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Space systems — Methods to decide thermal vacuum test cycles of recurring production according to precipitation efficiency and reliability

Systèmes spatiaux — Méthodes pour déterminer les cycles d'essais sous vide thermique de la production récurrente en fonction de l'efficacité et de la fiabilité des précipitations

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Introduction

The thermal vacuum test is one of the most important and expensive environment tests of space systems. The thermal vacuum test is required in general to demonstrate the ability of the test item to meet the design, function and performance requirements under the combination of vacuum conditions and temperature extremes experienced during spaceflight, and to screen out initial failure, known as infant mortality, such as workmanship error, integration error and latent material defect (ISO 15864). The number of thermal cycles, to be referred hence forth as simply cycles, is one of the test conditions in thermal vacuum test, is an essential parameter used to determine the screening effectiveness of initial failure. The number of cycles should be determined, generally based on technical aspects and with careful consideration of various factors such as test item complexity, heritage, and maturity of design and manufacturing, as well as reliability required of the test article. However as experienced in mass production industry, it is a natural expectation that as the design and manufacturing process of an item matures through continuous improvement of the manufacturing process, workmanship defects and initial failure will be reduced.

This [standard document](#) provides two technical methods specified to calculate the precipitation efficiency and reliability by the failure data to measure the quantity of screening effectiveness used to determine number of cycles of thermal vacuum test. These methods can be applied to reduce the number of cycles performed during a thermal vacuum test specified for recurring production of flight hardware, such as higher volume unit production runs and hardware produced for large constellation programs. This document supplements ISO 15864 used as either an option to reduce or a tailoring method to the baseline of thermal vacuum and thermal cycle acceptance tests specific for the recurring production hardware.

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Space systems — Methods to decide thermal vacuum test cycles of recurring production according to precipitation efficiency and reliability

1 Scope

This document provides technical methods to calculate the precipitation efficiency and liability of a flight model by measuring the screening effectiveness of thermal cycles. This document is applicable to the recurring production unit and other hardware assembly levels, as either an option to reduce or a method to tailor the baseline number of cycles for thermal vacuum and thermal cycle acceptance tests.

2 Normative references

The following documents are referred to in the text in such a way that some or all 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, *Space systems — General test methods for spacecraft, subsystems and units*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15864 and the following 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/>

<https://standards.iteh.ai/catalog/standards/iso/a5ff1180-3593-4d0d-82f2-b6da9d6bdd4/iso-fdis-9621>

3.1.1

failure

termination of the ability of an *item* (3.1.5(3.1.5)) to perform a required function

[SOURCE: ISO 10795:2019, 3.98]

3.1.2

flight model

model dedicated to being launched and operated in orbit and subjected to acceptance testing

3.1.3

hardware

items (3.1.5(3.1.5)) of identifiable equipment including piece parts (1.153), components (1.43), assemblies, subsystems and systems

[SOURCE: ISO 10795:2019, 3.119, modified — The abbreviated term "H/W" has been removed.]

3.1.4

initial failure

probability of *failure* (3.1.1(3.1.1)) or defect under an environmental test

3.1.5

item

node of a product breakdown structure

Note 1 to entry: An item can be any functional unit, subsystem, or system in ISO 15864 that can be individually considered.

Note 2 to entry: An item can be considered either as a "product" or a "component" on a "product breakdown structure" of more than two levels of decomposition. Items are designated "products" when described as being decomposed and designated "components" when described as decompositions.

[SOURCE: ISO 10795:2019, 3.134, modified — The domain "<space system>" has been removed; in note 1 to entry, a reference has been made to ISO 15864.]

3.1.6

latent defect

defect caused by workmanship error, integration error or latent material, which is not detectable in a stress-free environment, but is either screened under environmental test conditions or flight environment

3.1.7

precipitation efficiency

PE

probability of screening out *latent defects* (3.1.6(3.1.6)) in a specific environmental test

3.1.8

reliability

ability of an *item* (3.1.5(3.1.5)) to perform as required under given conditions for a given time interval

Note 1 to entry: In this document, reliability is equivalent to the probability that the *hardware* (3.1.3(3.1.3)) is failure-free.

[SOURCE: ISO 10795:2019, 3.198, modified — "a required function" has been replaced by "as required"; the original two notes to entry have been replaced by a new one.]

3.1.9

tailoring

process by which individual requirements of specifications, standards, and related documents are evaluated and made applicable to a specific project by selection and, in some exceptional cases, modification of existing or addition of new requirements

[SOURCE: ISO 10795:2019, 3.237]

3.1.10

test temperature range

difference between the maximum and minimum temperatures in a thermal vacuum test

Note 1 to entry: The thermal vacuum test is specified in ISO 15864:2021, 7.18.

3.2 Abbreviated terms

AT	acceptance test
MPE	maximum predicted environment
PE	precipitation efficiency
TCT	thermal cycle test
<u>TCT</u>	<u>thermal cycle test</u>
<u>TTC</u>	<u>telemetry, tracking and command</u>
<u>TVT</u>	<u>thermal vacuum test</u>
TTC	telemetry, tracking and command thermal vacuum test thermal environmental stress
TVT	screening
TESS	

4 Methods of TVT cycles determination

4.1 General

Thermal cycle and thermal vacuum tests (TVT) are required for system and certain types of subsystem/unit acceptance test (AT), as specified in ISO 15864:2021, Table 1 and Table 3. The number of cycles is determined in general by consideration of the overall development and test history of the hardware under test, for example, the complexity and heritage of design and tests of lower-level assemblies before integrated assemblies, TVT conditions such as temperature range and duration. Initial screening for latent defects of flight hardware, also called infant mortality, which is caused by manufacturing, material and workmanship defects, shall be demonstrated by the acceptance test. The determination of TVT cycles depends on the essential parameter used to measure the screening effectiveness for initial latent defects by the precipitation efficiency and reliability of the test. Although in ISO 15864 there is no statement for the value of number of cycles, the expected number of cycles for thermal environmental stress screening (TESS) is determined by the required precipitation efficiency (PE) and temperature range in TVT (11.2.4.4.1, IS 9621).

The number of TVT cycles for the relevant kinds of hardware (system, subsystem and unit) of recurring production can be tailored to reduce the number of cycles specified in baseline requirement by prior experience and studies of the failure database. This document provides the technical methods to support tailoring thermal vacuum test cycles of the relevant hardware. Methods used to calculate the precipitation efficiency and reliability are used to measure the quantity of the TESS effectiveness, by the priorly revealed failure database collected from the objective hardware. The failure database used in these methods shall support the justification of number of cycles determination.

The term of recurring production stated herein shall be replaced by spacecraft, subsystem or unit defined in ISO 15864 in case of tailoring the baseline of thermal vacuum and thermal cycle acceptance tests. Recurring production can be hardware used for constellation programs, or more generally, the hardware made with a constant block of design and manufacture, such as mass production hardware, replicating manufactured hardware.

The failure database may be extended to the hardware that has similarity in design, manufacture and part grade integrated in the production, but the technical rationale of supporting the similarity claim shall be justified. An example to support similarity can be when the hardware is designed and manufactured by

relative standards, reliability and quality control by same management standards, high class parts (e.g. class I) are used in the hardware

4.2 Failure data collection and analysis

The failure distribution function is used for estimating TESS effectiveness by the fatigue induced stress. Failure data collected shall be revealed that failures are relevant to initial defects due to foreign substance contamination in manufacturing and workmanship of the relevant hardware. Failure data collection at acceptance TVT shall provide the following basic information.

- a) ~~a)~~ The cycle numbers and test parameters, including minimum and maximum temperatures, in the TVT when the failure occurred. The minimum temperature of failure data collected should be 55 °C.
- b) ~~b)~~ The results from function tests performed. A function test shall be performed during and after exposure to the TVT environment to ensure the perceptiveness of potential failures. In cases that failures are discovered after exposing to TVT environment and the cycles when the failure occurred are difficult to be identified, an increased number of cycles should be assigned. This assignment of increased cycles is to obtain a conservative estimation.
- c) ~~c)~~ Failure data from previous and/or follow-on environmental tests. If the hardware is exposed to a number of environments sequential, for example, a vibration environment could be exposed on the hardware before or after TVT, the failure data collected shall be carefully analysed. Failures escaping from a previous exposure environment or into a follow-on exposed environment shall be carefully analysed to confirm if there are TVT environment related failures. If the failure related environment is indistinct, this kind of failure data shall not be included.
- d) ~~d)~~ Failure data from different lot tests. If the failure data ~~is are~~ collected from different lots or replicating manufactured hardware, the failure data should be carefully analysed to determine if there are different number of failure cycles between lots or replicating hardware. Test parameters to influence the TESS, such as temperature range, temperature transition rate, hardware operation, failure modes, should be carefully examined.
- e) ~~e)~~ Failure data from thermal cycle tests (TCT). Thermo-mechanical fatigue failures in TCT may be included in the failure database.

Typical failure data and initial defects of electronic units are shown in Table B.1 ~~Table B.1.~~

The collected failure data shall be sorted in ascending order by the cycle number x when the failure is discovered and their corresponding test temperature range ΔT . If there are k failures, the failure data shall be sorted to,

$$x = (x_1, x_2, \dots, x_k)$$

$$= (x_1, x_2, \dots, x_k)$$

(1)

$$\Delta T = (\Delta T_1, \Delta T_2, \dots, \Delta T_k)$$

$$\Delta T = (\Delta T_1, \Delta T_2, \dots, \Delta T_k)$$

(2)

where