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Improving Environmental Test Preparation

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Document Change Record

Issue	Date	Sheet	Description of Change
1	17.11.2012		First Issue
2	11.07.2013	All	The second issue makes changes to the format of the document making it easy to read and more clearly identifying important guidelines. The contents of the document, however, remain largely unchanged.

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1 INTRODUCTION

1.1 Introduction

Thermal testing represents an important step in the verification of all spacecraft hardware, be it on equipment, instrument or spacecraft level. Thermal tests are critical as the hardware is submitted to significant stress, often under time pressure. Consequently, it is of significant importance that these tests are thoroughly prepared for and that the necessary tools and processes are used to monitor them.

The ESA Study titled "Improving Environmental Test Preparation: Lessons Learned and Guidelines for Thermal Tests" aims at improving thermal test preparations, by creating a set of guidelines to help thermal engineers planning a thermal test.

When putting together guidelines for future thermal tests it is important that the experiences of past tests and current developments in thermal testing flow into these guidelines. This ensures that past problems are not repeated and that advances in technology can be used to their full extent. Such a review shall include experiences from different levels of testing (i.e. satellite level, instrument level, equipment level, etc) at a broad range of environmental testing conditions (i.e. simulated LEO, GEO, SSO, L2, interplanetary missions, etc). Therefore the guidelines may then be applied to an extensive variety of future thermal tests.

1.1.1 Scope

This document intends to help a thermal engineer in the preparation of thermal testing activities. Major topics are split into groups and for each group a checklist is presented. Each checklist is design to help thermal engineers identify major considerations and ensure that these are taken into account.

The checklists are based on the information gathered in the document “Thermal Tests – State of the Art and Review of Lessons Learned” [RD 01].

2 DOCUMENTS & ABBREVIATIONS

2.1 Applicable Documents

	Document No.	Issue	Description
[AD 1]	TEC-MTV/2011/3519 /In/BEL	Iss 1 Rev 3	Statement of Work: Improving Environmental Test Preparation - Lessons Learned and Guidelines for Thermal Test
[AD 2]	ESA PO 5401000860	20/10/ 2011	ESA Purchase Order for Improving Environmental Test Preparation: Lessons Learned and Guidelines for Thermal Test

2.2 Reference Documents

	Document No.	Issue	Description
[RD 1]	IETP-AST-TN-0001	1	Thermal Tests – State of the Art and Review of Lessons Learned
[RD 2]	GSFC-STD-7000	04 / 2005	General Environmental Verification Standard (GEVS)
[RD 3]	JPL D-22011	03 / 2002	System Thermal Testing
[RD 4]	MIL-HDBK-340A	04 / 1999	DoD Handbook: Test Requirements for Launch, Upper-stage and Space Vehicles, Volume 1 and 2
[RD 5]	MIL-STD-1540D	01 / 1999	DoD Standard Practice: Product Verification Requirements for Launch, Upper-stage and Space Vehicles
[RD 6]	SMC-S-016	06 / 1999	Space & Missile Systems Center Standard: Test Requirements for Launch, Upper-stage and Space Vehicles
[RD 7]	ECSS-Q-ST-70-04C	11 / 2008	ECSS - Space Product Assurance Thermal testing for the evaluation of space materials, processes, mechanical parts and assemblies
[RD 8]	ECSS-E-ST-31C	11 / 2008	ECSS - Space Engineering Thermal control general requirements
[RD 9]	ECSS-E-10-03A	02 / 2002	ECSS - Space Engineering Testing
[RD 10]	ECSS-E-ST-10-03C	06 / 2012	ECSS - Space Engineering Testing
[RD 11]	AIAA 2010-6289	2010	A. Avila, "Thermal System Verification and Validation Process" Paper presented at the 40th ICES, Barcelona, July 2010
[RD 12]	2008-01-2038	2008	H. Peabody, R. Stavely, W. Bast "Lessons Learned from the Wide Field Camera 3 TV1 and TV2 Thermal Vacuum Test Campaigns" Paper presented at the 38th ICES, San Francisco, July 2008
[RD 13]		08 / 2010	Thermal & Fluid Analysis Workshop (TFAWS) 2010 "Thermal Vacuum Testing: Test Preparation"
[RD 14]	JPL D-66278	08 / 2010	"James Webb Space Telescope (JWST) Test Assessment Team (TAT) Final Report

	Document No.	Issue	Description
[RD 15]	AIAA 2011-5010	2011	S. Barraclough, K. Smith, N. Fishwick, J. A. Romera-Perez "Thermal Test Verification of the Performance of LISA Pathfinder" Paper presented at the 41st ICES, Portland, July 2011
[RD 16]	AIAA 2011-5163	2011	B. M. Shaughnessy "Satellite Thermal Engineering - lessons from ICES" Paper presented at the 41st ICES, Portland, July 2011
[RD 17]	AIAA 2010-6165	2010	M. Maschmann "Cryogenic Thermal Test of the JWST NIRSpec" Paper presented at the 40th ICES, Barcelona, July 2010
[RD 18]	AIAA 2012-3425	2012	C. Brysbaert, J. Sicre, J.-Y. Disson, G. Mas "Challenging Environmental Testing for the RPW Experiment on Solar Orbiter" Paper presented at the 42nd ICES, San Diego, July 2012
[RD 19]	IETP-AST-TN-0003	1	Review of Thermal Testing Standards

2.3 Abbreviations and Acronyms

Short Form	Full Form / Description
AD	Applicable Document
AIT	Assembly, Integration and Test
AITP	Assembly, Integration and Test Plan
AIV	Assembly, Integration and Verification
AST	Airbus Defence & Space
CDR	Critical Design Review
ECSS	European Cooperation for Space Standardisation
EGSE	Electrical Ground Support Equipment
ESA	European Space Agency
ESD	Electrostatic Discharge
FBT	Functional Blank Test
GEVS	General Environmental Verification Standard
GMM	Geometrical Mathematical Model
GSE	Ground Support Equipment
H/W	Hardware
ICES	International Conference for Environmental Systems
I/F	Interface
JWST	James Webb Space Telescope
MGSE	Mechanical Ground Support Equipment

Short Form	Full Form / Description
MLI	Multi Layer Insulation
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NCR	Non-Conformance Report
NRB	Non-Conformance Review Board
OGSE	Optical Ground Support Equipment
PA	Product Assurance
PDR	Preliminary Design Review
QA	Quality Assurance
RFD	Request for Deviation
RFW	Request for Waiver
S/C	Spacecraft
STM	Structural Thermal Model
TB	Thermal Balance
TMM	Thermal Mathematical Model
TPRO	Test Procedure
TRPT	Test Report
TRR	Test Readiness Review
TSPE	Test Specification
TV	Thermal Vacuum
TVC	Thermal Vacuum Chamber

3 OVERVIEW

3.1 Checklists

The literature review and lessons learned [RD 01] and [RD 19] served as a starting point for the development of a guidelines checklist, covering the major issues identified during past tests and in other guideline documents.

Due to the shear amount of information available and the lengthy process of planning a test, a single checklist is not practical. To ensure that only relevant guidelines and lessons learned are addressed at the appropriate time, the checklists are broken down into smaller groups, based on major topics.

The major topics covered by the checklists are:

- Checklist for the Early Project Phases
- Checklist for Test Facility
- Checklist for Test Predictions
- Checklist for Ground Support Equipment
- Checklist for the Thermal Test Hardware and Instrumentation
- Checklist for the Data Acquisition and Alarms
- Checklist for Test Documentation & Procedure
- Checklist for the Test Preparation Work
- Checklist for the Test Readiness Review
- Checklist for the Test Performance & Organisation

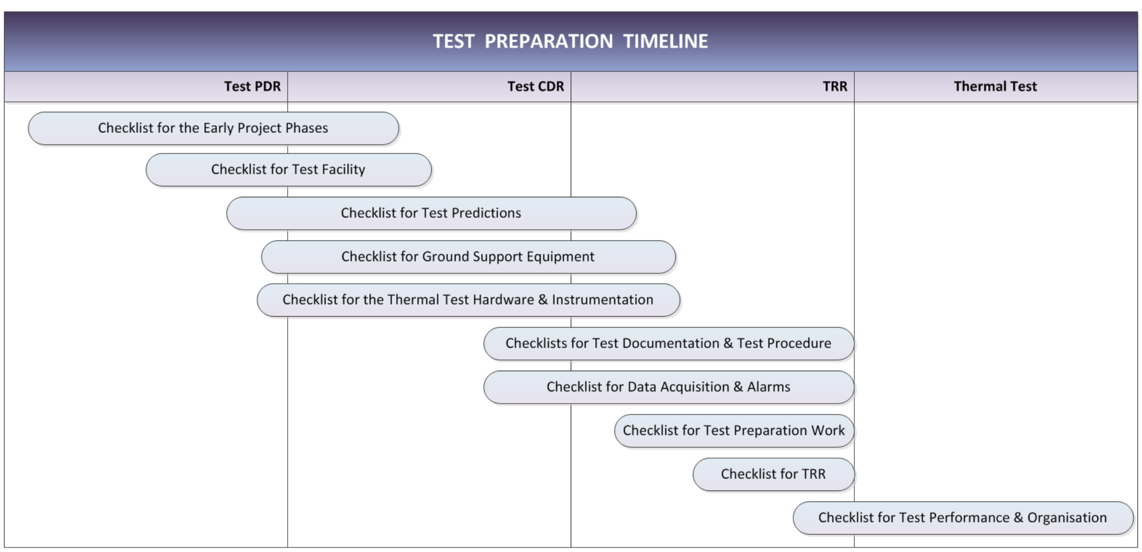


Figure 3-1 Approximate Timeline for using Checklists

These checklists are presented in Chapter 4 and are designed to help a thermal engineer (and or test director) prepare for various phases in the preparation and performance of a thermal test.

The checklists have been generalised so that they can be applied to almost any test. This means that under certain circumstances some of the items on a checklist may not be applicable, for example items which specifically relate to cryogenic or high temperature tests.

Each of the checklist items is given an ID. The order of items is based on the approximate sequence (if applicable) that one would follow when approaching the topic. The checklist ID is colour coded to indicate which team managers are primarily responsible for addressing this checklist item:

Test Director, AIT & Thermal Manager	Thermal Manager	Thermal Manager & QA	Thermal Manager & Other disciplines/facility

3.2 Guidelines

A number of non-checklist type guidelines are shown. These identify the most critical areas and are hence often repeated in the relevant checklist. The guidelines are colour coded into “Do”, “Do Not” and “Cryo Guidelines” categories:

GUIDELINE	A guideline with a green background is a **“DO”** guideline
GUIDELINE	A guideline with a green background is a **“DO NOT”** guideline
CRYO GUIDELINE	A guideline with a blue background is a guideline which is relevant only to tests in a **CRYOGENIC** environment

4 GUIDELINES & CHECKLISTS FOR THERMAL TESTS

4.1 Early Project Phases

One of the major issues identified in past test campaigns, is that activities related to the preparation of a thermal test are usually only given the correct amount of attention when the test is in the foreseeable future. This checklist aims to give thermal engineers a number of “general” points which should be considered early in the project (prior to PDR), ensuring that the test is properly prepared for and that no nasty surprises occur, which may affect project quality, costs and schedule. Early planning and consideration of thermal testing also makes it considerably easier to prepare a good facility specification and test plan.

Starting early also ensures that adequate time is available to design, manufacture and verify GSE and the test setup. Using an incremental verification approach, e.g.. breadboard testing, may also be an option which can help identify problem areas early and allow these to be addressed prior to a large thermal test.

Although preparing for a thermal test, it should not be forgotten that other testing (e.g. functional and performance) is often performed during a thermal test. Hence, it is important that through all preparation activities, the thermal engineer consults other stakeholders, such as the other discipline architects, the system engineer, the AIT manager, the PA manager and the customer. Communication between disciplines is vital to an efficient and successful test campaign. Understand what is important to the other disciplines and the customer, and make sure they understand what is important from a thermal point of view.

GUIDELINES for EARLY PROJECT PHASES

GUIDELINE	Design it so it can be tested, model it so it can be predicted, build it so it will be tested, test it as it is flown and fly it as it was tested. [RD 11] and [RD 12]

GUIDELINE	Ensure that all requirements are verifiable [RD 11]

GUIDELINE	Make harness routing (both test and flight harnesses) one of the major topics to be considered throughout the entire test preparation process.

GUIDELINE	Using an external (non-project) team of test experts, perform an independent review of the test plan. (perform early in preparation phase) [RD 14]

GUIDELINE	Identify applicable industry standards (e.g. ECSS) and read these standards.

GUIDELINE	It is recommended that test preparation reviews, such as a Test PDR, Test CDR or what NASA calls a Pre-Environmental Review (PER), are foreseen in the schedule.

CHECKLIST for EARLY PROJECT PHASES

ID	Description	Done
TST-01	Identify what needs to be verified by test (i.e. requirements).	
TST-02	Identify and prioritise key requirements and use these requirements to design and implement the test program. [RD 14]	
TST-03	Identify those verification tasks which ensure that the system operates at a minimal acceptable level. These requirements must be verified as soon as possible. [RD 14]	
TST-04	Identify the test objectives and clearly state the success criteria	
TST-05	Determine if tests are necessary or optional and then prioritise tests [RD 14]	
TST-06	Determine if an incremental thermal verification approach can be used to provide initial feedback, minimise risk and identify possible problems early in the verification process? (e.g. where can breadboard testing be useful) [RD 11]	
TST-07	Identify what will be difficult to test and why. Determine how these difficulties can be addressed.	
TST-08	If it is not possible to test under exact flight conditions, determine how the test specimen can be tested such that a corresponding model can be accurately correlated? [RD 16]	
TST-09	Identify stakeholders and consult (i.e. Speak to other disciplines – what do they require, what conflicts exist). Tip: Actively involve other disciplines and customer.	
TST-10	Prepare a schedule and resources plan for all test related activities. Tip: plan regularly meetings (even in early phases) to review status of preparation activities	
TST-11	Identify which thermal tests on which parts/units are necessary as per the industry standard	
TST-12	Identify the number of thermal cycles required (as per industry standard and customer requirements) – Acceptance, Qualification and Proto-flight	
TST-13	Identify the temperature levels which need to be tested (as per industry standard and customer requirements) – Acceptance, Qualification and Proto-flight	
TST-14	Identify which additional thermal tests, which are not required as per the industry standard, are required as per the customer's requirements.	
TST-15	Identify the maximum allowable test tolerances (as per industry standard and customer requirements)	
TST-16	Identify any thermal uncertainty margins which may be required (as per industry standard and customer requirements)	
TST-17	Identify any thermal balance requirements (as per industry standard and customer requirements)	

4.2 Test Facility

Writing the specification for a test facility and then selecting a facility are an important part of the test preparation process. Particularly tests under cryogenic, extremely high solar loads or under non-earth planetary atmospheres need to carefully consider the adequacy of a test facility.

This checklist aims at helping the thermal engineer identify some of the issues that need to be considered when writing a facility specification and selecting the appropriate chamber and test facilities.

GUIDELINES for TEST FACILITY

GUIDELINE	Involve other disciplines in the analysis of the appropriateness of a facility.

GUIDELINE	Consider the routing of the harness in selecting flange locations. Consider harness flexibility and length.

GUIDELINE	For tests using solar simulation – when a high solar intensity is used (e.g. mercury orbit or close to sun) ensure that the facility provides a solar simulator intensity map, such that the test profile can be adjusted accordingly. Ensure that the solar beam homogeneity is acceptable for the test.

CRYO GUIDELINE	For **CRYOGENIC** tests [RD 17]: • identify any hot spots inside the chamber (e.g. rail mountings, harnesses). • identify any openings in the LN2 shroud (e.g. opening for vacuum pumps)

CHECKLIST for TEST FACILITY

ID	Description	Done
FAC-01	Identify any specific facilities that are required (e.g. helium, ISO Class 5 cleanroom, ESD, working area/offices)	
FAC-02	Identify which testing facilities are capable of verifying the requirement in a flight like environment. Take into consideration such items as cooling power, heating power, solar beam dimension and intensity, shroud temperature and homogeneity, size and motion interface [RD 16]	
FAC-03	Identify which facilities would require modification to perform the test. Identify any risks involved with such a modification. [RD 16]	
FAC-04	If it is not possible to test under exact flight conditions, how can the test specimen be tested such that a corresponding model can be accurately correlated? [RD 16]	
FAC-05	Determine if purging is required for the test specimen. If so check that the necessary purging ports with the required flow rates are available at the test facility.	
FAC-06	Determine what instrumentation is required for the test (e.g. temperature sensors, IR camera). What is the minimum number of test temperature sensors needed. Can the facility manage this number? Tip: always plan plenty of spares	
FAC-07	Determine how many test heaters (and corresponding power supplies) are required for the test. Can the facility manage this number? Tip: always plan plenty of spares	
FAC-08	Determine how many electrical interfaces are required for the test (e.g. at flanges). Check that the facility can manage this number. Tip: always plan plenty of spares	
FAC-09	What type of IR heating systems are available from facility side (e.g. shrouds, IR lamps, calrod heaters, mounting plates)	

4.3 Test Predictions

Thermal test predictions are an important tool in planning a thermal test. Using the thermal model, the thermal engineer can ensure that the test will allow the verification of the relevant requirements, identify possible constraints, calculate the probable test time and identify possible areas where the test can be optimised. Hence it is important that adequate attention is given to performing these test predictions.

Spend the necessary effort to modify the flight thermal model into a test thermal model. Ensure that the modelling is done in such a fashion that the model can be easily correlated after the test, e.g. nodes based on sensor locations and the use of parameters (refer to ECSS Handbook Thermal Analysis Guidelines)

Depending on the test environment e.g. for cryogenic testing and high intensity solar loads, the detailed models of the chamber and GSE may be needed. Instead of relying purely on the facility provided CAD or thermal models the thermal engineer should inspect the chamber personally and identify any differences and integrate these changes into the thermal model.

Harness modelling is often not included, although the harness setup can have a notable impact on the thermal subsystem, through the influence of parasitics and joule heating. Hence, the thermal engineer should include both the test and flight harness in the modelling.

The predictions shall also allow the verification that the GSE and harnesses (including connectors) stay within their allowable temperature limits.

MLI and those units sensitive to changes in dissipations should be carefully examined in a sensitivity analysis. A useful exercise is creating a “change in temperature vs. change in power” table, based on results of a sensitivity analysis. This table can be used as a reference during testing to identify the cause of higher or lower than expected temperatures and, if necessary, address these inconsistencies by verifying and adjusting the dissipation accordingly.

GUIDELINES for TEST PREDICTIONS

GUIDELINE	Ensure that modelling is done such that the model can be easily correlated after the test (e.g. parametric, nodes corresponding to temperature sensor locations, etc.)
GUIDELINE	Check that the facility provided chamber model is detailed enough for the test. This is particularly important for cryogenic and very high temperature tests.
GUIDELINE	Create a separate thermal model just for the test. This model should be based on the thermal model being tested (e.g. structural-thermal, qualification, flight, etc.)
GUIDELINE	Ensure that enough attention is given to the modelling of GSE and other test hardware.
GUIDELINE	Ensure that both the test and flight harnesses are modelled.
GUIDELINE	Check that the test article, the GSE and harnesses stay within the allowable temperature range, with margins.
GUIDELINE	Perform an inspection of the test article, GSE and chamber and check that model corresponds to the test setup.
GUIDELINE	For tests using solar simulation – when a high solar intensity is used (e.g. mercury orbit or close to sun) ensure that the facility provides a solar simulator intensity map, such that the test profile and model can be adjusted accordingly.

CHECKLIST for TEST PREDICTIONS

ID	Description	Done
PRE-01	Using a simplified thermal model, identify any possible issues (e.g. temperature cannot be reached using setup).	
PRE-02	Using a simplified thermal model, identify the expected time for the test and each test cycle.	
PRE-03	Has a separate test thermal model been created, based on the flight thermal model? Have all deviations from the flight configuration been taken into account and clearly documented in the test prediction report?	
PRE-04	Ensure that GSE (such as adapters, mounting plates, etc.) are taken into account in the thermal model.	
PRE-05	Ensure that all components (e.g. harness connectors, heaters, etc.) that are expected to reach a temperature close to the temperature limits, are modelled accurately.	
PRE-06	When modelling MLI, ensure that high uncertainties are used. (due to parasitic heat fluxes through MLI, i.e. bends, attachments, etc)	
PRE-07	Perform a sensitivity analysis on critical units (e.g. change in temperature vs. change in power)	
PRE-08	Ensure that the test article, the GSE and harnesses stay within the allowable temperature range. Ensure that temperature margins are taken into consideration.	
PRE-09	Identify the critical (temperature) locations on the test item. Ensure these locations are instrumented with temperature sensors, where appropriate.	
PRE-10	Using the test predictions, optimise the phases and test sequence (e.g. testing time, parallel testing)? [RD 12]	

4.4 Ground Support Equipment (GSE)

Ground Support Equipment can fall into a number of categories such as Optical (OGSE), Mechanical (MGSE) and Electrical (EGSE). As the GSE is used to help verify the actual test specimen, it is important that the GSE is designed, manufactured and tested with the same thoroughness as the test specimen itself.

Do not design the test around the GSE! You want to test in cryogenic conditions at 40K, but the GSE solution offered only allows testing at temperatures of 70K or higher, well in this case the solution is not acceptable. Modifying the test setup to match the GSE to save GSE costs only creates problems in the “test as you fly” approach and may actually end up resulting in higher costs for the rest of the project.

As a guide GSE should not be reused for another project, unless the testing tasks are identical or very similar. Adapting a piece of GSE which is already available to cover new requirements can easily end up costing more in manpower and modifications than the development of a new dedicated piece of GSE.

GSE is typically designed to be thermally isolated from the test specimen and the testing environment, to minimise the influence of the GSE, on the test results. Consider what impact this will have on the test – how long will it take to cool down the test adapter or warm-up a mirror? Waiting for the test adapter to reach the desired temperature when the rest of the test setup is already at the desired temperature is time consuming and costly.

GUIDELINES for GROUND SUPPORT EQUIPMENT (GSE)

GUIDELINE	Design the GSE around the hardware.
GUIDELINE	Do **NOT** design test around the GSE
GUIDELINE	The use of GSE from another project is **NOT** recommended. If a piece of GSE is re-used ensure that the tasks to be performed are identical.
GUIDELINE	The GSE shall **NOT** be the critical part during any part of the test. This is particularly applicable to test heaters (e.g. ensure test heaters use a high derating)
GUIDELINE	Thoroughly plan GSE verification with adequate margins.
GUIDELINE	Ensure that the GSE is designed to be robust with adequate reliability and/or redundancy
GUIDELINE	Involve other disciplines in the design and analysis of the GSE.

CHECKLIST for GROUND SUPPORT EQUIPMENT (GSE)

ID	Description	Done
GSE-01	Identify what GSE will be needed and how long it will take to design, manufacture and verify the GSE. Consider schedule implications.	
GSE-02	When designing GSE, which will be exposed to large temperature changes, consider the effects of thermal expansion (e.g. tight fit a room temperature may be very loose at cryo)	
GSE-03	Verify the GSE and ensure that it is designed with adequate margins (e.g. heaters)	
GSE-04	Select appropriate connectors for GSE. Be cautious when using smaller and susceptible connectors. Ensure that connector temperature limits are acceptable for the test.	
GSE-05	Identify locations for suitable harness feedthroughs, for any GSE harnesses, in the test chamber	
GSE-06	Identify the routing to be used for the GSE harnesses. Consider the flexibility and allowable bending radii. If required limit motion through use of guide rails.	
GSE-07	Identify what effect the GSE will have on test duration (e.g. consider GSE which is thermal isolated from the test setup).	
GSE-08	Identify locations without a temperature sensor which may become critical (temperature, contamination, etc.). How can the risk at these locations be reduced (e.g. filter mounts are 5°C colder than the filters, hence when filter mounts are at 50°C the filters will be at approximately 55°C)	
GSE-09	When using test heaters perform a sensitivity analysis of the effects of the power setting on the test specimen. This information can be used as a quick reference guide for adjusting heater power in the scenario that the test specimen is either colder or hotter than expected (e.g. 1W additional power will increase the temperature by 10°C)	
GSE-10	Determine if a bake-out is required prior to installing GSE in the chamber [RD 13]	
GSE-11	Identify what effects outgassing of materials, under vacuum conditions, will have on the test and/or test specimen. [RD 18]	
GSE-12	Prepare a list of people who are allowed to operate the GSE (i.e. trained personnel)	
GSE-13	Determine if an in-chamber video camera can be installed, inside the chamber, to monitor the test and test specimen. [RD 15]	

4.5 Thermal Test Hardware and Instrumentation

Thermal testing hardware and instrumentation includes such items as MLI, heaters, temperature sensors and the relevant cabling or wiring.

Selecting and preparing the appropriate test hardware is important in ensuring that the test performs as desired and in guaranteeing that the data can be properly measured and recorded. Planning the location of test sensors, heaters and other test hardware should be performed as soon as possible.

Temperature sensors should be selected based on temperature range and required accuracy. Often investing slightly more money in more accurate temperature sensors can be of advantage. Some sensors may need to be mounted using adapter plates or clamps - if this is the case consider what effect this will have on the sensors. If certain tapes are used for fixing sensors take into account the thermal optical properties, of these tapes, when exposed to simulated solar loads in a test.

Test MLI can be used to cover a warm test harness during testing, such as to minimise the influence on the test results. When this is done it is important to make certain that the harness does not exceed the allowable temperature limits (can be checked in model predictions). MLI may also need to be grounded during a test and this should be clearly planned prior to integration work in the chamber. The effects of the grounding cable should also be considered from a thermal point of view.

In some cases test hardware may need to be baked-out prior to testing, to reduce outgassing during the test. This needs to be taken into account in the preparation schedule.

GUIDELINES for THERMAL TEST HARDWARE & INSTRUMENTATION

GUIDELINE	Use calibrated sensors

GUIDELINE	Integration of test hardware, such as MLI or sensors, may need to be done in parallel to other integration activities, due to scheduling issues. If this is the case take into consideration that the work may take longer than planned.

GUIDELINE	When simultaneous work is being undertaken on a test specimen take caution when integrating MLI, as MLI can be easily damaged.

GUIDELINE	Ensure that all test hardware is procured in time. Sensors, cables, heaters and MLI foils may have a long lead time or require approval due to export restrictions.

GUIDELINE	Ensure that additional spare hardware is ordered and available for the test.

GUIDELINE	Allow adequate time to plan the exact location of the temperature sensors.

GUIDELINE	Use the model predictions to help determine the placement of sensors (e.g. critical locations as per model and don't forget the model will need to be correlated later)

CHECKLIST for THERMAL TEST HARDWARE & INSTRUMENTATION

ID	Description	Done
H/W-01	When planning location of temperature sensors, ensure that each sensor is measuring what you (the thermal engineer) want to measure. Take into account how the sensor is fixed (e.g. clamped, screwed, the use of adapter plates, etc)	
H/W-02	Ensure that redundant temperature sensors are used at all critical locations.	
H/W-03	Ensure that temperature sensors are appropriate for the test (e.g. temperature range and accuracy)	
H/W-04	Identify what effects the test instrumentation will have on the test environment (e.g. sensors may affect surface temperature, more instrumentation = less flight like). [RD 13]	
H/W-05	Identify what effects the test setup will have on the temperature sensors (e.g. false readings through tapes used to fix sensors and/or sensor leads).	
H/W-06	Identify what effects the test environment and setup will have on the MLI (e.g. MLI shrinkage, does the MLI actually cover the test article fully, BOL/EOL properties)	
H/W-07	Identify what effects outgassing of materials, under vacuum conditions, will have on the test and/or test specimen. [RD 18]	
H/W-08	Determine if a bake-out is required prior to installing hardware in the chamber (e.g. MLI, cables, ty raps). [RD 13]	
H/W-09	Select appropriate connectors for test hardware. Be cautious when using smaller and susceptible connectors. Ensure that connector temperature limits (with margins) are acceptable for the test.	
H/W-10	Identify the routing to be used for the thermal hardware harnesses. Consider the impact of the selected route on sensor measurements (e.g. unwanted parasitic heat loads)	
H/W-11	Identify locations for suitable harness feedthroughs, for any thermal hardware harness, in the test chamber.	
H/W-12	Consider harness derating rules even for test harnesses.	
H/W-13	When using tailor made sensors consider the use of a different type of sensor, at the same location, to verify sensor accuracy.	
H/W-14	When planning to wrap a test harness or harness bundle in MLI take into consideration the temperature limits of the harness. Particularly RF and power cables may exceed temperature limits.	
H/W-15	It may be necessary to ground MLI. If this is the case take the following into account: (i) grounding leads may affect thermal performance (e.g. parasitic coupling) (ii) all grounding points shall be identified in the interface control drawings and cross checked with MLI interface drawings (iii) for cryo applications avoid the use of copper grounding wires	
H/W-16	Ensure that the location of all test sensors and heaters are clearly documented, including identifier, serial numbers, types and limitations. Take pictures of the sensor locations.	

4.6 Data Acquisition, Emergencies and Alarms

Data acquisition and data control play an important role in ensuring that a test runs as desired and in checking that relevant criteria are met. Therefore the proper amount of attention needs to be given to the data acquisition tools available.

Alarms are used during the test to warn of possible violation of requirements or in the worst case, damage or destruction of equipment. Prior to testing, a thermal engineer should identify what alarms are necessary and ensure that these are implemented for the test.

GUIDELINES for DATA ACQUISTION, EMERGENCIES & ALARMS

GUIDELINE The robustness and stability of the data acquisition tool are crucial to the test being successful. Ensure that the tool is stable and has adequate redundancy capabilities (e.g. no data loss, data recovery in case of problem)

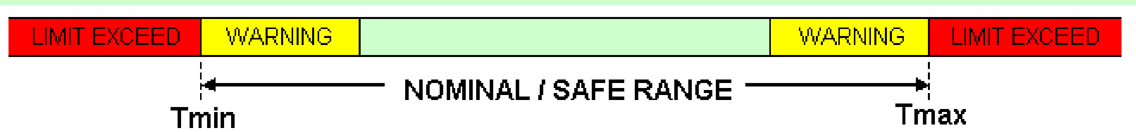
GUIDELINE Where possible the data acquisition tool should have tele-testing capability, allowing users to access the data real time.

GUIDELINE Where possible the data acquisition tool should allow access via the internet, such that the real time data can be accessed from anywhere at any time.

GUIDELINE The data acquisition tool should have the capability to set alarms which inform the thermal engineer or operator of a possible problem

GUIDELINE Alarms should be at least available in the form of a visual alarm and where possible also audio alarm.

GUIDELINE Alarms should be split up into two groups: Yellow Alerts (or Warnings) and Red Alerts (limit exceeded).



GUIDELINE Anticipation of Potential Issues

Ask yourself and the facility the following questions:

i. What if there is a power outage?
   ➪ *is there a backup generator or UPS?*
ii. What if the spacecraft is turned off?
iii. What if the acquisition system crashes?
iv. What if the pressure in the chamber increases?
v. What if the test heaters fail?
   ➪ *risk of getting too low in temperature*
vi. What if a thermal sensor fails at a critical location?
   ➪ *am I blind at this location*
vii. What if the motion stops (e.g. test with spin motion)?
   ➪ *for Bepi or SolO this could result in a risk of getting too hot in temperature*

Mitigation actions should be identified and documented in the emergency procedures.

CHECKLIST for DATA ACQUISTION, EMERGENCIES & ALARMS

ID	Description	Done
DEA-01	Ensure that the data acquisition tool automatically creates a backup copy during testing. The procedure should also contain steps to manually backup data	
DEA-02	Some data acquisition tools can also be used to actively change heater power settings. Check if capability is available and determine if appropriate for the test.	
DEA-03	Apply alarms to temperature limits, temperature gradients and temperature rates of change prior to testing	
DEA-04	The alarm settings should be determined prior to testing and input into the data acquisition tool, prior to starting the thermal test.	
DEA-05	When setting a yellow alert take into consideration the response time of the test specimen (e.g. if the rate of change is 0.5°C/min and it takes 2 minutes to inform the facility and then another 10 minutes for the interface temperature to be adjusted the temperature will have changed by 6°C since the alert)	
DEA-06	Prepare an action plan, prior to starting the thermal test, in which clearly defined steps inform the thermal engineer of what to do if a Yellow or Red Alert occurs.	
DEA-07	Inform the facility and customer about all defined alarm settings.	
DEA-08	Ensure that enough computer monitors are available to easily view critical temperature sensors. One monitor, for 50 important sensors is not enough.	
DEA-09	Together with the Facility answer the following questions: i. What if there is a power outage? ⇨ is there a backup generator or UPS? ii. What if the spacecraft is turned off? iii. What if the acquisition system crashes? iv. What if the pressure in the chamber increases? v. What if the test heaters fail? ⇨ risk of getting too low in temperature vi. What if a thermal sensor fails at a critical location? ⇨ am I blind at this location vii. What if the motion stops (e.g. test with spin motion)? ⇨ for Bepi or SolO this could result in a risk of getting too hot in temperature Mitigation actions should be identified and documented in the emergency procedures.	
DEA-10	Ensure that step-by-step emergency and contingency procedures are prepared. These should be broken down into 3 groups: (i) Deviations from normal operations (ii) Non-critical failures, and (iii) Severe failures	

4.7 Test Documentation & Procedure

The preparation of test documentation can often be a long a process that requires a lot of attention. A well prepared Test Specification (or Plan) and Test Procedure play an essential role in the success and efficiency of a test.

The Test Specification, also known as the Test Plan, is a document which gives a general summary of the test including test objectives and requirements to be verified, an overview of the test facility and test setup, as well as the test sequence and organisational aspects.

Using the Test Specification as a baseline the Test Procedure can be prepared. While the specification gives a general summary of the test, the test procedure includes a step-by-step description of what needs to be done during the test.

In some cases instead of updating the Test Specification, prior to the test, the information flows directly into the Test Procedure, such that Test Procedure replaces the obsolete Test Specification. If both documents are used in parallel, the Test Procedure should only include the step-by-step procedure, with all other information in the Test Specification.

The checklist for test documentation has been split into two parts. The first is a short checklist which covers general points and guidelines for the documentation. The second checklist focuses exclusively on the Test Procedure and the content of the Test Procedure.

GUIDELINES for TEST DOCUMENTATION

GUIDELINE	The Test Specification should be prepared prior to the project CDR and reviewed by an external (non-project) review panel.

GUIDELINE	In collaboration with other relevant disciplines begin writing the Test Procedure early. Note: a number of iterations are usually required before the final document is ready.

GUIDELINE	Ensure that any relevant integration preparation work is included in the AIT preparation procedure. Typically this document is prepared by the AIT test manager.

CHECKLIST for TEST DOCUMENTATION

ID	Description	Done
DOC-01	Identify what documentation is required based on the industry standard (e.g. ECSS) and when this documentation needs to be ready.	
DOC-02	Prepare a Test Specification (sometimes called a Test Plan) including topics such as requirements, objectives, setup, facility, environment, instrumentation, GSE, test sequence and organisational aspects. This should be done prior to CDR.	
DOC-03	Decide whether a single document approach (i.e. Test Procedure) or dual document approach (i.e. Test Procedure and Specification) will be used for the test	
DOC-04	Prior to testing the Test Specification should either be updated (dual document approach) or integrated into the Test Procedure (single document approach). The document should include a detailed plan of thermal test hardware locations.	

GUIDELINES for TEST PROCEDURE

GUIDELINE Use pictures in the Test Procedure to illustrate and make procedure easier to understand. [RD 16]

GUIDELINE Ensure that the steps found in the Test Procedure are clear and understandable

GUIDELINE Ensure that the steps found in the Test Procedure are **NOT**:

- open to interpretation (e.g. detail level to low)
- to complex to navigate and implement (e.g. detail level to high)

GUIDELINE Plan functional testing before performance testing. This allows problems to be analysed and corrective actions to be taken, ensuring that performance testing can be performed more efficiently. [RD 14]

GUIDELINE Define a stability criteria and agree on this criteria with the customer prior to testing:

Example:

$$\left|T_{average}(t) - T_{average}(t-5h)\right| < 0.50\,K$$ (e.g. a temperature gradient of ΔT / Δt = 0.10 K/h)

where $T_{average}(t)$ = Temperature averaged over 1 hour, between t = 5h and t = 6h

$T_{average}(t-5h)$ = Temperature averaged over 1 hour, between t = 0h and t = 1h

The values for the period of time and the temperature gradient can be modified as required.

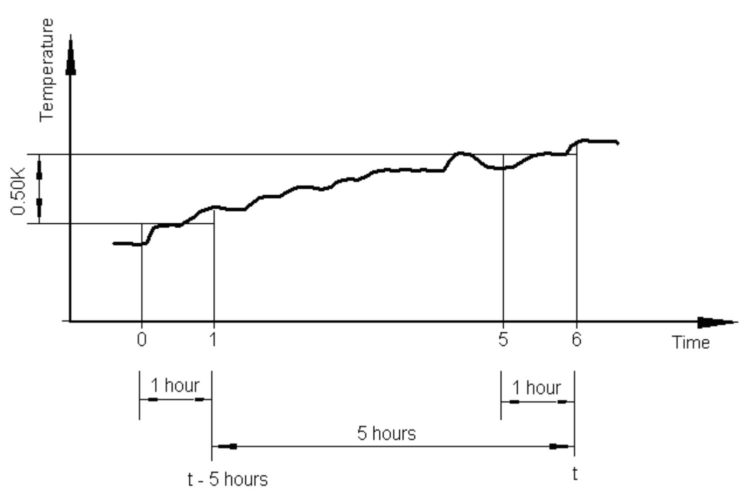


Figure 4-1 Stability criterion

GUIDELINE	Avoid the use of dwell times where a stability criteria is more appropriate (e.g. thermal balance phases)

GUIDELINE	Include manual steps for backing up data in the Test Procedure

GUIDELINE	Prior to beginning the test the customer and project shall agree on the criteria for declaring each phase completed.

GUIDELINE	The final phases (i.e. returning to room temperature) should be planned and fully agreed to (by the customer and project) prior to beginning the test (e.g. temperature rate of change, stabilities, etc). This will avoid discussions about "speeding-up" this phase during the test.

GUIDELINE	Do **NOT** rush the final phases simply to finish the test faster. In doing so the test specimen may be put a risk.

GUIDELINE	When preparing the "As Run" procedure the following rules should be followed • print only on "single side" • ensure the procedure is stabled and placed in a folder • ensure there is enough space for comments (if not print on A3)

Additional Tip: The figure below shows an example of a step-by-step procedure table used for larger tests. The table can be adapted for smaller tests

Step No.	Test-Step Description	Nominal Value	Tolerance	Actual Value	Comments	Date / Time	QA	Thermal
1.1	Record Phase Start Date and Time							

Figure 4-2 Step-by-step procedure columns

The nominal value column indicates the expected outcome value for this step (if applicable) with the corresponding tolerance shown in the next column. The actual outcome is recorded in the actual value column. For large thermal tests both QA and Thermal sign of on each step, for smaller tests this may be reduced to one signature.

Ensure that adequate empty space is available for comments for each step. The first step of each phase is typically to note the starting time and date of the phase.

Additional Tip 2: Instead of using a number of steps in the step-by-step procedure to change facility conditions use a single “Using a Request Sheet” step. For example, instead of:

Step No.	Test Step Description	No.…
3	Set LN2 shroud to <90K	
4	Set GHe shroud to 20K (±1K)	
5	Ensure a temperature change of less than 10K per hour (≤10K/h)	

Replace with:

<table>
<tr><th>Step No.</th><th>Test Step Description</th><th>No.…</th></tr>
<tr><td>3</td><td>Using a Request Sheet request the following:
<table>
<tr><td>LN2 Shroud</td><td>< 90 K</td><td>@</td><td>≤ 10 K/h</td></tr>
<tr><td>GHe Shroud</td><td>20 K $^{+1\,K}_{-1\,K}$</td><td>@</td><td>≤ 10 K/h</td></tr>
</table></td><td></td></tr>
</table>

The original version maybe unclear to some of the test personnel - should I set the LN2 shroud to <90K and then wait until it reaches < 90K before I perform the next step, or can I perform all three steps together using one request sheet? Is the ≤10K/hr applicable to steps 3 to 5 or only to step 5?

CHECKLIST for TEST PROCEDURE

ID	Description	Done
PRO-01	Ensure that a clear list of goals and test success criteria are included in the Test Procedure	
PRO-02	Ensure that clear and understandable phase goals are pre-defined. Ensure that the criteria for completing a phase and moving on to the next phase are agreed on by both the customer and project prior to beginning the test.	
PRO-03	Ensure all steps are clear and understandable by all team members, even basic activities (e.g. fitting sensors, measuring heater resistance, etc.). [RD 16]	
PRO-03	Use the comments column to make the reasons for performing a specific step clear. (e.g. Step: Set temperature to 47K, Reason: 50K is nominal minus 3K for acceptance)	
PRO-04	Has the stability criteria been agreed upon by both the thermal engineer and the customer?	
PRO-05	If dwell times are used, clearly identify the reason for the dwell time. (e.g. Wait for a period of 2 hours to ensure that the entire sample has reached a temperature of 30°C)	
PRO-07	Ensure that step-by-step emergency and contingency procedures are prepared. These should be broken down into 3 groups: (iv) Deviations from normal operations (v) Non-critical failures, and (vi) Severe failures	
PRO-08	The test procedure shall indicate the initial status of the hardware (test specimen and GSE) to clearly describe the starting configuration of hardware prior to starting the test.	

4.8 Test Preparation Work

Typically a dry-run or Functional Blank Test (FBT) takes place prior to a thermal test. For a Functional Blank Test, in which the full test setup without the test specimen is tested, preparation activities can be fairly substantial. Often such a FBT may take place at the same time that integration activities are occurring on the test specimen; hence it is important to plan resources for the preparation work accordingly.

Upon completion of the FBT or dry run preparation work for the thermal test can begin, in which the test specimen must be prepared and placed inside the thermal testing chamber.

These final integration preparation activities require close co-ordination between the Electrical AIT, Mechanical AIT, Optical AIT (if applicable), the facility, the cleanliness engineer and the thermal engineer. Work is often performed in parallel with other activities and hence it is important that everyone involved has an understanding of what other team members are doing to ensure efficiency and minimise risk of damage to hardware. Only those staff who need to be working on the preparation activities should be anywhere near the test setup – try to keep the number of people standing around watching to a minimum as they may get in the way.

Critical sequences may be rehearsed, such as the movement of a satellite. Team members actively involved in such an activity should be given clear responsibilities, to minimise the risk of a collision with the chamber wall, or damage to testing hardware (e.g. MLI).

For cryogenics tests there are a number of additional checks which should be performed during preparation.

It is highly recommended that photos of the facility and the test setup are made prior to closing the chamber. As the correlation of the thermal model typical begins a few weeks (sometimes months) after the test, a thermal engineer often ends up scratching his head and asking himself “What was the location of that piece of MLI?” or “Were exactly was the test sensor?” In this respect photos are very helpful in model correlation.

GUIDELINES for TEST PREPARATION WORK

GUIDELINE	Plan to rehearse critical sequences (e.g. movements of satellite in a chamber) to identify possible issues (Just because the CAD model says there is clearance, doesn't mean there will be enough clearance). The rehearsal also allows the test director to allocate responsibility for such phases (e.g. who looks where).

GUIDELINE	Ensure that the facility is kept up to date on the status of the schedule and preparations, as well as the goals of the test and the test setup

CRYO GUIDELINE	For tests under **CRYOGENIC** conditions ensure that all shroud openings and any local hot spots are closed or covered

CRYO GUIDELINE	For tests under **CRYOGENIC** conditions strive to use long harnesses which are thermally well coupled to chamber shroud.

CHECKLIST for TEST PREPARATION WORK

ID	Description	Done
PRP-01	Ensure adequate AIT staff, with the necessary training, are planned for preparation work well in advanced of both Functional Blank Test and actual test. Take into account other AIT activities (particularly during FBT)	
PRP-02	Plan for adequate preparation time. Consider that working in an ISO Class 5 Cleanroom (CR5) environment is more difficult than in ISO Class 8 Cleanroom (CR8) and that therefore activities in CR5 can take considerably longer.	
PRP-03	Ensure that the required tools and materials are available prior to begin preparation work	
PRP-04	Ensure that the facility uses the same nomenclature (e.g. sensor abbreviations), units and co-ordinate systems (different co-ordinate systems may lead to confusion in the case that a spacecraft is tilted inside the chamber)	
PRP-05	Ensure that prior to being preparation work that the chamber is inspected.	
PRP-06	When preparing for a functional blank test or the full test the facility should be provided with a list of people who are required to have access to relevant facilities. These people should have the appropriate training (e.g. CR5, ESD, etc)	
PRP-07	Ensure that the facility is informed about what information needs to be recorded and measured during testing. This should be tested in a dry run or functional blank test.	
PRP-08	In addition to the AIT preparation plan, prepare a list of any additional tasks which need to be performed prior to testing (e.g. issues identified in the Functional Blank Test)	
PRP-09	For cryogenic tests – perform a Night Vision Goggle check as follows: [RD 17] (i) Place a light between the chamber shroud and chamber wall (ii) Have someone with NVG sit inside the chamber (iii) Close chamber door and any other openings (e.g. flanges) (iv) Person inside chamber can now identify any openings in the shroud (e.g. view factor from warm chamber wall to any cold areas	
PRP-10	For cryogenic tests – has the routing of the harness been considered with respect to the influence of parasitic heat and joule heating? If possible ensure that test harnesses are long to reduce thermal conductivity from warm chamber flange to cold unit and ensure that the harness is well fixed (thermally coupled) to the thermal shroud (e.g. using tape) at multiple locations.	
PRP-11	For cryogenic tests – cover any shroud openings or GSE hot spots identified (e.g. with plates or MLI). Note: when using MLI take into consideration the impact (e.g. temperature limits of harness covered by MLI)	

4.9 Test Readiness Review (TRR)

Prior to starting a thermal test a Test Readiness Review (TRR) is held to ensure that all necessary documentation, planning and precautions have been taken into account. This checklist identifies the major points which should be considered prior to beginning the TRR and addressed during the TRR:

CHECKLIST for TEST READINESS REVIEW (TRR)

ID	Description	Done
TRR-01	Has an external (non-project) team of test experts, performed an independent review of the test plan (e.g. Test CDR or Pre-Environmental Review)? [RD 14]	
TRR-02	Identify any open issues from the Functional Blank Test which may impact the test.	
TRR-03	Ensure that all relevant materials and processes have been properly qualified prior to thermal testing	
TRR-04	Identify all RFWs and RFDs which may impact the test.	
TRR-05	Identify all open NCRs which may impact the test (including Facility NCRs)	
TRR-06	Ensure that the relevant qualification/acceptance documentation for lower level items (e.g. assemblies, mechanisms, etc) is available.	
TRR-07	Ensure that all relevant documents have been prepared and issued (e.g. Test Plan/Specification, Test Procedure and Emergence Procedures).	
TRR-08	Ensure that a facility readiness document has been provided by the facility operator.	
TRR-09	Prepare a decision criteria and contingency plan, e.g. If a problem occurs what needs to be done? What testing can be done without opening the chamber? [RD 14]	
TRR-10	Ensure that responsibilities are clearly defined and known to all parties	
TRR-11	Identify what effects outgassing of materials, under vacuum conditions, will have on the test and/or test specimen. [RD 18]	
TRR-12	Check that the cleanliness of the test specimen and the test setup meet the requirements.	
TRR-13	Ensure that the temperature stability criterion been agreed upon by both the thermal test engineer and the customer.	
TRR-14	Ensure that the hardware and facility are thoroughly inspected. Remember to perform a KIP or MIP prior to starting the test.	
TRR-15	Take photos of the final setup. These may help identify problems during the test, model correlation and other issues. (Tip: take a lot of photos)	
TRR-16	Record and distribute the telephone numbers of team members.	

4.10 Test Performance & Organisation

Proper organisation and briefing of the test team is not only important in ensuring that the test is performed correctly, but also in guaranteeing that the test team is not overworked or overstressed. Briefings should be held prior to the test and on a daily bases to keep everyone up to date.

The test room, in which the test team works, should be equipped with whiteboards and other posters (e.g. schedule, shift plan, etc) to provide visual information for the test team. Additionally, all test related documentation should be available in hardcopy form and placed in clearly marked folders.

During test performance it is also important that any lessons learned are recorded. These lessons learned should be documented and discussed in a post-test lessons learned session.

GUIDELINES for TEST PERFORMANCE & ORGANISATION

GUIDELINE The following items should be hang-up in the main test room

- (i) the test schedule/profile of all phases including boundary conditions
- (ii) overview of the location of temperature sensors and heaters
- (iii) a list with all important telephone numbers
- (iv) the shift plan
- (v) a whiteboard, used to display important information

GUIDELINE The following documentation should be available (hard copy) during the test

- (i) a copy of the flight and the test predictions
- (ii) a table of set points and alarms
- (iii) a table of acceptance and qualification temperature limits for each unit
- (iv) an instrumentation plan with a description of all thermal flight & test hardware
- (v) facility documentation
- (vi) emergency procedures
- (vii) pictures of the test setup
- (viii) calibration curves for sensors

GUIDELINE Ensure that external (e.g. non-project) team members are fully briefed on the test item and the reason for testing. If possible these team members should have the opportunity to either view the test specimen and test setup or take part in test hardware integration.

GUIDELINE Use only written Request Sheets to communicate with the facility operator. Do **NOT** use telephone or verbal communication to make a request.

GUIDELINE During emergency take the necessary time to assess the situation and develop an action plan – do **NOT** make hasty decisions.

GUIDELINE Use a log-book to record relevant events during testing

GUIDELINE Include a member of each discipline and the test facility in daily test meetings

GUIDELINE During testing make a note of any lessons learned, in either the log book or the test procedure. This includes recommended changes to the procedure, particularly if further testing is foreseen

GUIDELINE Upon test completion perform a lessons learned session in which all lessons learned are reviewed and documented

GUIDELINE In collaboration with the test facility, plan the test team shift to start with an offset of at least 1 hour to that of the facility team.

GUIDELINE Prior to beginning the test, set clear rules for staff who are "on-call", e.g. how quickly must the staff member be at the test facility, how will on-call staff be fitted into the shift schedule and how will "on-call" time be compensated.

GUIDELINE Limit the number of days a person is on shift to a maximum of 10 days. Do **NOT** exceed 10 days

GUIDELINE Limit the duration of a shift to 9 hours.

GUIDELINE Involve team members in the shift planning. Strive to take personnel wishes into account (e.g. shift preferences and number of days to work without a break). Keep your team members happy and motivated!!

Additional Tip 1: The table below shows one of the more common shift plans used for a larger thermal test requiring "24 hours / 7 days a week" supervision and a few common options used for shift times. The four team members (T1 to T4) work for a maximum of six days in a row, before taking two days off. After the two days off the team member then takes over the next shift (e.g. 6 days early shift, 2 days off, 6 days late shift).

Table 4.10-1 Example of a shift plan

Day:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Early Shift	T1	T1	T4	T4	T4	T4	T4	T4	T3	T3	T3	T3	T3	T3	T2	T2
Late Shift	T2	T2	T2	T2	T1	T1	T1	T1	T1	T1	T4	T4	T4	T4	T4	T4
Night Shift	T3	T3	T3	T3	T3	T3	T2	T2	T2	T2	T2	T2	T1	T1	T1	T1

Table 4.10-2 Common Shift times

Shift	Option 1	Option 2	Facility
Early Shift	08:00 to 16:00	06:00 to 14:00	07:00 to 15:00
Late Shift	16:00 to 00:00	14:00 to 22:00	15.00 to 23:00
Night Shift	00:00 to 08:00	22:00 to 06:00	23:00 to 07:00

Some test facility team run shifts with an offset of 1 hour to the two common options. This ensures that the shift handover of the facility and the test team does not occur at the same time and hence that someone is always paying attention to what is happening to the test environment and the test specimen. This is recommended for all tests.

CHECKLIST for TEST PERFORMANCE & ORGANISATION

ID	Description	Done
PRF-01	Ensure that all team members are briefed on the emergency procedures.	
PRF-02	Ensure that relevant personnel been allocated responsibilities for critical tasks.	
PRF-03	Have clear rules been established for "on-call" staff?	
PRF-04	Ensure that the test shift plan has been prepared in accordance applicable regulations/laws.	
PRF-05	Ensure that shift plan allows team members to get adequate rest and that team members are not overworked. A limit of 10 days of shift work in a row is recommended.	
PRF-06	For each shift plan an overlap time in which the team member completing his shift can brief the team member starting his shift (e.g. shift handover meetings).	
PRF-07	Upon completion of the lessons learned session, update the Test Procedure for future tests (e.g. for additional models) as soon as possible.	

5 CONCLUSION

There is a large amount of information regarding thermal testing available today, much of which is easily accessible to the public online. However, the shear amount of information available makes it difficult to locate specific lessons learned. Many documents and papers may imply that lessons learned are included, but unfortunately these often do not contain much new information.

Due to the amount of information available, important lessons learned may not be clearly identified and passed on to other engineers, which can be seen in that some lessons tend to appear fairly frequently in various forms of documentation. Good examples are “Test as you Fly”, preparing for a test early and the proper planning of harness routing. This ESA study "Improving Environmental Test Preparation: Lessons Learned and Guidelines for Thermal Tests” is aimed at identifying previous lessons learned and presenting this information in a simplified form, being the Checklists and Guidelines which can be found in this document.

The checklists and guidelines are designed to help a thermal engineer in preparing and performing thermal tests. These checklists and guidelines are by no means a complete and comprehensive list of all of the topics which must be considered by a thermal engineer, they do cover some of the most common and critical issues identified in the review of material already available.

When preparing for a thermal test the checklist and guidelines should be used in conjunction with the various documents which are publicly available. Thermal engineers should use all resources which are available to them, including their colleagues - some lessons learned may not be found in a database.

The topic “lessons learned” is an ongoing one and one in which all thermal engineers are responsible for contributing to. The information covered in the checklists and guidelines is based on the information available today, but the amount of information will continue to grow in the future and the checklists adapted accordingly as time progresses.