



Thermal & Fluid Analysis Workshop 2003

JPL's Thermal Testing Philosophy

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JPL's Mission



Thermal Test Discussion Panel

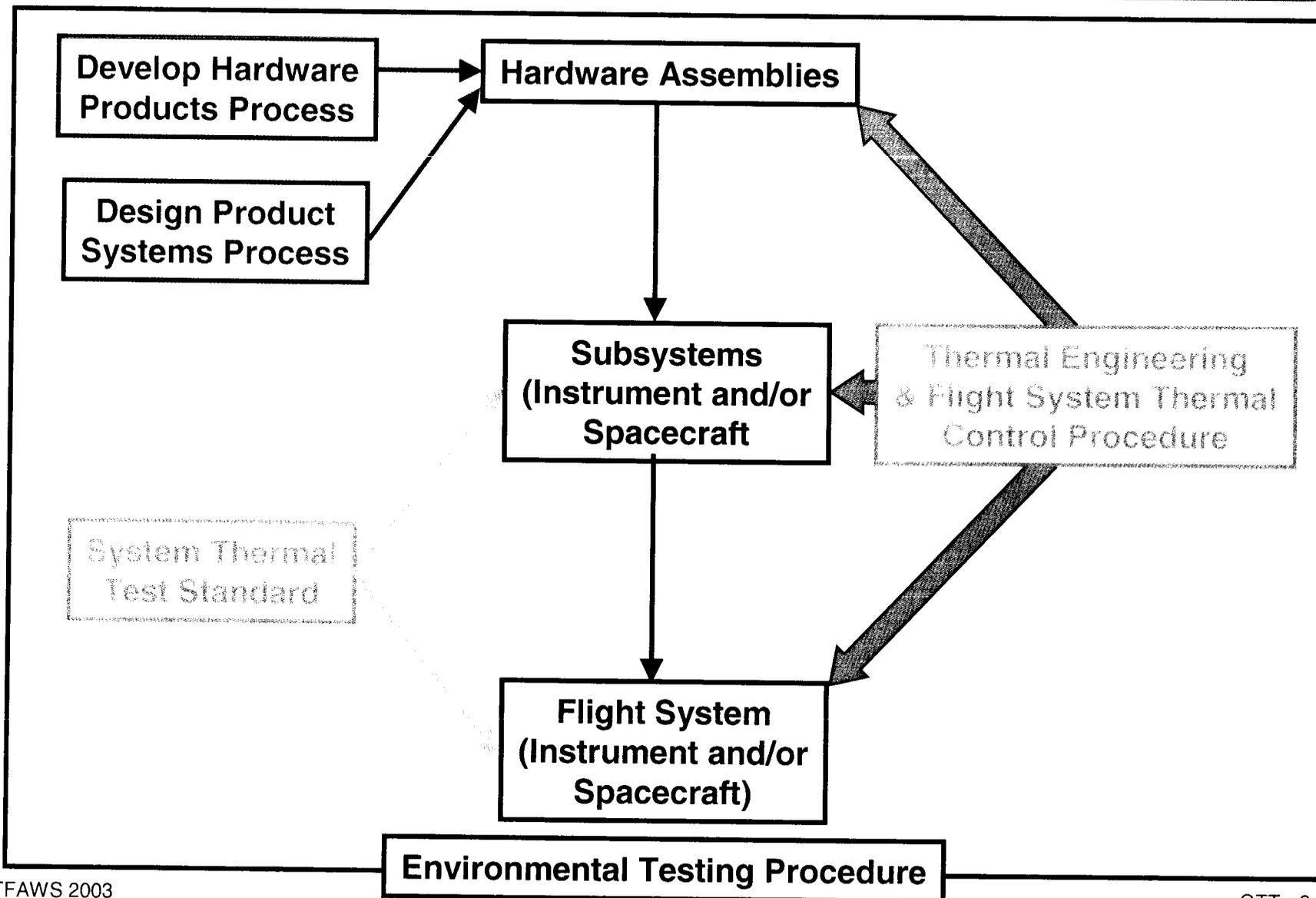
- **JPL is an operating division of the California Institute of Technology & is a Federally Funded Research & Development Center (FFRDC)**
- **JPL's primary mission, performed under contract to NASA, is the robotic exploration of the solar system; for example**
 - **Mars Scouts 2007, Mars Reconnaissance Orbiter, Mars Exploration Rover, Mars Odyssey, Mars Global Surveyor**
 - **Deep Impact, Dawn, Stardust, Genesis**
 - **Galileo, Cassini, Ulysses, Voyager**
- **JPL also has significant involvement with NASA programs in Earth Sciences & Astrophysics**
 - **TOPEX/Poseidon, Jason, Jason 2, GRACE, CloudSAT**
 - **NSCAT, QuikSCAT, SeaWinds, MLS, MISR, AIRS, TES**
 - **SIR-C, SRTM**
 - **SIM, SIRTF, GALEX, WF/PC on HST, IRAS**



Overview of JPL's Products & Processes



Thermal Test Discussion Panel





JPL's Thermal Testing Philosophy for Thermal Design Purposes



Thermal Test Discussion Panel

- **JPL uses early thermal development testing in the thermal design evolution cycle to proactively develop robust designs**
 - Empirically determine key driving thermal parameters that are difficult to quantify analytically
 - Understand temperature sensitivity to key boundary conditions
 - Demonstrate proof-of-concept
- **System thermal testing serves multiple objectives**
 - Empirically validate system-level thermal design for thermally extreme conditions
 - Validate flight system functionality under flight-like environmental conditions
 - Include verification of flight thermal hardware such as electrical heaters with mechanical thermostats, temperature sensors, heat pipes, etc.
 - Gather test data for analytical thermal model correlation
 - Calibrated tool for “Verification by Analysis”



JPL's Thermal Testing Philosophy for Hardware Products



Thermal Test Discussion Panel

- **JPL uses protoflight (PF)/qualification (QUAL) to uncover workmanship defects & vulnerable design features**
 - **Interplanetary flight systems require high reliability since their in-flight duration may be several years**
 - **These types of missions experience minimal thermal cycling**
 - **Thermal cycles are limited on flight hardware to 33% of expected ground + flight**
 - **Dwell times at hot or cold soak test cases protracted to ensure reliability**
 - **Earth-orbiting & Mars-surface missions experience more pronounced thermal cycling**
 - **Hardware packaging must demonstrate life cycling to 3 times expected flight (packaging verification qualification)**
 - **Non-compliance requires a Project waiver**
 - › **One-time or limited use items (e.g., deployment mechanisms)**
 - **Typically, these tests are conducted in vacuum ($< 10^{-5}$ torr)**
- **Flight acceptance (FA) testing used to certify hardware whose design has undergone QUAL testing**



JPL Governing Thermal Testing Documents



Thermal Test Discussion Panel

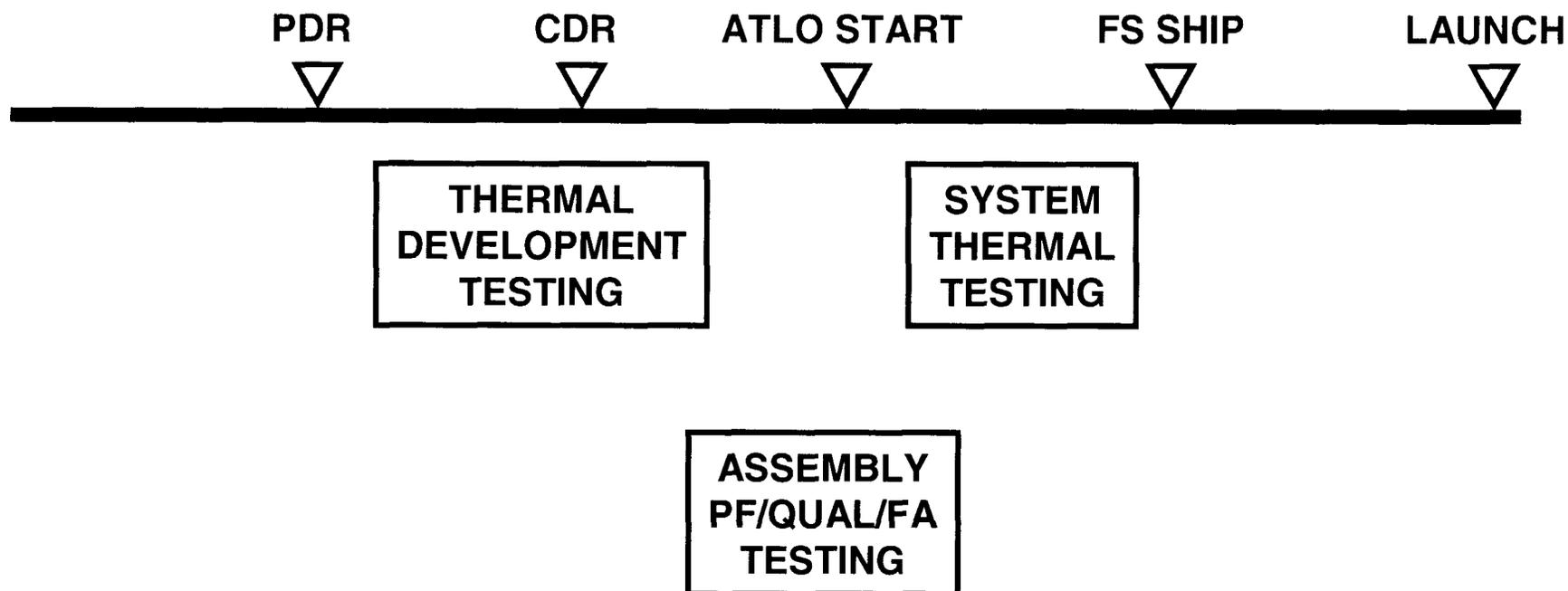
TYPE OF THERMAL TEST	GOVERNING DOCUMENT	INTERNAL JPL DOCUMENT ID
System or Flight Assembly Level Thermal Balance	System Thermal Testing Standard	58172
	Design Product Systems Process	57354
	Environmental Testing Procedure, Revision 3	33832
Flight Assembly PF/QUA/FA	Assembly and Subsystem Level Environmental Verification Standard	60133
	Develop Hardware Products Process	57752
	Environmental Testing Procedure, Revision 3	33832
Thermal Development	Thermal Engineering and Flight System Thermal Control Procedure, Revision 1	33014
	Environmental Testing Procedure, Revision 3	33832



Typical Thermal Testing Flow



Thermal Test Discussion Panel





Environmental Requirements Are Mission-Unique



Thermal Test Discussion Panel

- **JPL Design Principles recommend specific temperature margins & thermal cycling**
- **Each project develops an “Environmental Requirements Document (ERD)”**
 - **Captures Design Principles as the baseline**
 - **Provides for tailoring based on such criteria as critical functionality & lifetime**
 - **Prescribes mission-unique specifications for temperature margin between allowable flight temperature (AFT) & test levels (PF/QUAL/FA), PF/QUAL/FA dwell times, & number of thermal cycles**



Thermal Design Validation Considerations (1/3)



Thermal Test Discussion Panel

- **System-level thermal testing enables validation of flight thermal hardware**
 - Primary & secondary heater strings including thermostats, if any
 - Heater power margin
 - General guideline is a maximum 75% duty cycle in the worst-cold case
 - Temperature sensor measurements comparison to test thermocouple readings
 - Heat pipe/CPL start-up
- **Steady-state criteria**
 - Each flight system responds differently
 - Prescribing a temperature rate of change or heat flow criteria is arbitrary without incorporating specific thermal characteristics
 - While JPL specifies a temperature rate of change, steady-state determination is left to the discretion of the test conductor
 - If the steady-state temperatures can be credibly extrapolated from test data, then a test case can be considered “steady”



Thermal Design Validation Considerations (2/3)



Thermal Test Discussion Panel

Test Characteristic	Thermal Development	System or Flight Assembly Thermal Balance
Number of Thermal Cycles	Not applicable if no flight hardware used	Minimized since thermal cycling is considered a limited & consumable resource
Dwell Time	Sufficient for steady-state determination	Sufficient for steady-state determination
Temperature Range	Allowable flight temperature (AFT)	Allowable flight temperature (AFT)



Thermal Design Validation Considerations (3/3)



Thermal Test Discussion Panel

Test Characteristic	Thermal Development	System or Flight Assembly Thermal Balance
Temperature Extremes	Not to exceed a known material limit and/or safe condition if no flight hardware used	Not to exceed FA
Transition Rate	Not to exceed a known material limit and/or safe condition if no flight hardware used	Not to exceed a safe hardware condition; Limiting items include optics (<8°C/hr)
Thermal Stability	<0.3°C for 3 consecutive hours or at discretion of cognizant test conductor	<0.3°C for 3 consecutive hours or at discretion of cognizant test conductor



Hardware Certification Considerations



Thermal Test Discussion Panel

Test Characteristic	Flight Assembly PF/QUAL/FA
Number of Thermal Cycles	<u>Fight assemblies:</u> Typically 3 to 10 cycles <u>Packaging:</u> 3 times worst-case flight
Dwell Time	Tailored on a unique Project basis, Typically 144 hours HOT & 24 hours COLD
Temperature Range	<u>PF/QUAL:</u> AFT - 15°C to AFT + 20°C (Electronics shall minimally be -35 to +75°C) <u>FA:</u> AFT ± 5°C

Test Characteristic	Flight Assembly PF/QUAL/FA
Temperature Extremes	<u>PF/QUAL:</u> AFT - 15°C to AFT + 20°C (Electronics shall minimally be -35 to +75°C) <u>FA:</u> AFT ± 5°C
Transition Rate	Not to exceed a safe hardware condition; Limiting items include optics (<8°C/hr)
Thermal Stability	<0.3°C for 3 consecutive hours or at discretion of cognizant test conductor

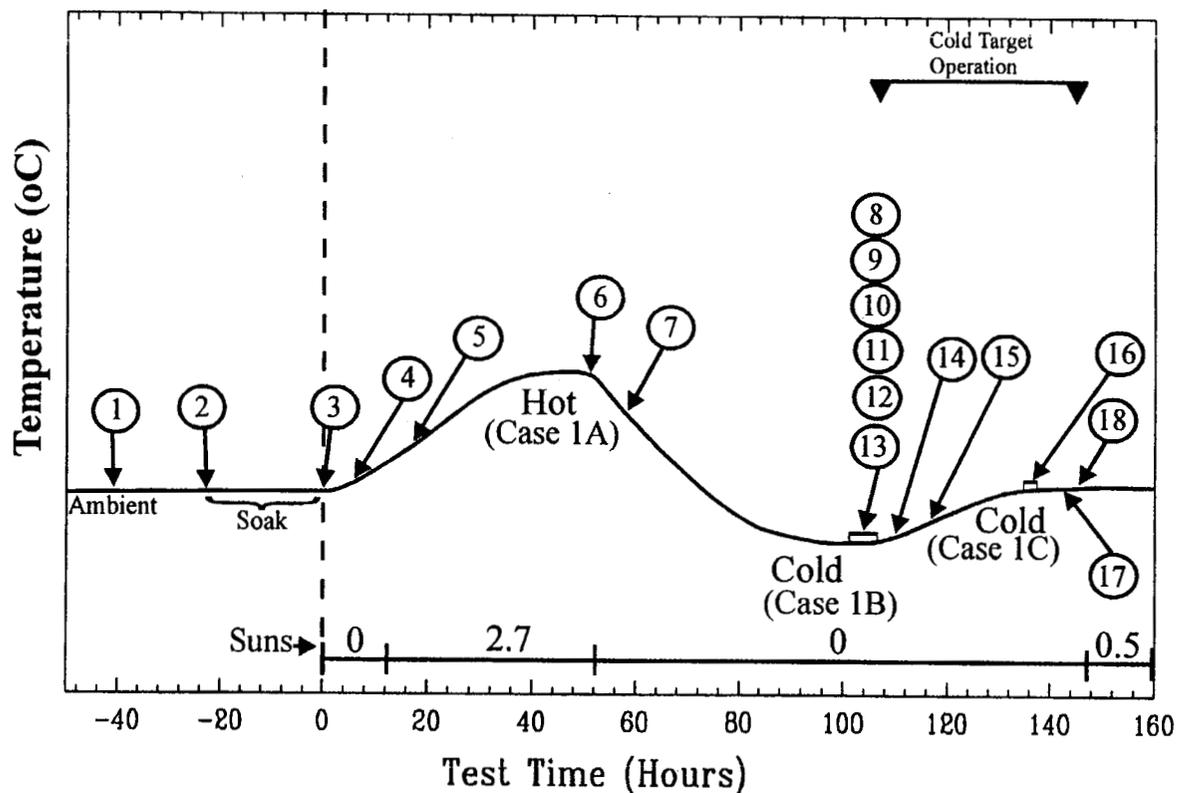


Thermal Balance Test Profile



Thermal Test Discussion Panel

Cassini STV Test Phase 1 Event Timeline



Event No.	Description
1	S/C Baseline Test
2	Close Chamber
3	Nitrogen Flush
4	Start Cooling Shrouds
5	Turn OFF Purge
6	Configure Power for Case 1A
7	Turn off Heaters TBD for Cooldown
8	Acceleration
9	Configure Power for Case 1B
10	CIRS Interference Test
11	CAPS HV Test
12	CDA Interference Test
13	ISS Interference Test
14	Radar 30 minute Turn-ON
15	RWA 30 minute Turn-ON
16	Turn on Heaters for warm-up acceleration
17	Configure Power for Case 1C
18	CIRS, VIMS & ISS Functional Tests and CIRS Microphonics Test
19	Configure Power for Backfill
20	turn ON Purge

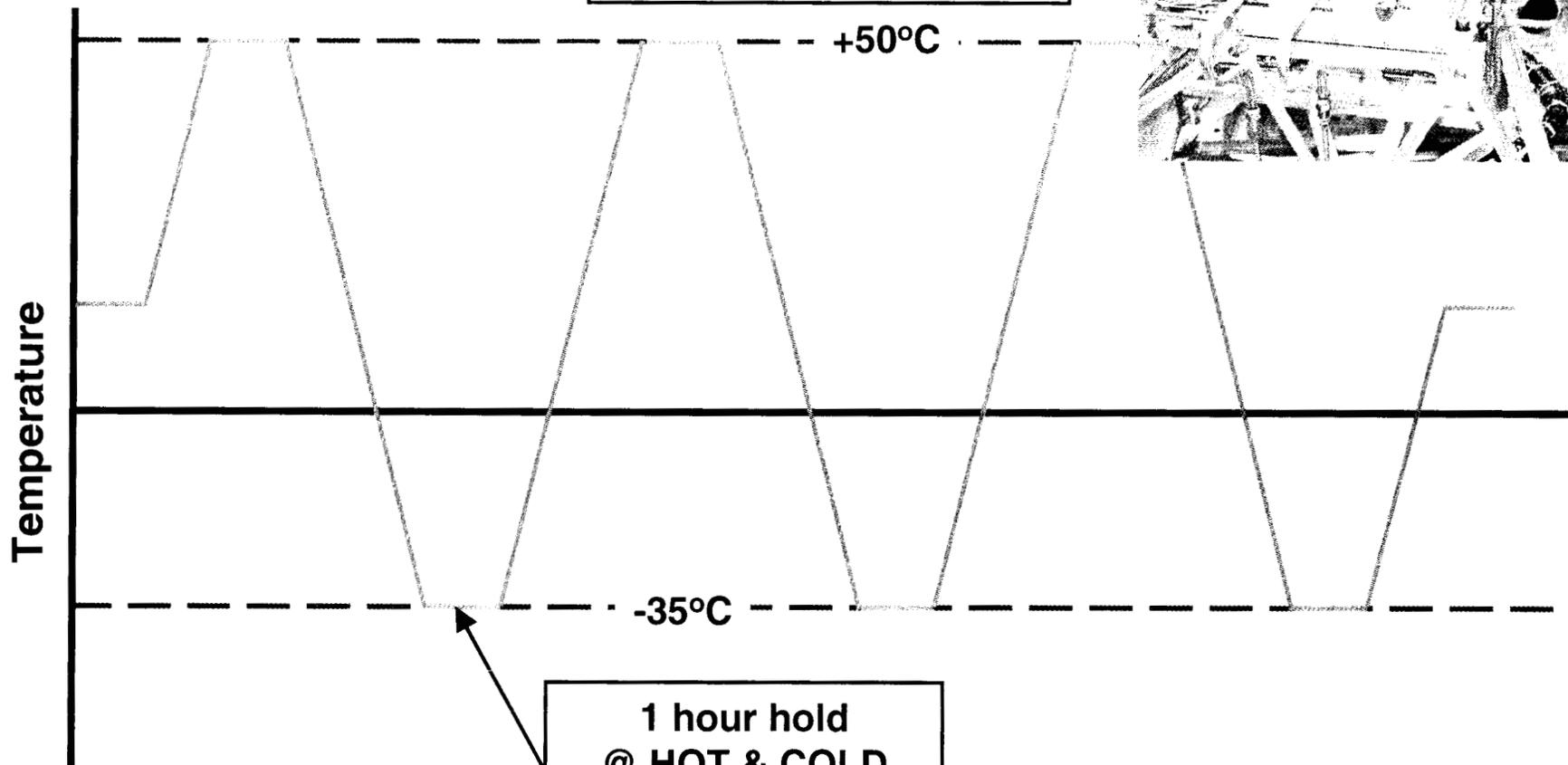
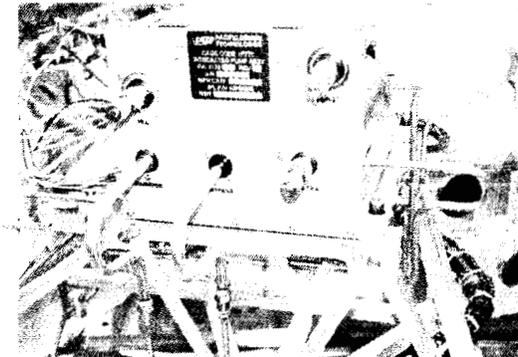


MER IPA SN001 PF Thermal Vacuum Test Profile



Thermal Test Discussion Panel

3 thermal cycles with 50
& 24 cumulative hours
hot & cold, respectively



1 hour hold
@ HOT & COLD
Start at least once
at each plateau

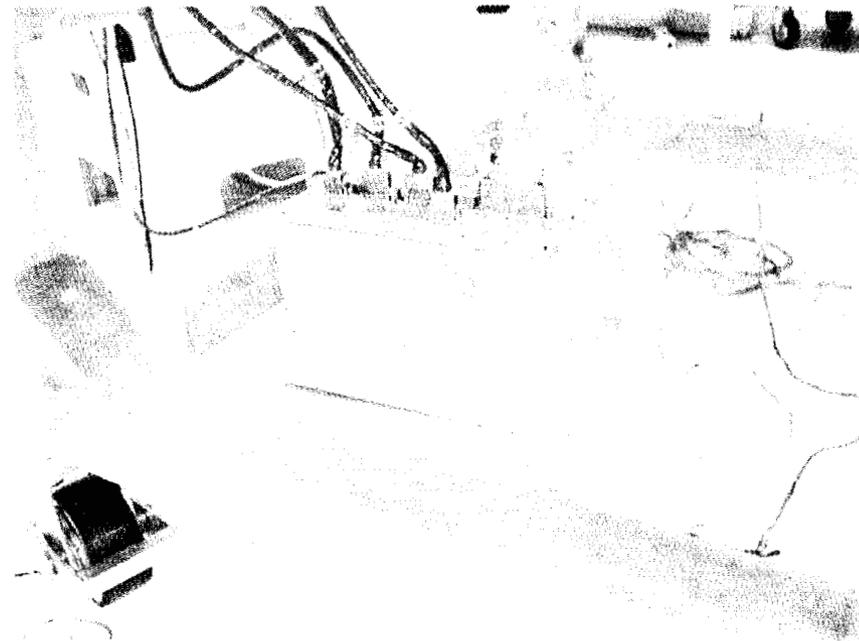


Case Study – Electronics Box



Thermal Test Discussion Panel

- **An externally mounted power distribution box (PDB)**
 - Nominal power dissipation: 36 watts
 - Safe mode power: 8 watts
 - **AFT limits:**
 - Op: -20 to 45°C
 - Survival: -20 to 50°C
 - **Predicted temperature range:**
 - -5 to 34°C for a 5-year low-earth orbit mission (EOL optical properties & dissipation)
 - **Requires thermostatic heaters to maintain PDB at or above -15°C**
 - Thermostat setpoints: -15 & -5C
 - Powered on survival bus operating between 24 & 32V





Thermal Design Assumptions



Thermal Test Discussion Panel

Primary & backup survival heater strings that have both power switches enabled

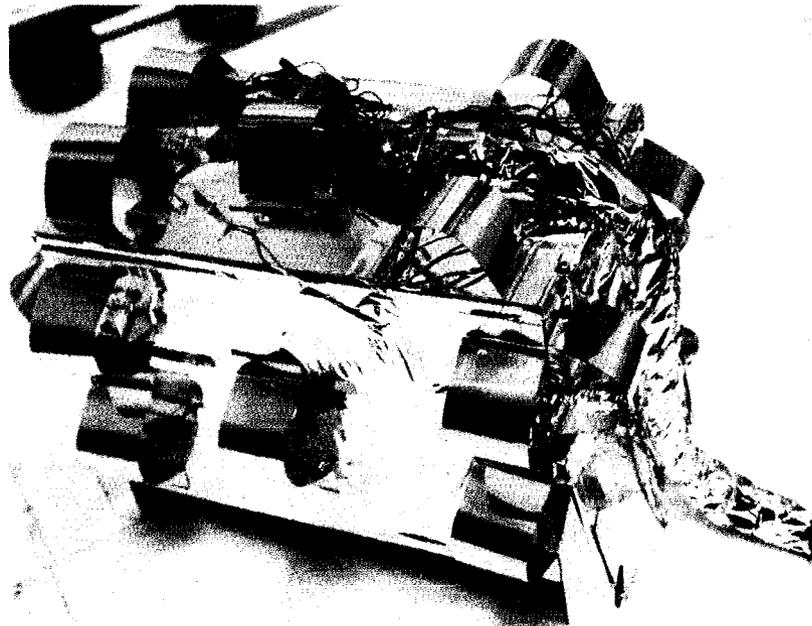
Primary & backup thermostats setpoints staggered

Radiator area probably needed, provisions in place to permit easy area modification

Insulation covers entire unit except for radiator area

No heat flow allowed through mounting I/F

AFT limits apply to the bulk average temperature



Heater power < 24W (current draw < 1 amp, only series thermostats required)



Hardware Design Assumptions (1/2)



Thermal Test Discussion Panel

- **Assume PF test program**
 - **PF operating test levels: -35 (cold) & 70°C (hot)**
 - Driven outside $-15/+20^{\circ}\text{C}$ margin to meet minimum of -35 to 70°C
 - 3 to 10 thermal cycles
 - Dwell cumulative 24 hrs cold & 144 hrs hot
 - Assume a temperature ramp rate of 120°C/hr is acceptable
 - **PF survival test levels: no cold test required, covered by operational test**
 - Unit “turn-on” at non-operating levels captured by PF operating test
 - **Assume hardware can fit into 3-foot diameter thermal vacuum chamber**

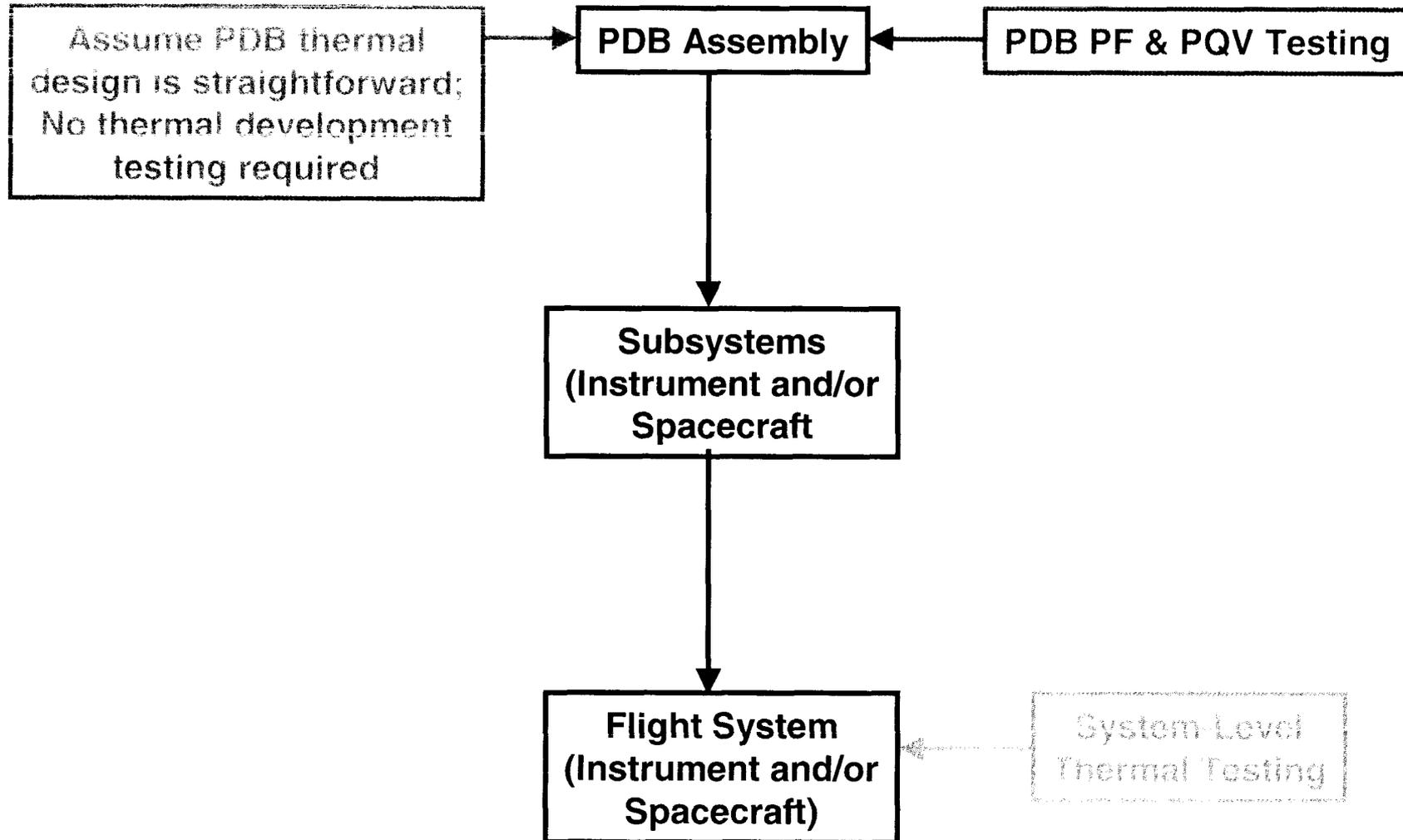
- **Assume electronics packaging qualification successful**
 - **Assume 2 cycles a day for 5 years = 3650 flight cycles**
 - **Assume ground testing adds additional 6 thermal cycles**
 - **3 times life = 10,968 thermal cycles**



Hardware Design Assumptions (2/2)



Thermal Test Discussion Panel



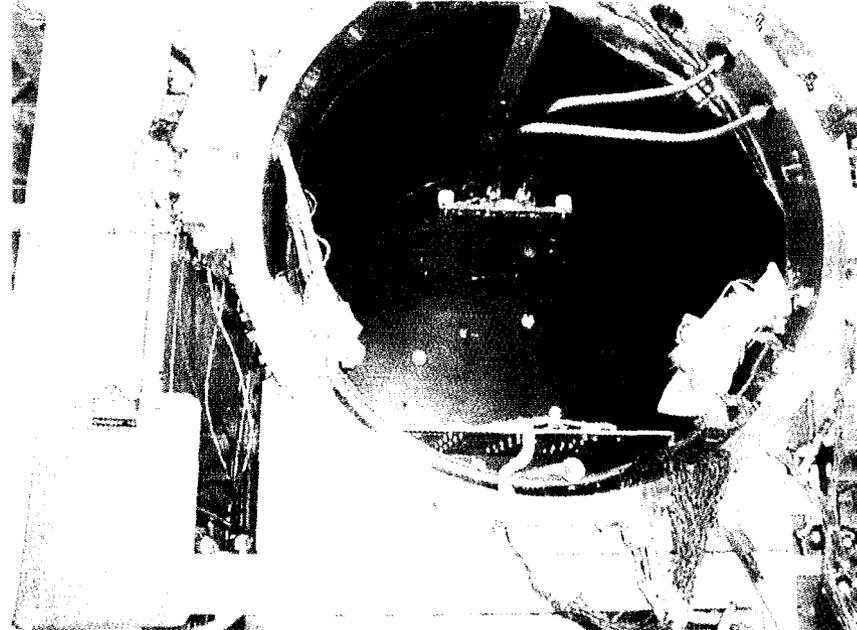


PF Testing



Thermal Test Discussion Panel

- **PF testing accomplished by mounting flight hardware to a heat exchanger & using chamber shroud**
 - PDB will be covered with a test thermal blanket
- **If multiple units were fabricated (i.e., flight spare), these units could be tested to FA levels upon concurrence from QA**
 - FA operating levels: -25 to 50°C
 - FA dwell times: 24 hrs cold & 50 hrs hot
 - FA number of thermal cycles: probably 3





System Thermal Test (1/2)



Thermal Test Discussion Panel

- **Validate PDB power dissipation**
 - Obtain copy of Hardware Requirements & Certification Review (HRCR) power sheet
 - Verify power dissipation with PDB ATLO engineer
- **Establish extreme thermal test conditions**
 - Internal power & external environment
- **Determine if any special PDB tests are required**
 - Primary & secondary heater string validation
 - Consider power sensitivity for radiator sizing
 - Empirical data for verification by analysis
- **Determine if PDB needs a test heater**
 - EOL heat load simulation
 - Acceleration, warm-up, fail-safe and/or special test requirements
- **Determine PDB test instrumentation locations**



System Thermal Test (2/2)



Thermal Test Discussion Panel

- **Establish test yellow & red alarms**
 - Yellow: AFT limits
 - Red: FA levels
- **Understand & accommodate ATLO's functional test needs for the PDB**
 - Review end-to-end functionality V & V rather than focusing on temperature requirements
 - Determine need for any special test targets or support equipment
- **Develop contingency plans in the event the design is deficient**



References



Thermal Test Discussion Panel

- Siebes, G. “System Thermal Testing Standard,” Internal JPL Document D-22011, March 15, 2002.
- Yarnell, N. “Design, Verification/Validation and Operations Principles for Flight Systems,” Section 4.8.2.1, Thermal Control Design Margin, Internal JPL Document D-17868, March 3, 2003.
- Greenfield, M. “A Guide for Temperature Control Engineers on Planning, Instrumentation, and Thermal Testing Activities for Spacecraft Level Solar Thermal Vacuum (STV) Tests,” Section 3.0, Instrumentation Planning, Internal JPL Document D-7626, April 1990.
- Gilmore, D. (editor) *Spacecraft Thermal Control Handbook, Volume I: Fundamental Technologies*, American Institute of Aeronautics and Astronautics, Inc., Reston, VA, Chapter 19, Thermal Testing, 2002.