Thermal Testing Short Course

Why Do You Test? / “Foundations” of Test

Glenn Tsuyuki
Jet Propulsion Laboratory
California Institute of Technology

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Course Objectives

- Become familiar with a systems engineering approach to thermal testing

- Understand the different types of thermal testing

- Understand the process for planning, preparing, and executing a thermal test including those involving flight hardware

- Understand methods of test environment simulation & temperature control

- Understand the role of analysis in test planning and preparation

- Examine how the elements of planning, preparing, and executing are exercised in a case study
A Good Test is Worth 1000 Analyses

- The operative word is “good”
  - A good test is one that singly focuses to meet your primary objectives & accommodates the needs of secondary objectives including functionality
  - Primary objectives are synthesized by asking yourself why are you conducting a test?
  - Generally, an empirical test is performed to improve your knowledge of some hardware of design aspect
  - A poorly conceived test is practically worthless
Why Do We Perform Tests?

- To characterize parameters that are difficult to quantify analytically
- To characterize design performance/behavior

DEVELOPMENTAL TESTING
We Don't Plan to Fail, We Fail to Plan

At the heart of a “good” test is a good test plan

- MECH & ELECT SUPPORT EQUIP
- OBJECTIVES
- FACILITIES

- INSTRUMENTATION
- DATA ACQUISITION EQUIP

- SCHEDULE
- SAFETY
- BUDGET
- QA
- WORKFORCE

- INSTITUTIONAL/PROJECT POLICIES
What Makes a “Good” Test

- Well defined objectives (primary & secondary)

- A test case matrix that directly maps into the objectives

- Understanding your role & duties in planning, preparing, executing, and documenting the test

- Understanding your resource constraints
  - Financial budget
  - Schedule
  - Facilities including instrumentation & data acquisition
  - Mechanical & electrical ground support equipment
  - Workforce

- Tapping into the test experiences of others
  - Conduct peer reviews of your plan & approach
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Types of Thermal Testing

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There Are Three General Categories

**DEVELOPMENTAL TESTING**

- To characterize parameters that are difficult to quantify analytically
- To characterize design performance/behavior

- Thermal environment is known
- Temperature is a dependent parameter

*Thermal Test Short Course*
Thermal Development Testing

- Used to assist design development, especially for situations that are difficult to characterize analytically and are key thermal design drivers
  - Insulation performance, especially MLI blankets
  - Interface contact conductance
  - Bearing conductance

- Used to expand thermal design space beyond a “single point”
  - Investigate if a design approach is feasible (“proof-of-concept”)
  - Determine design sensitivity to key thermal parameters

- This type of testing aims to reduce design deficiency risk

- Typically, non-flight hardware used for test article
  - You must understand your needs for the fidelity of the test article (thermal control model or thermal mock-up)
MER Propellant Line Thermal Blanket Development Test

**Objective**
- To characterize effective emittance for a series of blanket geometries
  - Straight
  - Tee
  - Elbow

**Results**
- Results were imported into analytical model for heater sizing
  - Thermal balance for a propellant line zone is on the order of a few tenths of Watts
APEX Camera & Electronics
Thermal Development Test

Objectives
- To determine amount of Mars nighttime survival heater power for the camera
- To determine amount of camera warm-up heater power
- To determine camera thermal response to transient changes in atmospheric & effective sky temperatures
- To determine effectiveness of electronics thermal insulation
  - Novel approach that uses stagnant in-situ Mars atmosphere
- To characterize electronics heat loses through insulation, mounting, and cabling

Results
- Adopted novel insulation approach as baseline
- Verified survival & warm-up heater camera power
- Correlated analytical model to transient test data
Assembly Protoflight/Qualification OR Flight Acceptance Testing

- Used to demonstrate assembly workmanship and design reliability
  - Sometimes referred as “margin testing”

- Test temperature levels, dwell times, temperature ramp rates, and number of thermal cycles are dictated by institutional or project policies

- Traditional test program is QUAL/FA or PF
  - EM hardware subjected to QUAL testing
  - FLT hardware subjected to FA testing
  - OR FLT hardware subjected to PF testing
Mars’01 Lander Heat Pipe Flight Acceptance Test

Objectives

- Validate flight units function in reflux mode in-air
- Validate capability to transfer 1 watt under various tilt angles
- Quantify thermal gradients along heat pipe
- Compare pre-start-up thermal gradients to analytical predictions

Results demonstrated that flight units would transfer sufficient heat during cruise to Mars
- Hardware accepted for flight
MER Integrated Pump Assembly
Thermal Protoflight Testing

Objective
- Demonstrate in-specification performance (pump ΔP & flow rate) over temperature ranges greater than allowable flight temperature (AFT) limits

- Operating AFT limits
  - -20°C to +30°C

- Operating Protoflight (PF) limits
  - -35°C to +50°C

- Dwell durations
  - Cumulative 24 hours cold
  - Cumulative 50 hours hot

- Number of thermal cycles
  - 3 times lifetime requirement
  - 3 test cycles

Test results met objectives
- Hardware accepted for flight
System- OR Assembly-Level Thermal Balance Testing

- Used for thermal design validation and hardware functionality in expected thermal environment
  - “Validation” versus “Verification”
  - First discovery of a design deficiency is very costly (budget & schedule) to rectify at this point
  - Hardware functionality includes thermal items such as heaters, thermostats, temperature sensors, heat pipes/CPLs, & pumps

- Two basic approaches
  - Empirical
    - Bounding worst-case thermal environments
  - Combination of test & analysis
    - Specified hot & cold thermal environment to obtain data for analytical model correlation
    - Analytical model utilized to demonstrate design requirement compliance
• Objectives
  – Validate instrument thermal design for worst-hot & -cold Earth orbit conditions
  – Validate survival (primary & secondary) heater string operation
  – Validate optical performance

• Design validation was empirical
  – Test results met objectives
    • Design maintained allowable flight temperatures for extreme environmental cases
    • Primary & secondary survival heater strings validated
Objectives
- Validate thermal design for mission worst-hot & -cold conditions
  - Solar simulation used
  - IR lamps used for off-sunpoint simulation
- Validate mechanical pump fluid loop operation
- Validate primary & secondary thermostatic heater strings

Design validation was empirical
- Test objectives met
- Uncovered swapped primary & backup thermostats on four assemblies
- Determined –Z sun sensor did not require silverized Teflon tape
• Objectives
  - To perform representative steady-state & transient cases to gather empirical data for analytical model correlation
    * Simulation of Mars surface environment extremely challenging (e.g., diurnal solar heating, wind simulation, 3/8 gravity field, CO₂ atmosphere)
  - To validate critical deployments & releases at cold temperature
  - To perform science instrument calibration at various temperatures

• Design validation used a combination of test & analyses

• Results
  - Test data confirmed development test results that WEB thermal design is robust
  - Provided empirical data for actuator heater warm-up validation
  - Demonstrated critical deployments & science calibrations