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Space systems — Thermal vacuum environmental testing

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Contents

Page

Foreword

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The on-orbit environments of spacecraft, with their vacuum state, cryogenic and black background, and complex heat transfer, are harsher and more complex than the ground environment. They have a strong impact on the success of spacecraft mission. Thermal balance tests (TBT) and thermal vacuum tests (TVT) at spacecraft level are conducted to ensure the units in spacecraft operate normally in specified pressure and thermal range.

This document provides methods and specifies general requirements for spacecraft level thermal balance tests and thermal vacuum tests. However, the technical requirements in this document can be tailored by the parties for some special spacecraft, such as manned vehicle, deep space explorer, extra-terrestrial body lander or the satellites with emphasis on low-cost and fast delivery, which are characterized by extensive use of non-space-qualified commercial-off-the-shelf (COTS) units.

This document acts as a supplement to ISO 15864 and ISO 19683. It is applicable to test project designers and test organizations. It also serves as a reference for spacecraft designers and test facility manufacturers.

Space systems — Thermal vacuum environmental testing

1 Scope

This document provides methods and specifies general requirements for spacecraft level thermal balance tests (TBT) and thermal vacuum tests (TVT). It also provides basic requirements for test facilities, test procedures, test malfunction interruption emergency handling and test documentation. The methods and requirements can be used as a reference for subsystem-level and unit-level test article.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 15864:2021, *Space systems — General test methods for spacecraft, subsystems and units*

ISO 17566:2011, *Space systems — General test documentation*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
maximum predicted temperature
highest temperature that can be expected to occur during the entire life cycle of the *subsystem* (3.4)/*unit* (3.8) in all operational modes plus an uncertainty factor

3.2
minimum predicted temperature
lowest temperature that can be expected to occur during the entire life cycle of the *subsystem* (3.4)/*unit* (3.8) in all operational modes plus an uncertainty factor

3.3
spacecraft
integrated set of *subsystems* (3.4) and *units* (3.8) designed to perform specific tasks or functions in space

3.4
subsystem
assembly of functionally related *units* (3.8), which is dedicated to specific functions of a system

3.5
thermal balance test
test conducted to verify the adequacy of the thermal model and the adequacy of the thermal design

3.6
thermal uncertainty margin
temperature margin included in the thermal analysis of *units* (3.8), *subsystems* (3.4) and *spacecraft* (3.3) to account for uncertainties in modelling parameters such as complex view factors, surface properties, contamination, radiation environments, joint conduction and interface conduction and ground simulation

3.7
thermal vacuum test
test conducted to demonstrate the capability of the test item to operate according to requirements in vacuum at predefined temperature condition

Note 1 to entry: Temperature conditions can be expressed in terms of temperature level, gradient, variation and number of high-low temperature cycles.

3.8
unit
lowest level of hardware assembly that works with specified complex electrical, thermal and/or mechanical functions

4 Symbols and abbreviated terms

AT	acceptance test
EGSE	electrical ground support equipment
FM	flight model
IR	infrared
MGSE	mechanical ground support equipment
OSR	optical solar reflector
PFT	proto-flight test
QT	qualification test
TBT	thermal balance test
TQCM	temperature-controlled quartz crystal microbalances
TVT	thermal vacuum test
UPS	uninterruptible power supply
UV	ultraviolet

5 Test purpose

5.1 Thermal balance test

The purpose of the thermal balance test is to provide the data necessary to verify the analytical thermal model and demonstrate the ability of the spacecraft thermal control subsystem to maintain the specified operational temperature limits of the units throughout the entire spacecraft.

5.2 Thermal vacuum test

5.2.1 General purpose

The purpose of the thermal vacuum test is to demonstrate the ability of the test item and its units to meet the design requirements under vacuum conditions and temperature extremes that simulate those predicted for flight. TVT detects material, process and workmanship defects that would respond to vacuum and thermal stress conditions.

The test level and test duration are described in 6.2.2.1 and 6.2.2.2 respectively.

5.2.2 Qualification test

During the qualification test (QT), the thermal vacuum test serves to validate the performance of the qualification model (QM) in the intended environments with the specified qualification margins.

5.2.3 Proto-flight test

During the proto-flight test (PFT), the thermal vacuum test serves to validate the performance of the proto-flight model (PFM) on the first flight in the intended environments with the specified proto-flight margins.

5.2.4 Acceptance test

During the acceptance test (AT), the thermal vacuum test serves to validate the performance of the flight model (FM), except the one used as pro-flight, in the intended environments with the specified acceptance margins.

6 Test methods

6.1 Thermal balance test

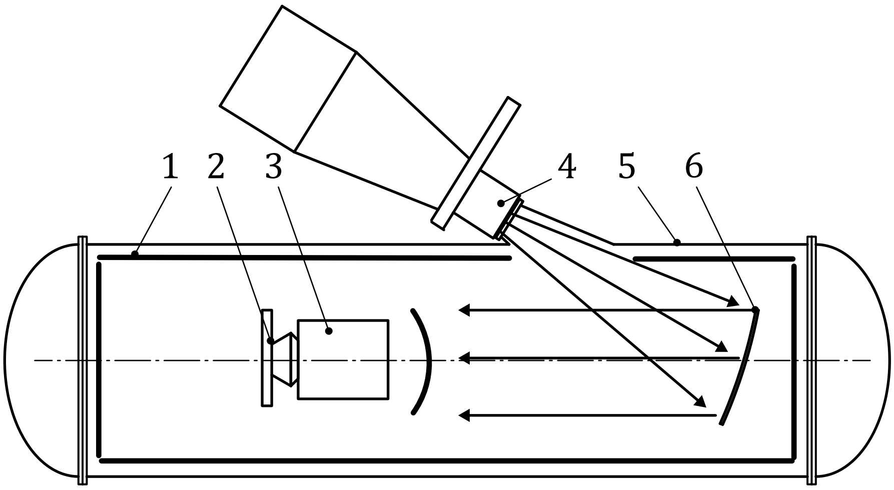
6.1.1 Test description

The on-orbit external thermal flux simulation can be conducted by one of the following methods:

a) Incident flux method

The intensity, spectral content and angular distribution of the incident solar, albedo and planetary irradiation encountered by on-orbit spacecraft are simulated by using solar simulator system, shown in Figure 1 or using the other method (e.g. with axial location of solar simulator).

The solar simulator is composed of the xenon lamp, the filter and the collimator. Generally, the test article is installed on a motion simulator (rotating platform) to simulate the different attitudes on orbit. For the requirements of a solar simulation system, see 7.3.4.5. For the main characteristic of a solar simulator, see Annex A.



Key

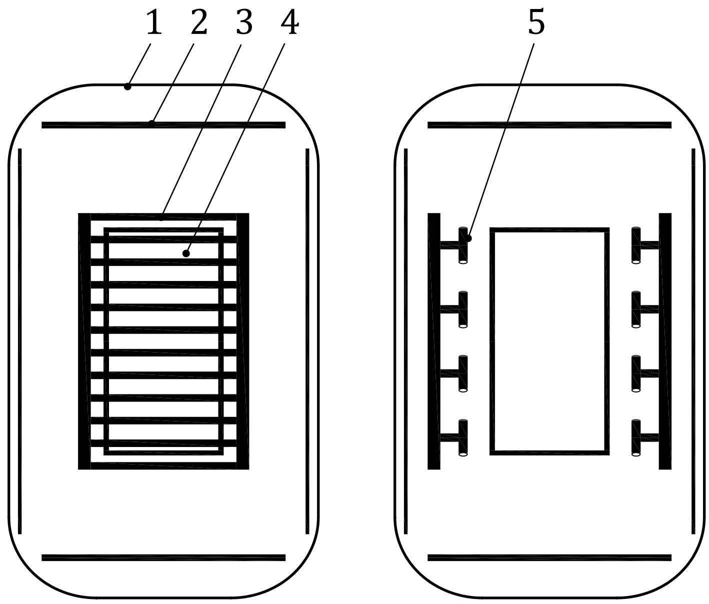
1 shroud
2 motion simulator
3 test article
4 solar simulator
5 vacuum chamber
6 collimator

Figure 1 — Solar simulation method

This method is suitable for spacecraft with complex shapes and large differences in surface thermal characteristics. It can provide incident illumination with matching spectral, uniformity and stability of irradiance, divergence angle for the thermal test of the spacecraft. However, it is difficult to simulate the effects for performance degradation of thermal control coatings at end of lifetime. This method may be restricted for the effect of reflection light or heat from surfaces of shroud and MGSE, large operating cost and heat pipes on-board normally working horizontally.

b) Absorbed flux method

The absorbed solar, albedo and planetary irradiation for on-orbit spacecraft, are simulated by using infrared (IR) heaters (cage, lamps, calrods and thermal plate) with their spectrum adjusted to the external thermal coating properties, or by using film heaters attached to spacecraft surfaces with the absorbed heat flux controlled by electrical power, shown in Figure 2. For the requirements for IR heater and film heater, see 7.3.4.3 and 7.3.4.4. Annex B describes the design flow of an IR heater in the absorbed flux method in TBT.



Key

1 vacuum chamber
2 shroud
3 IR cage or IR thermal plate
4 test article
5 IR lamp/calrod array

Figure 2 — Absorbed flux method

This method is suitable for spacecraft with simple shapes and similar in surface thermal characteristics. It has the advantage of high reliability, low manufacturing and operation cost. It may be restricted for the containment released from MGSE, limited temperature ramp and the numbers of heating loops or electrical power.

c) The combination of methods a) and b)

The combination of the methods a) and b) can be used for heat flux simulation of different surfaces of the test article in TBT.

Generally, the following shall be considered during test article design:

— The profile, structures, materials, instrument and device layout, cable network, various thermal control measures, envelop dimension, surface state, installation and connection mode, internal heat sources, thermal capacity shall meet the requirements of thermal design and simulation.

— The thermal simulation model of spacecraft or its units may be designed specially, whose thermal capacity and heat consumption are in accord with that on orbit.

— The large antenna, solar array and other external components may not participate in the test, but their radiation heat effects shall be evaluated. Conduction heat shall be simulated on installation interfaces by proper heat insulation, heat leakage compensation, or constant temperature.

— Additional radiation flux created by thermal vacuum chamber, MGES and heating devices frames shall be taken into account.

— If the natural convection effects cannot be ignored under the ground gravitation condition, pressurized cabin convection boundary shall be simulated by adjusting the gas temperature, pressure and velocity on the units' surface to ensure the heat transfer is equivalent.

— The propellant tank is filled with protective gas.

6.1.2 Test conditions

6.1.2.1 Test cases design

TBT cases depend on the mission, spacecraft design, spacecraft operational modes, and times required to reach stabilization. According to the internal heat source heating mode, orbital heating mode and other thermal boundary conditions, there are four types of operating cases.

a) Case 1

Internal heat source, simulative orbital heating and other thermal boundary conditions are constant;

b) Case 2

Internal heat source works in a set periodic change mode, while the simulative orbital heating and other thermal boundary conditions are constant;

c) Case 3

Internal heat source works in a set periodic change mode; the simulative orbital heating and other thermal boundary conditions are in the periodic orbit change mode;

d) Case 4

Internal heat source, simulative orbital heating mode or other thermal boundary conditions are in the aperiodic change during the specified phase.

For b) and c), the cyclic test for several periods can be repeated either with the heat source operating mode and simulative orbital heating mode in one orbit period until the temperature of test model is steady periodically, or with several orbit periods as one test period until the temperature of test model is steady periodically.

The design principles of the test cases are as follows.

— Test phases shall simulate cold and hot conditions to verify all aspects of the thermal hardware and software, including heater operation, radiator sizing, and critical heat transfer paths.

— Test cases shall obtain sufficient critical parameters required for thermal analytical model verification and flight mission indication.

— To validate the adequacy of the thermal control design, the cases shall contain hot case and cold case at least. Consideration should be given for testing an “off-nominal” case such as a safehold or a survival mode.

— Generally, the test for the only purpose of verifying thermal analytical model shall contain transient case.

— Transient case shall be set when the influence of on-orbit heat flux or other thermal boundary conditions on spacecraft temperature increases with time.

6.1.2.2 Temperature stabilization

The exposure shall be long enough for the test article to reach temperature stabilization so that temperature distributions are ensured in the steady-state conditions. The test temperature shall be considered as stabilized, in case that

a) temperature monitored at the test article is within the allowed tolerance around the specified test temperature;

b) temperature change rate is lower than the value allowed for stable conditions.

