum conditions
    - No RF or high-voltage components, no part susceptible to arcing, etc.
    - Demonstration required in previous Qual/Protoqual testing

Proposed Tailoring You May See

No Thermal Vacuum Exposure During Protoqual Unit Testing

- Tailoring Suggestion
  - *Do not test protoqual units in thermal vacuum environment if unit is not vacuum sensitive.*
  - *Significant cost savings*

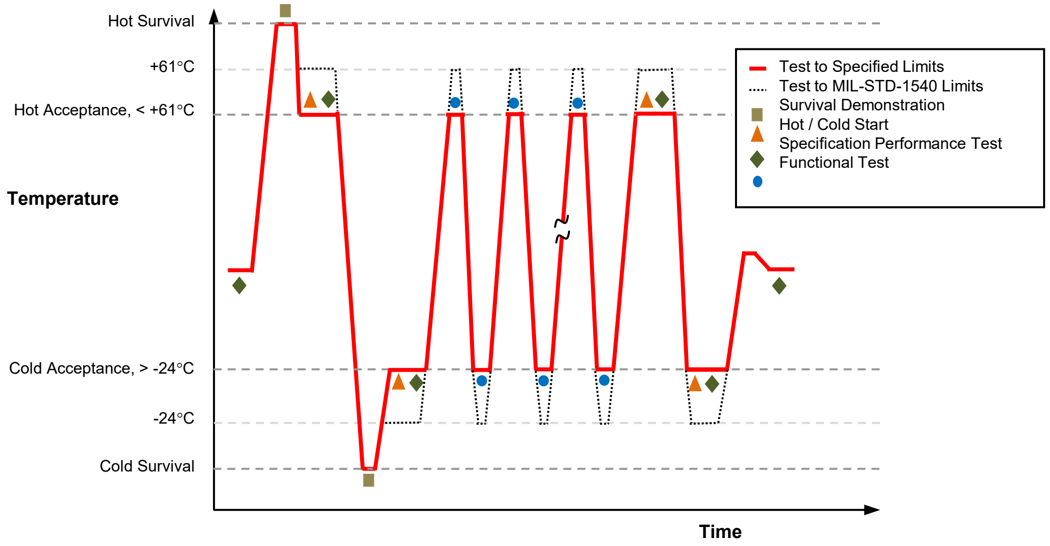
- Baseline Rationale
  - *SSC-S-016 requires thermal vacuum exposure for all qualification and protoqualification units*
  - *Purpose is to demonstrate <u>lack</u> of vacuum sensitivity prior to deleting test from subsequent acceptance units*
  - *Hardware must "earn the right" to delete vacuum in acceptance*
  - *Risk of a priori deleting vacuum at unit level is discovery of actual vacuum sensitivity in SV thermal vacuum test, starting at launch campaign. Recovery may be difficult.*

- Baseline Recommendation
  - *Perform compliant thermal vacuum testing on Qual or Protoqual units*

Test Temperature Tailoring

Operation Restricted to Unit Allowable Temperature Limits

- When unit performance and operation are constrained to a temperature range narrower than required in SSC-S-016
  - *e.g., cannot meet* -24°C/+61°C *range*
  - *Testing is performed to the constrained temperature range*
  - *Reduced demonstration of ESS*



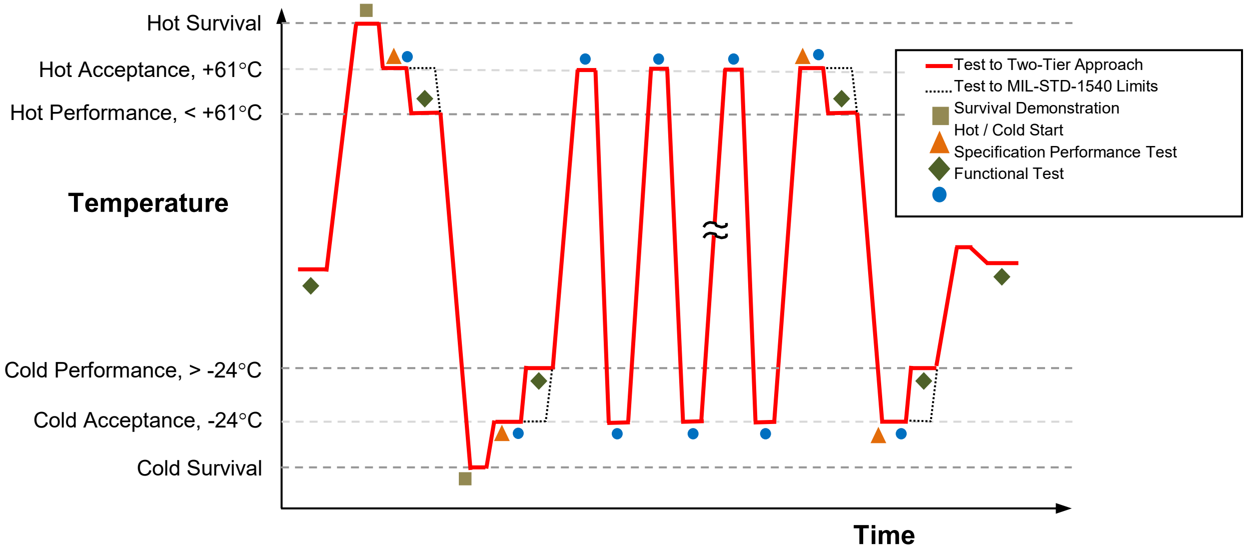
- Consequences
  - *Ensures that units with known and proven thermal design limits are not damaged*
  - *Performance margin not demonstrated*
  - *Additional cycles required to meet ESS objectives*
  - *Test planning complicated by requirement differences between units and operation of thermal hardware*

Testing to allowable limits greatly reduces test effectiveness at unit level, makes higher level test difficult, and impacts mission flexibility

Test Temperature Tailoring

Two-Tier Testing

- Exposes the electronic unit to ESS temperature range and conducts performance tests at narrower screening temperature ranges



- *Applicable for units with well known and proven performance limitations*

- Consequences
  - *Screens hardware over the SSC-S-016 temperature range while demonstrating performance over the performance design limits*
  - *Performance margin not demonstrated*
  - *Restricts mission flexibility for unplanned flight scenarios*
  - *Higher likelihood in re-testing or reduced margin with design modifications*

Two-tier testing has significant program impact and should only be considered when performance cannot be demonstrated over the SSC-S-016 default temperature ranges

Burn-In Hours and Thermal Stress

- Frequent Assertion: Accrual of Burn-In time at ambient temperature is effective and should count against 200-hour requirement
  - *Burn-In testing at the unit level is an environmental stress screen whose purpose is to surface infant mortality failures*
  - *SSC-S-016 Requirement: Additional thermal cycles or hot acceptance dwell until 200 total thermal test hours are accrued*
    - Hot acceptance dwell preferred for diffusion-driven defects
    - Additional cycling preferred for fatigue-driven defects
  - *Thermal stress is required for burn-in testing; Ambient operation provides little meaningful acceleration of thermal stress for screening*

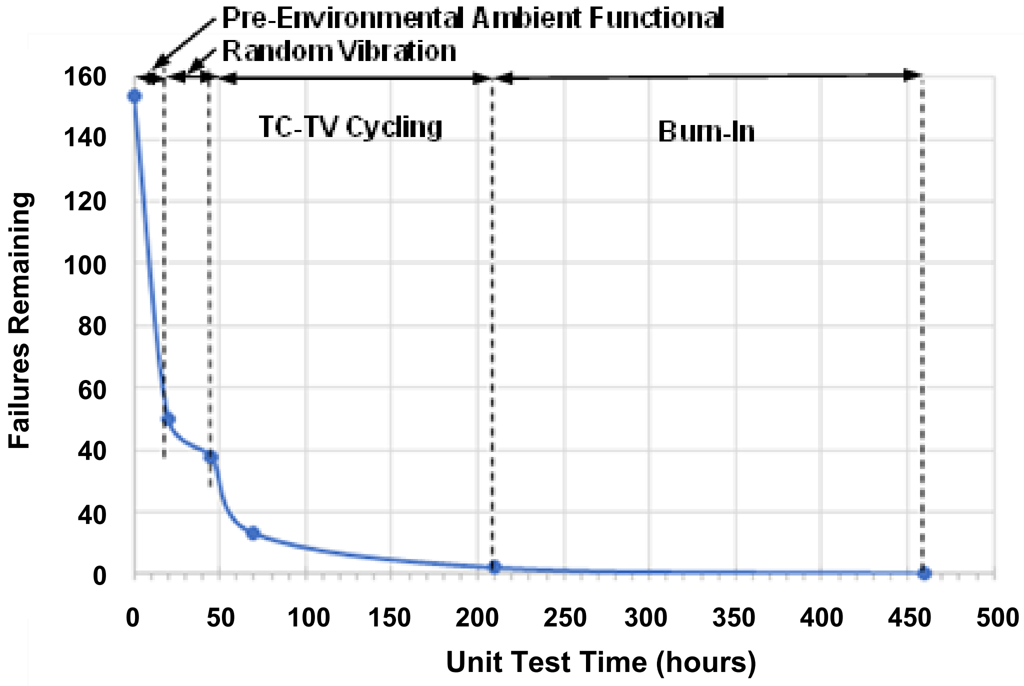
- Lockheed Martin (LM) paper* states that a 10-cycle unit acceptance TV test (1 long + 8 short + 1 long) takes, on average, 178 hours
  - *When 14 cycle TV test is run (1 long + 12 short + 1 long), the 200-hour requirement will likely be met without added cycling*

- SSC-S-016 (2026) update will lower the duration requirement
  - *175 hours for internally-redundant units*
  - *150 hours for non-internally-redundant units*

* D. A. Smith (LMSC), *Acceptance Test Effectiveness Including High Intensity Acoustics*, IES, 1988. p. 124

Burn-In – Test Duration

LM Study Used to Establish Burn-In Test Duration

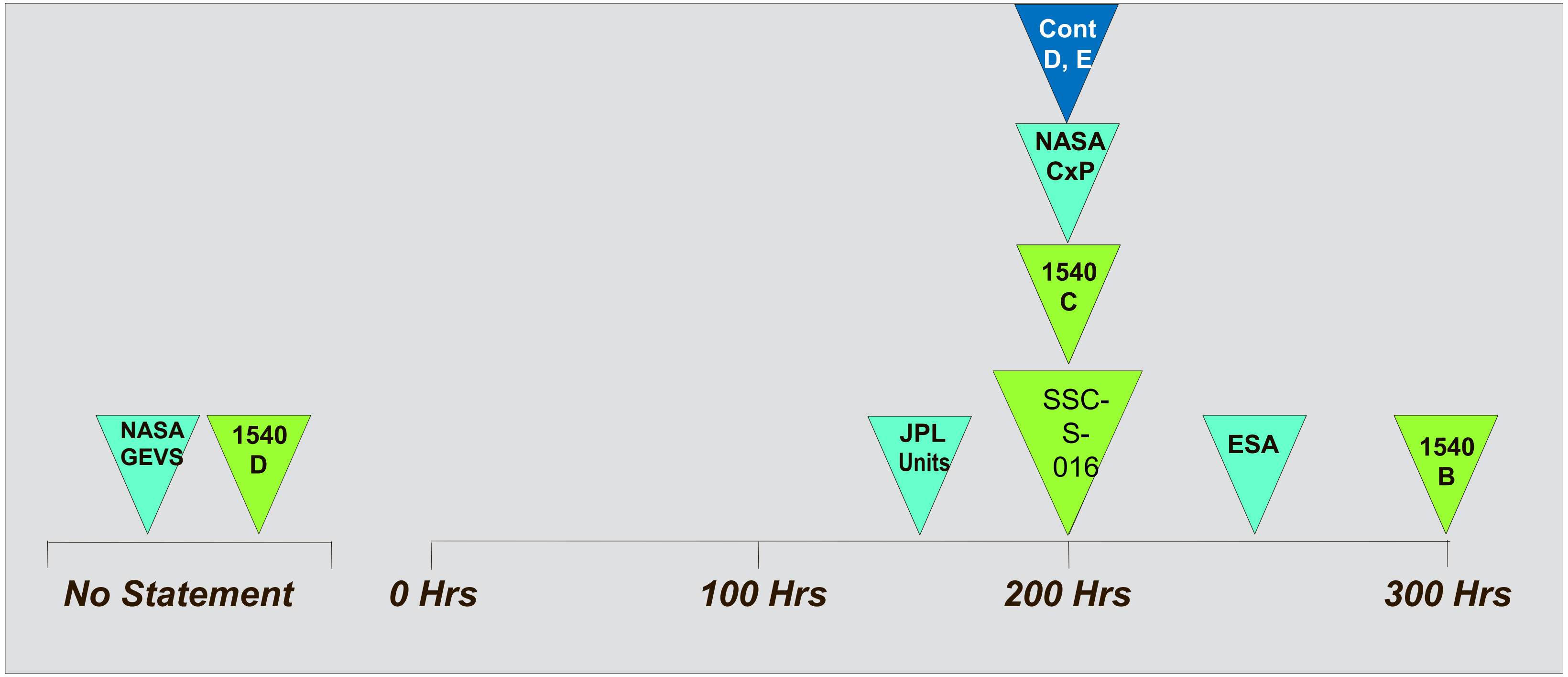


D. A. Smith (LMSC), *Acceptance Test Effectiveness Including High Level Acoustic Testing*, IES ,1988

Data support the burn-in duration requirement <u>reductions</u> from 300 hours to 200 hours in MIL-STD-1540B and to 150-175 hours in SSC-S-016 (2026)

Burn-In – Test Duration

- SSC-S-016 Burn-In requirements for elevated temperature and time are not overly conservative



Note: Certain prime contractors additionally perform HALT/HASS* testing that is much more severe than SSC-S-016 screening requirements.
HALT = Highly accelerated life testing
HASS = Highly accelerated stress screening

* M. Silverman; *Summary of HALT/HASS Results at an Accelerated Reliability Test Center*, 1998 Proc. Reliability and Maintainability Symposium; IEEE, pp. 30-36.

Proposed Tailoring You May See

Unit Thermal: Ambient Burn-In

- Tailoring Suggestion
  - *Allow Burn-In hours to be accrued at ambient temperature*

- Baseline Rationale
  - *Burn-In is an environmental stress screen*
  - *Thermal stress required for infant mortality anomaly propagation to failure*
  - *Ambient testing provides minimal thermal stress*
  - *Elevated temperature accelerates failure processes*

- Baseline Recommendation
  - *Ambient time not allowed for Burn-In time accrual.*
  - *Additional thermal cycling or hot acceptance dwell required*

Proposed Tailoring You May See

Thermal: Failure Free Cycles In Unit Thermal Cycling

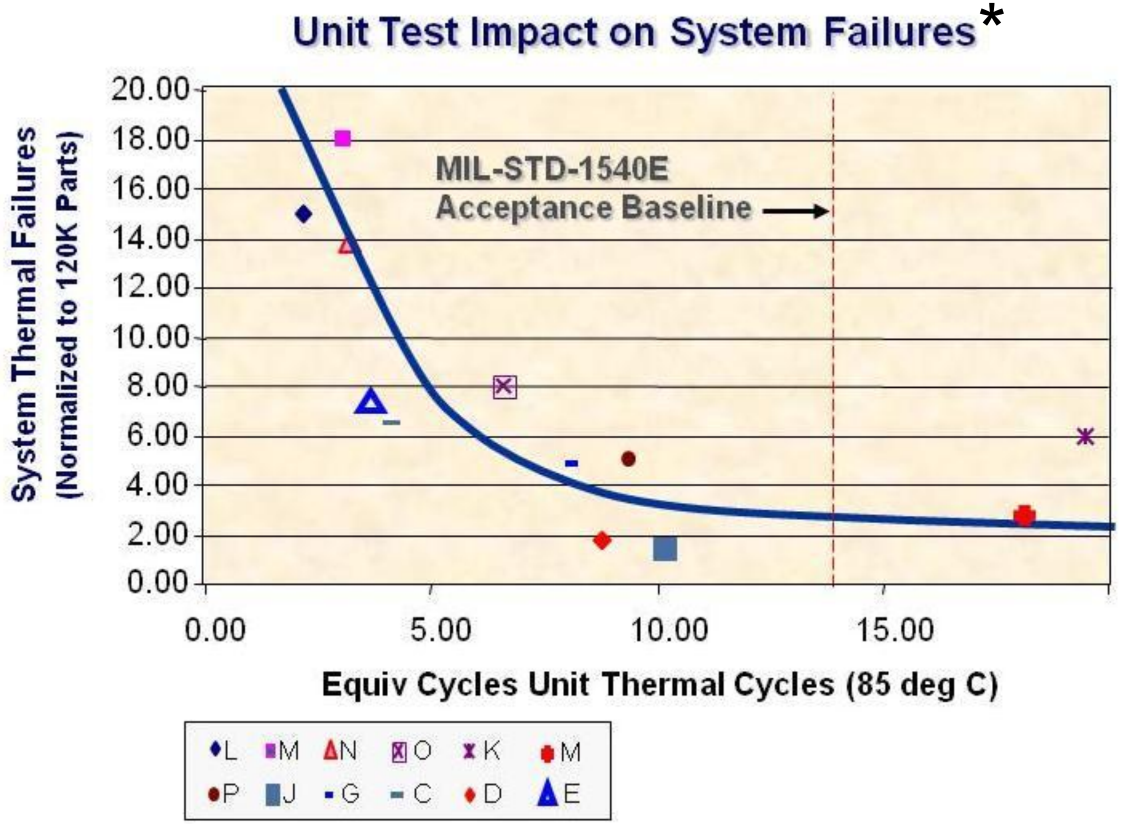
- Tailoring Suggestion
  - *Give relief from the last three cycles failure free requirement*

- Baseline Rationale
  - *Purpose of requirement is to ensure flight-worthiness of units after exposure to test environment*
  - *Requirement provides assurance that unit has successfully passed test objectives and is ready for next level of assembly*
  - *Deleting this requirement allows units to “limp through” unit testing with little confidence that all latent defects have been identified*

- Baseline Recommendation
  - *Maintain requirement to demonstrate unit integrity, flight-worthiness and build maturity necessary for successful completion of test objectives*

Unit/Vehicle Thermal Cycle Relationship Impacting Overall Test Effectiveness

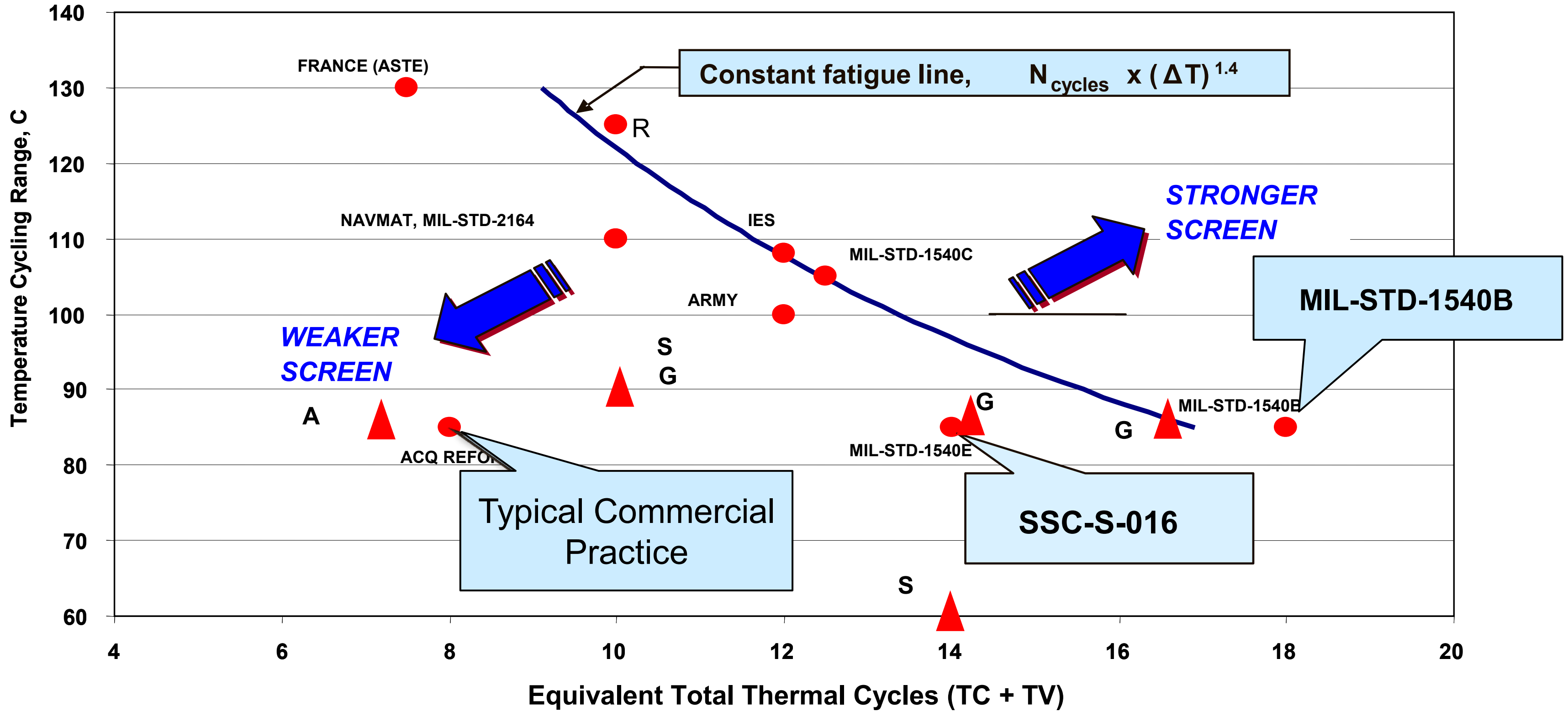
- Increased thermal cycles at unit level correlates with decreased anomalies in vehicle TV
- Corrective action at vehicle level cost and schedule impact is x10 compared with unit level
- Corrective action at vehicle level is on the critical path



* *Space Quality Improvement Council Summary Minutes and Actions*, 16 December 2008, The Aerospace Corporation

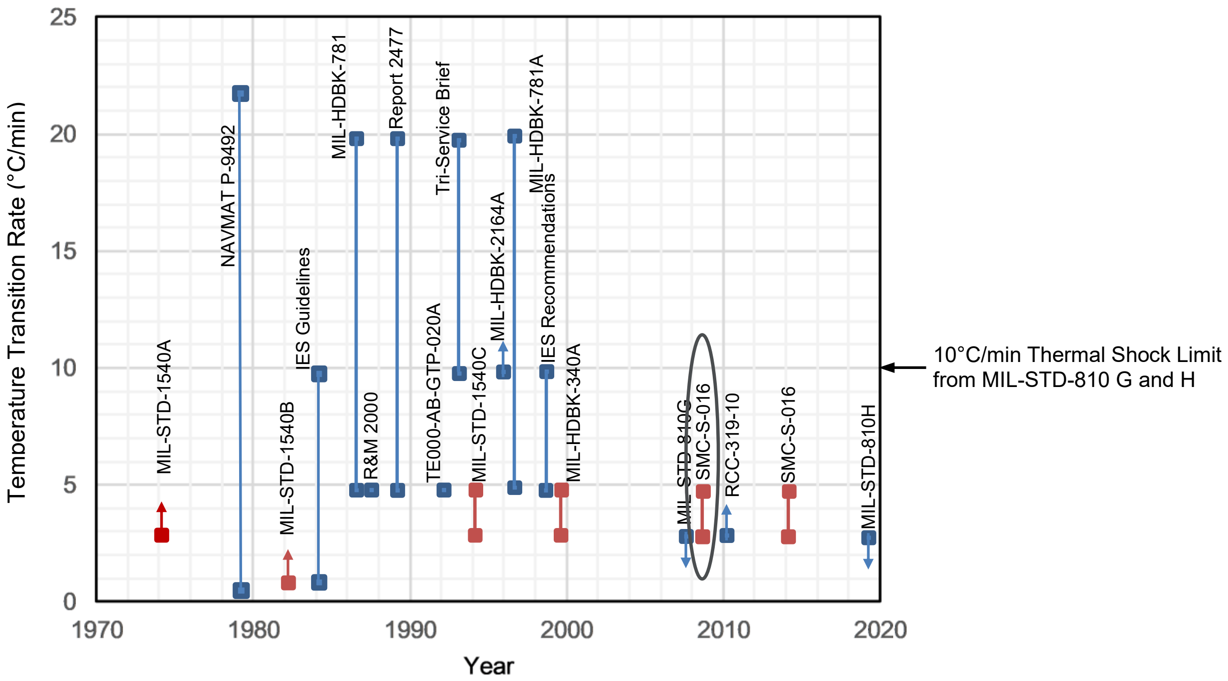
Comparison of Unit Acceptance Thermal Test Practices

- SSC-S-016 less severe than many similar and historical thermal requirements
  - *Allowance made for recent data and test practices*



Industry Survey of Temperature Transition Rate Requirements

- When failure test data is not available, industry surveys are conducted to determine if SSC-S-016 requirements are consistent with best practices
- Temperature transition rate industry survey
  - *SSC-S-016 requirement of 3-5°C/minute transition rate is consistent with and less severe than many other government requirements*



Welch, J. W. "Review of SMC-S-016 Requirements for Temperature Transition Rate During Unit Thermal Testing, Aerospace Report TOR-2022-00322, 30 November 2021.

Unit Thermal Test Parameter Requirements in SSC-S-016

- Minimum temperature range requirements for flight hardware
- Additional cycling may be necessary to demonstrate life for orbital requirements
- Flightproof test strategy is not applicable for thermal environments

Test Type / Parameter	Acceptance	Proto-Qualification	Qualification
Temperature Range	85^{o}C Minimum	95^{o}C Minimum	105^{o}C Minimum
Temperature Extremes	MPT or at least -24^{o}C to +61^{o}C	MPT -5^{o}C/+5^{o}C or at least -29^{o}C to +66^{o}C	MPT -10^{o}C/+10^{o}C or at least -34^{o}C to +71^{o}C
Number of cycles	14	20 (*)	27
Burn-In	200 hrs(**)	200 Hrs(**)	Enveloped

MPT: Maximum / Minimum Predicted Temperature
(*) SSC-S-016 (2014) reduced cycle count from 27 to 20 for protoqual
(**) : Cycled over acceptance temperature range, or dwell at hot acceptance temperatures. Values reduced to below 200 hours in 2026 version

Comparison of SSC-S-016 and GEVS Thermal Test Requirements

- For electronic units, SSC-S-016 has more testing and wider temperature range
  - *SSC-S-016 tests include TC, TV and burn-in*
  - *SSC-S-016 has a default screening of -24°C to +61°C at acceptance*
  - *SSC-S-016 has significantly more thermal cycles accrued*

- For vehicles, testing is similar between the two standards
  - *GEVS has a slightly wider temperature range*

Test	SSC-S-016 Unit Testing	GEVS Unit Testing	SSC-S-016 Vehicle Testing	GEVS Vehicle Testing
Acceptance	10 TC + 4 TV (14 Total Cycles) -24C to +61C (200 Hr BI)	8 TV cycles MPT ±5C	4 TV cycles MPT	4 TV cycles MPT ±5C
Protoqualification / Protoflight	16 TC + 4 TV (20 Total Cycles) -29C to +66C (200 Hr BI)	8 TV cycles MPT ±10C	4 TV cycles MPT ±5C	4 TV cycles MPT ±10C
Qualification	23 TC + 4 TV (27 Total Cycles) -34C to +71C	8 TV cycles MPT ±10C	8 TV cycles MPT ±10C	4 TV cycles MPT ±10C

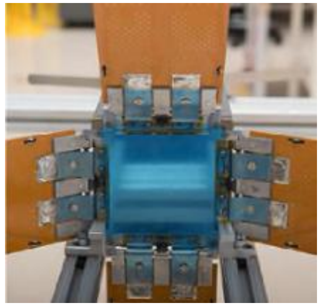
GEVS-STD-7000B, 04/28/2021

Thermal Testing of Non-Electronic Units

Unit Thermal Testing

- Mechanical unit testing
  - *Less stress required because primary intent in not screening, but demonstration of performance in a flight-like environment*
    - Thermal vacuum test (not TC) to simulate flight conditions
    - Fewer cycles and test temperatures based on flight predictions

Acceptance	Protoqualification	Qualification
1 Cycle	3 Cycles	6 Cycles



Simple deployment mechanism with hinges
[Image courtesy of NASA]

- Other thermal tests
  - *Deployment mechanisms required to demonstrate performance in a thermal environment*
    - TV test with consideration for thermal gradients, transient effects
  - *Batteries*
    - TV of cell at cell provider and of battery pack at prime contractor
    - Intent is to demonstrate adequacy of heat paths and thermal control

Li-Ion battery cells
[Image courtesy of NASA]

Welch, J. W., *"Lessons Learned in the Application of Thermal Test Requirements for Spacecraft Units,"* AIAA 2008-4119, June 2008

Subsystem/Payload Thermal Testing

- SSC-S-016's thermal requirements for subsystems and payloads
  - *Thermal vacuum testing only*
  - *Goal is to move vehicle level requirement verifications to a level where they can be better demonstrated*

Hardware	Structure	Bus	Payload
Qualification and PQ Hardware	ER	ER	R
Acceptance Hardware	-	ER	R

R=Required, ER=Evaluation Required, - = Not Required

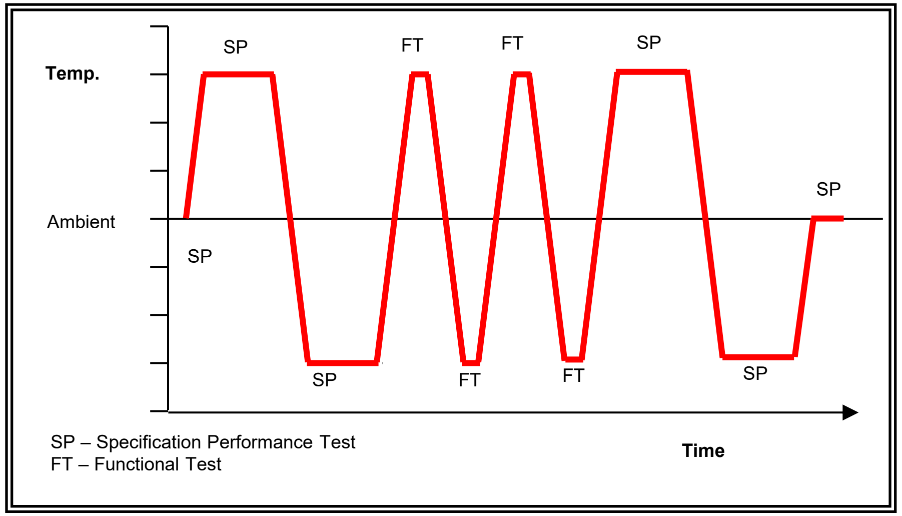
- Considerations
  - *Increased size and complexity of space vehicles*
  - *Long duration of vehicle level vehicle integration*

- Advantages over vehicle-level testing
  - *Utilize smaller vacuum chambers*
  - *Easier to level heat pipes*
  - *Design the test to specific test item*
    - Environment and test equipment
  - *Easier to correlate thermal balance test data*
  - *Provides more time for correcting problems*

Vehicle Thermal Vacuum (TV) Testing

Thermal Profile

- Thermal vacuum testing performed to 4 cycles for acceptance and PQ vehicles
  - *Performance specification tests on first and last cycle*
  - *Powered and monitored during intermediate cycles and transitions*
    - Trending
    - Anomaly detection
  - *Temperature range is based on worst case model predictions plus appropriate temperature margins*
    - No default ESS temperature range as used in unit thermal testing
    - Payload is divided into thermal zones and performance testing begins when first unit in each zone to reach goal temperature level
    - Thermal control subsystem (heaters, heat pipes, doublers, etc.) will impact ability to achieve goal temperature levels

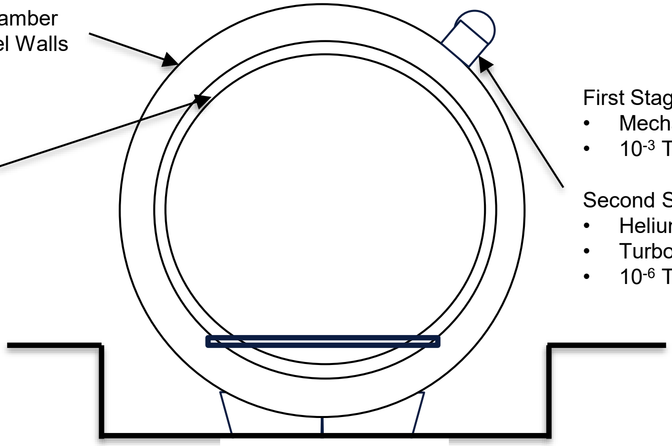


Vehicle TV test focuses on demonstrating mission performance and not intended as an environment for screening units

Thermal Vacuum Test Chamber

Horizontally-Loading Chamber

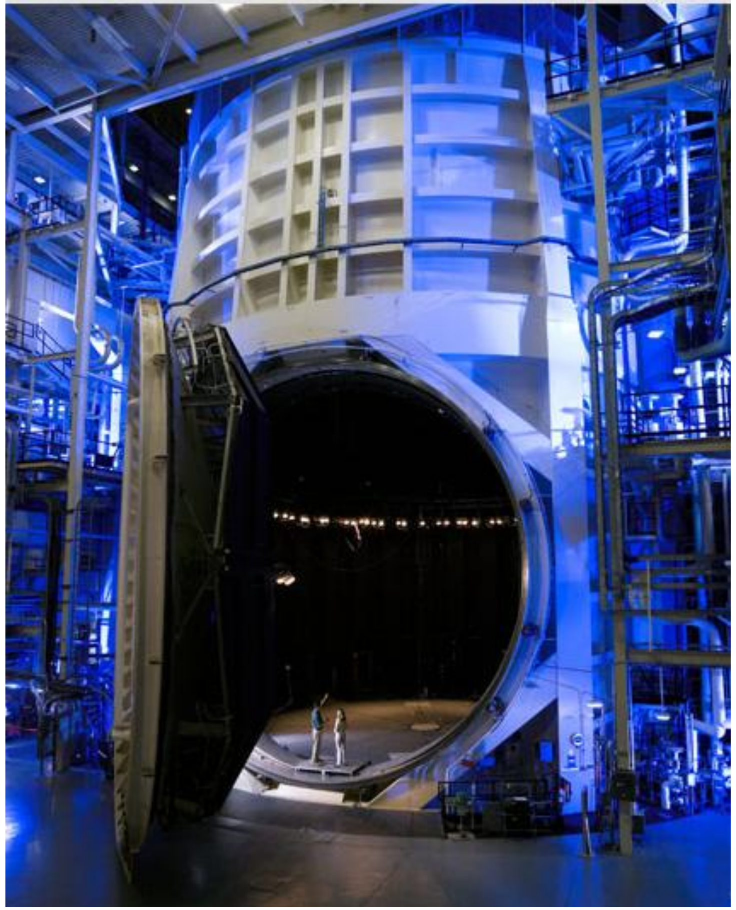
NASA Thermal Vacuum Chamber at Johnson Space Center
Photo courtesy of NASA (www.nasa.gov)



Thermal Vacuum Test Chamber

Horizontally-Loading Chamber

Dimensions:	19.8 m (65 ft) dia x 36.6 m (120 ft) high
Working dimensions:	
Inside LN_2 shroud:	16.8 m (55 ft) dia x 27.4 m (90 ft) high
Inside He shroud:	13.7 m (45 ft) dia x 24.4 m (80 ft) high
Test article weight:	68,100 kg (150,000 lb)
Pumps:	Staged rouging pumps Turbo molecular pumps Cryo absorption pumps Helium refrigeration unit (20 K (-424 °F)
Pump-down time:	12 hours (10^{-7} Torr)
Re-pressurization:	Controllable dry gas purge and heated shroud
Chamber shroud:	Subcooled to 90 K (-298 °F) LN_2 shroud Deep space cooling to 35 K He shroud Can be heated to 312 K (102 °F) with GN_2
Wall emissivity	0.95
Measurement capability:	Data system capable of 1,000 test article channels
History:	Tested Apollo spacecraft with and without the mission crew.



NASA Johnson Thermal Vacuum Chamber A
Photo courtesy of NASA (www.nasa.gov)

Vehicle Thermal Cycle Testing

- Performed as an option preceding TV testing
  - *Discussed in Appendix A of SSC-S-016*
  - *Number of required TV cycles are reduced from TV-only testing*
  - *Exercises different failure mechanisms than TV*
  - *TC and TV are not interchangeable*

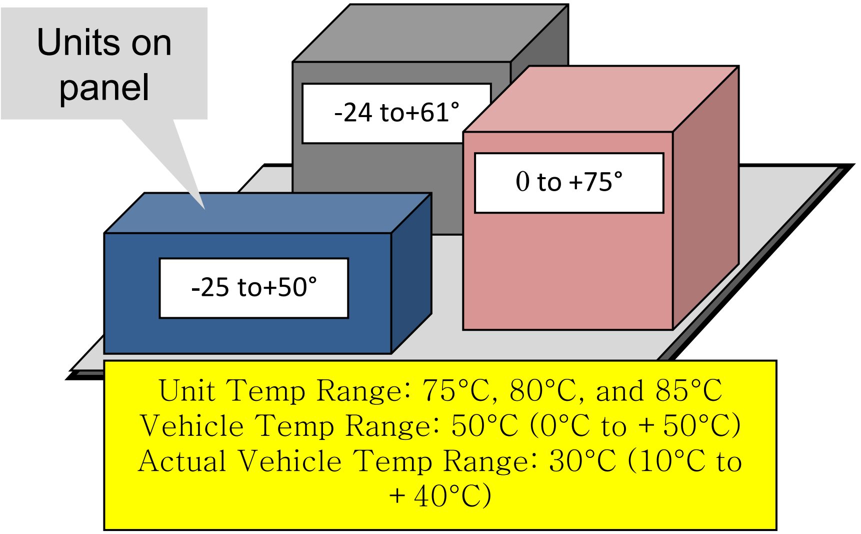
- Advantages
  - *Additional screening*
    - Faster transitions
    - Early screening when performed earlier in AI&T phase
  - *Resolve performance and test procedure problems before TV testing (cost savings)*

- Disadvantages
  - *Additional test time required*
  - *Risk of temperature exceedances. Temperature transitions will be faster than in thermal vacuum test and need to be monitored continuously*

Key Limitation for Vehicle Level Temperature Levels

“We’ll Catch it at the Vehicle Level”

- Subsystem, payload and vehicle test temperatures use worst case prediction range with appropriate thermal margin
  - *Test temperature range typically far more benign than at unit level*
    - No default temperature range (e.g., -24°C to +61°C)
  - *Regions are divided into thermal zones; first temperature sensor in the zone to reach the test temperature indicates the start of thermal dwell*
    - Typical for most units to experience temperature levels far more benign than seen at unit level
  - *Thermal control hardware prevents temperature gradients or extremes*
    - Heater activity set cold test temperatures
    - Heat pipes minimize thermal gradients

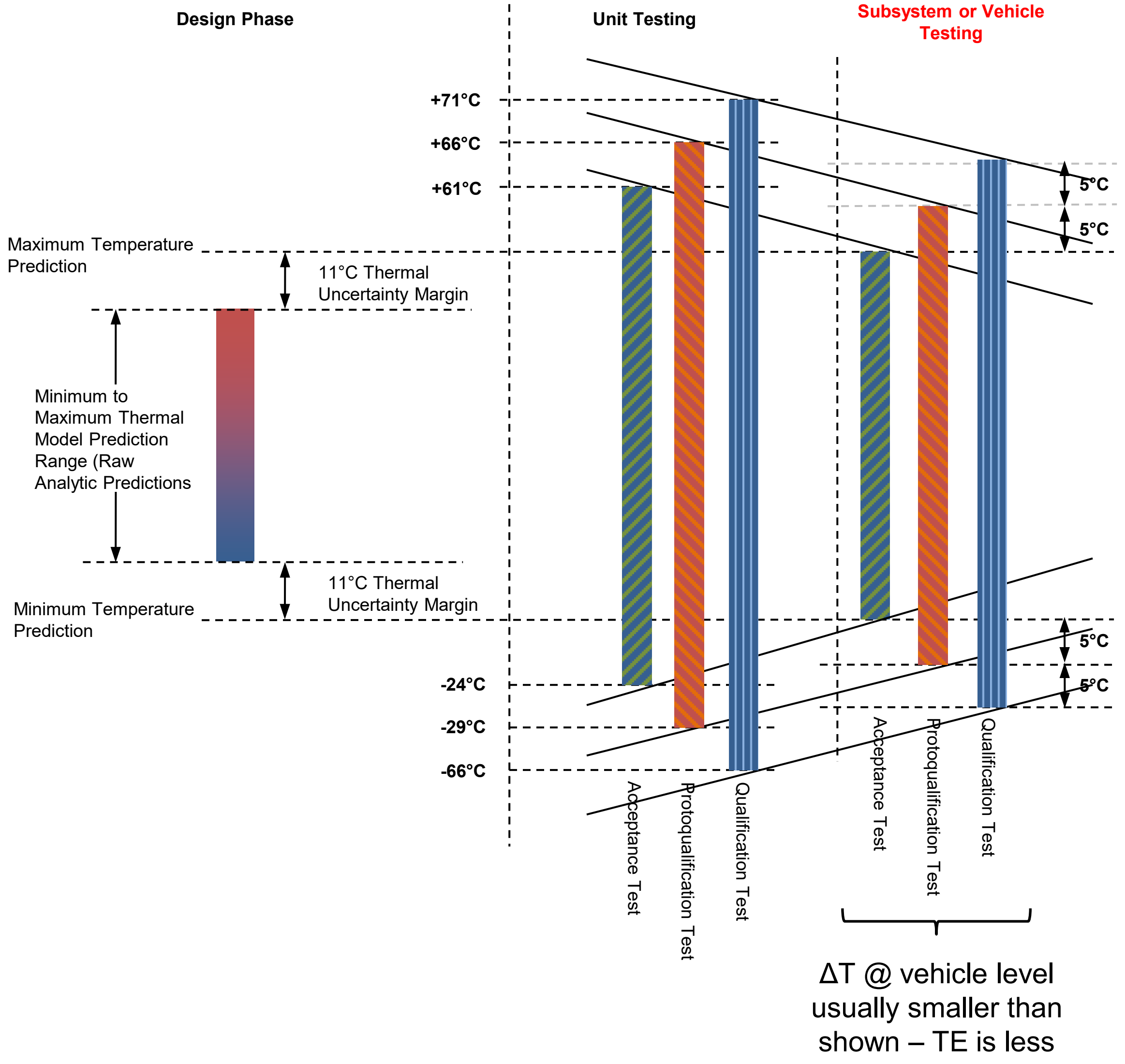


Test environment at unit level significantly more effective for ESS objectives than at higher levels of assembly

Rationale for Vehicle Temperature Range

- Test margins identical to unit-level testing

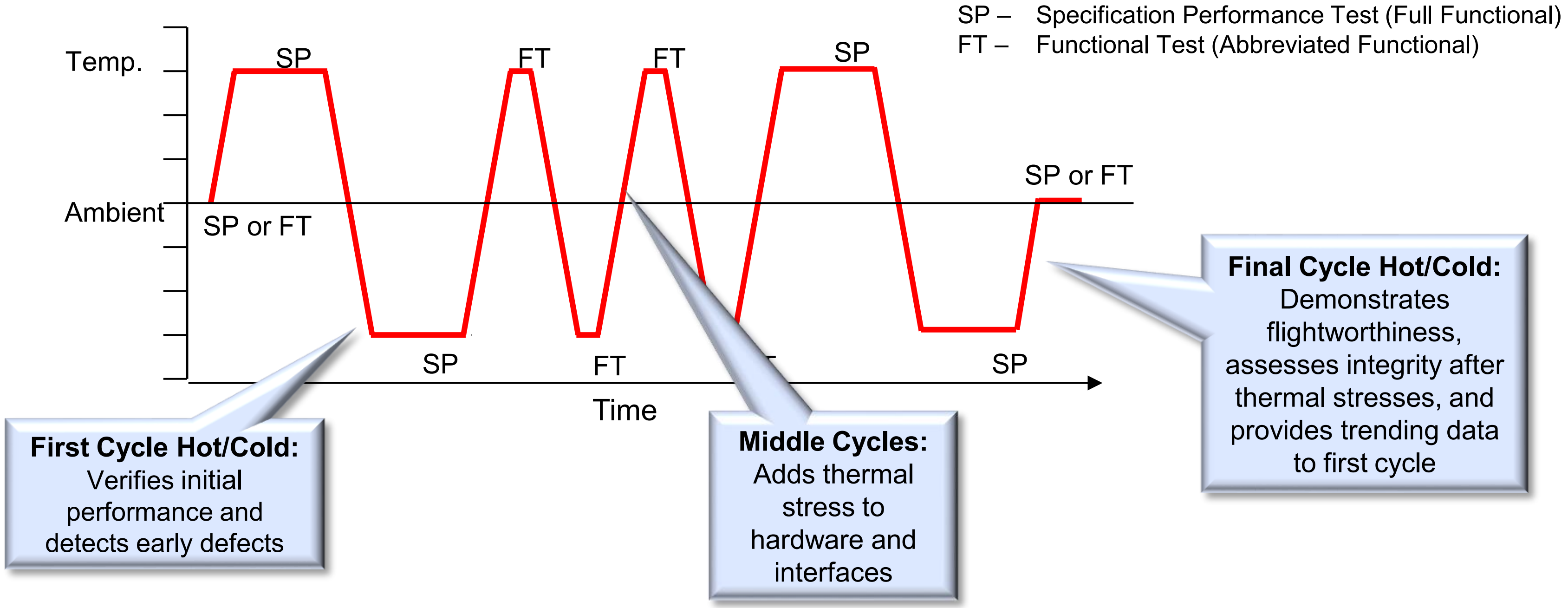
- Test temperature range typically less than at unit level
  - *No screening temperature range (e.g., -24°C to +61°C) at higher levels of assembly*
  - *Reduces the risk of over-testing a unit at higher levels of assembly*
  - *Thermal environments are realistic of flight conditions and expectations (TLYF)*



Rationale for Vehicle Thermal Cycles

- Vehicle-level cycles require same number of cycles for protoqualification as acceptance
  - *Trend is different than seen at the unit level where protoqualification cycles are the same as qualification cycles*
    - More screening at the unit level of assembly
    - At the vehicle level, hot/cold performance verification is primary emphasis

- Four cycles for acceptance and protoqualification consistent with industry practice



Proposed Tailoring You May See

Vehicle Thermal Vacuum: Delete Full Performance Testing On First Cycle

- Tailoring Suggestion
  - *"It will save time if we do full performance testing only on the last cycle. That's our standard practice."*

- Baseline Rationale
  - *Suggestion generally made to save test time*
  - *Most anomalies are caught on the first TV cycle in performance tests. If functional tests replace performance tests on the first cycle, screening is less perceptive and failures will be (hopefully) found later in the TV test*
  - *Contractor cannot trend from ambient pre-test performance to last TV cycle*
  - *Must trend from ambient pre-test to first vacuum cycle, to last vacuum cycle to generate complete picture; consistent environment required for trending*
  - *Vehicle TV finds more failures than any other vehicle environmental test*

- Baseline Recommendation
  - *Perform compliant tests – full functional and performance testing, hot and cold, first and last vacuum cycle. Recommendation optimizes mission success*
  - *Due to cost and schedule constraints, programs are approving this waiver*
    - Resulting is more failures found on the final cycle during performance testing

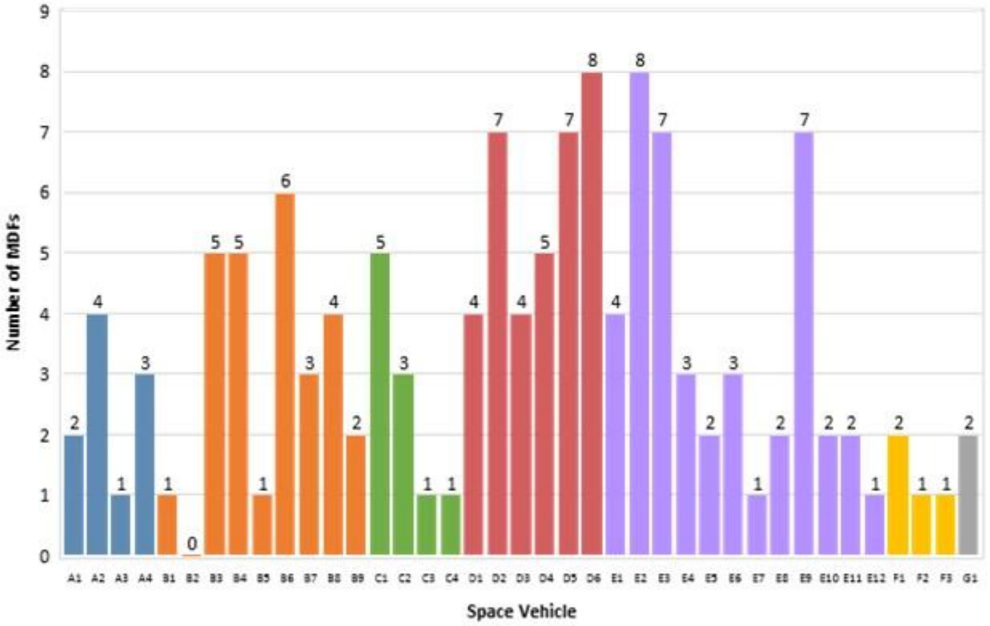
Test Effectiveness of the Vehicle Level Thermal Vacuum Test

- 40 vehicles of DoD programs across 7 programs tested between 2001 and 2017
  - *Mission degrading failures (MDFs) in vehicle TV tests are those that would impact mission performance or program reliability **
  - *Escapes are failures that "should have detected earlier" because the same test environment occurred*

- 130 MDFs directly associated with the conditions and environments imposed by the TV test
  - *42% escapes*
  - *3.3 MDFs per vehicle*
  - *Negligible difference between PQ and acceptance vehicles*

- No "fall-off" in MDFs found as vehicle number increased in program builds

	Direct	Escapes	Total
MDFs	76	54	130
MDFs/satellite	1.90	1.35	3.25



* *Welch, J. W., Zhao, B. Z. and McVay, D. J., Insight into the Value of the System Level Thermal Vacuum Test*; 31st Aerospace Testing Seminar, 2018.

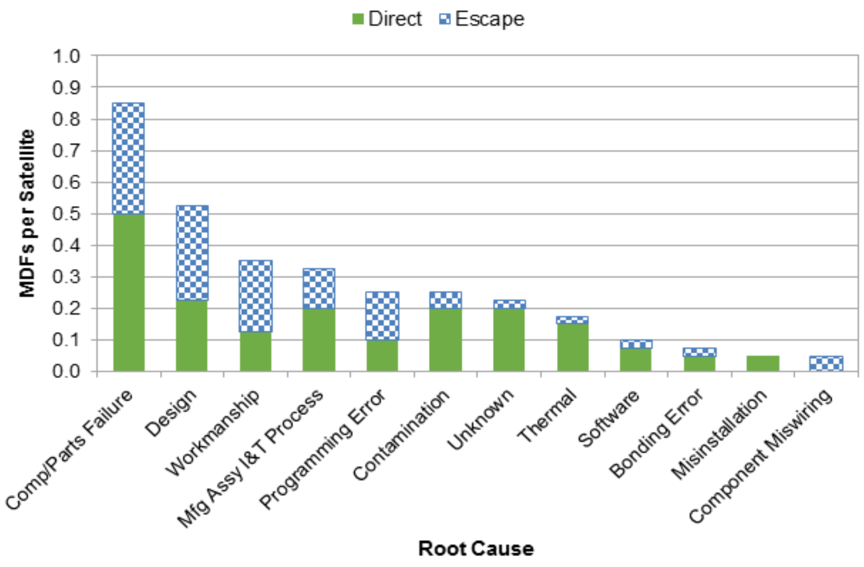
Arnheim, B. and Wright, C., Insight into the Value of the System Level Thermal Vacuum Test; 20th Aerospace Testing Seminar, 2001.

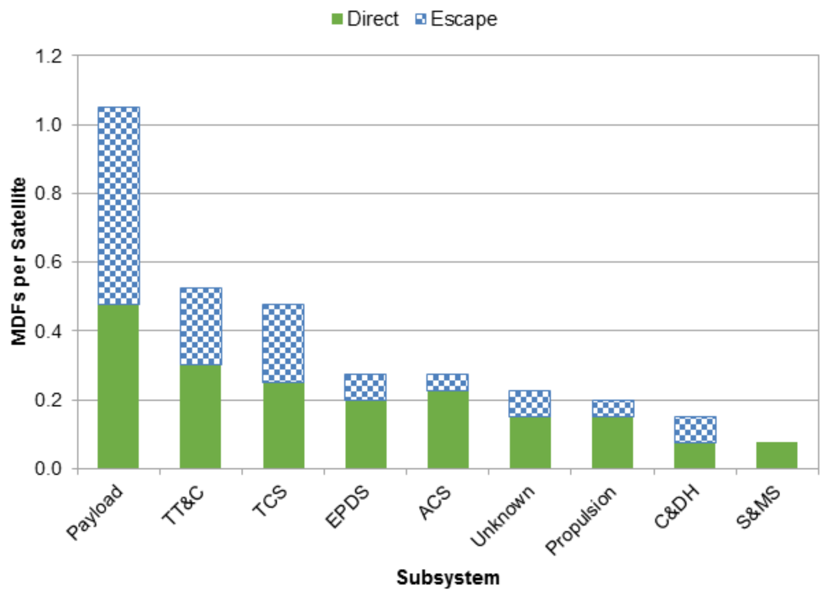
Data does not show a vehicle number after which defects are significantly lower

Failure Root Cause/Subsystem Categorization in Vehicle Thermal Vacuum Test

- Component/part failure is the most common root cause
  - *Escapes were high for top root case failure categories*

- Payloads were the most common subsystem for failures
  - *Escapes were high for the top root cause failure categories*





Items and subsystems with the highest failures also had high escape rates

Rationale for Thermal Balance Test Approach

- SSC-S-016 specifies thermal balance testing for model correlation during first cycle of the first vehicle TV test
  - *Advantages of TB testing on first cycle*
    - If thermal subsystem problems are found, test configuration (vacuum) can be broken with less impact to retest
    - Gives thermal analysts more time to review TB data and conduct additional verification testing because vehicle is still under vacuum for subsequent TV testing
    - Thermal model correlation performed concurrently with TV testing (first cycle), allows more time for correlation activity

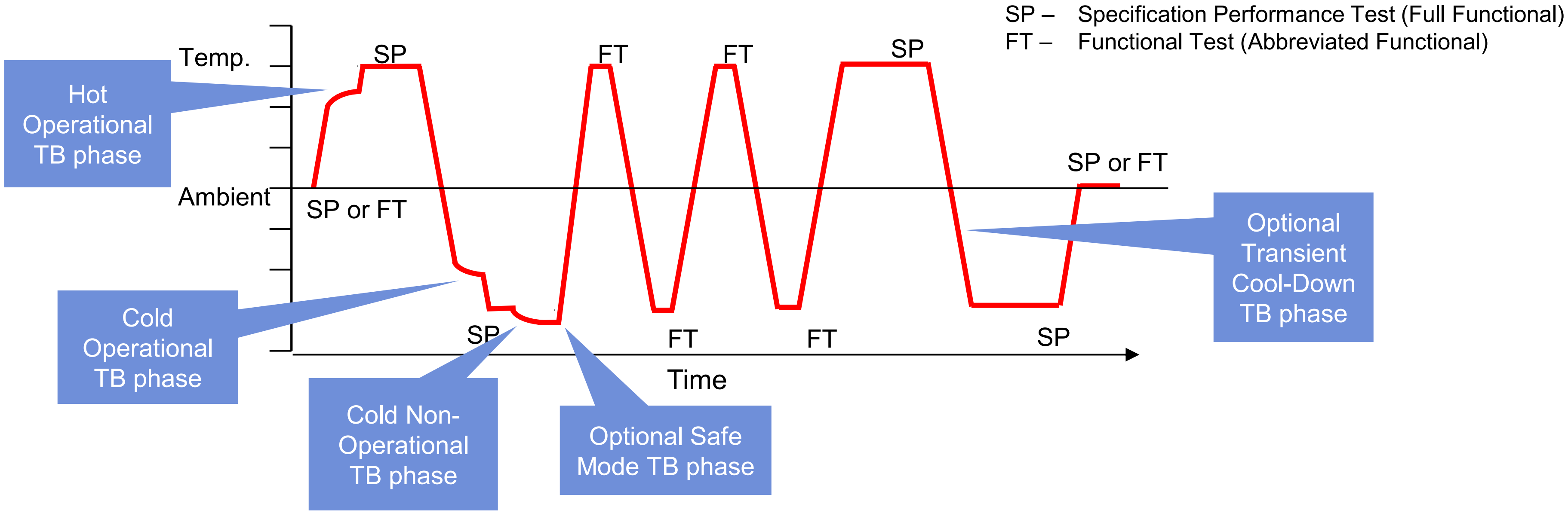
- At least three test phases are necessary for TB testing
  - *Hot operation, cold operation, and cold non-operation*
  - *Thermal model correlation requires at least two data points that represent approximate extremes in thermal conditions (operational phases)*
  - *Non-operational phase needed for additional correlation point and verification of survival requirements and heater design*

- For hardware not designed to reach steady state, correlate temperature change and rate of change rather than steady-state temperatures.

Vehicle Thermal Balance (TB) Testing

- Vehicle-level test performed as part of the vehicle TV test
  - *Verification of the thermal control subsystem*
  - *Obtaining data for thermal model correlation*
    - Steady-state temperatures and heater duty cycles
    - At the vehicle level, hot/cold performance verification is primary emphasis

- Chamber environment is set to a flight-like conditions and the vehicle reaches a steady-state temperature in that environment
  - *Resulting temperatures are then compared to model predictions*
  - *Verifies thermal hardware (heaters, heat pipes, etc.) performance*



Subsystem and Vehicle Thermal Test Parameters

Test Type / Parameter	Acceptance	Proto-Qualification Flightproof	Qualification
Temperature Extremes	MPT**	MPT +5^{o}C/-5^{o}C	MPT +10^{o}C/-10^{o}C
Number of TV Cycles	4 TV	4 TV	8 TV
Number of TV + TC Cycles	2 TV + 3 TC	2 TV + 3 TC	4 TV + 6 TC

** MPT: Maximum / Minimum Predicted Temperature

Thermal Testing

Summary

- Unit level thermal testing performs two functions
  - *Among the most effective and perceptive screening tests*
  - *Demonstration of operation within design limits*
    - Verify thermal analysis
  - *Environmental stress screening to "weed out" early failures*
    - Standard retains requirement for unit level testing: board testing alone is not deemed sufficient

- Vehicle level thermal testing verifies
  - *Performance*
  - *Interfaces*
  - *Thermal models*

- SSC-S-016 test levels and duration are in-family with industry surveys and other government environmental stress screening standards
  - *Tests may need to be adapted for launch vehicle and interceptor hardware not intended for steady-state operation*

See also "Application Guidelines and Rationale for Thermal Testing Requirements" Aerospace ATR-2015-01479

Thank you