



BSI Standards Publication

Methods for product accelerated testing

National foreword

This British Standard is the UK implementation of EN IEC 62506:2023. It is identical to IEC 62506:2023. It supersedes BS EN 62506:2013, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee DS/1, Dependability.

A list of organizations represented on this committee can be obtained on request to its committee manager.

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient's own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

© The British Standards Institution 2024
Published by BSI Standards Limited 2024

ISBN 978 0 539 13655 5

ICS 03.120.01; 21.020

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2024.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

English Version

Methods for product accelerated testing
(IEC 62506:2023)

Méthodes d'essais accélérés de produits
(IEC 62506:2023)

Verfahren für beschleunigte Produktprüfungen
(IEC 62506:2023)

This European Standard was approved by CENELEC on 2023-12-12. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.



European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

The text of document 56/2000/FDIS, future edition 2 of IEC 62506, prepared by IEC/TC 56 "Dependability" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 62506:2023.

The following dates are fixed:

- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2024-09-12
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2026-12-12

This document supersedes EN 62506:2013 and all of its amendments and corrigenda (if any).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

Any feedback and questions on this document should be directed to the users' national committee. A complete listing of these bodies can be found on the CENELEC website.

Endorsement notice

The text of the International Standard IEC 62506:2023 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standard indicated:

IEC 62740:2015	NOTE Approved as EN 62740:2015 (not modified)
IEC 60812	NOTE Approved as EN IEC 60812
IEC 61163-2	NOTE Approved as EN IEC 61163-2
IEC 60300-3-4	NOTE Approved as EN IEC 60300-3-4
IEC 60068 (series)	NOTE Approved as EN 60068 (series)
IEC 61014	NOTE Approved as EN 61014
IEC 61163-1	NOTE Approved as EN 61163-1
IEC 61164:2004	NOTE Approved as EN 61164:2004 (not modified)
IEC 61125:2018	NOTE Approved as EN IEC 61125:2018 (not modified)

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60050-192	-	International electrotechnical vocabulary - Part 192: Dependability	-	-
IEC 60300-3-5	-	Dependability management - Part 3-5: Application guide - Reliability test conditions and statistical test principles	-	-
IEC 60605-2	-	Equipment reliability testing - Part 2: Design of test cycles	-	-
IEC 60721	series	Classification of environmental conditions	EN 60721	series
IEC 61123	2019	Reliability testing - Compliance test plans for success ratio	EN IEC 61123	2020
IEC 61124	2023	Reliability testing - Compliance tests for constant failure rate and constant failure intensity	EN IEC 61124	2023
IEC 61649	2008	Weibull analysis	EN 61649	2008
IEC 61709	-	Electric components - Reliability - Reference conditions for failure rates and stress models for conversion	EN 61709	-
IEC 61710	-	Power law model - Goodness-of-fit tests and estimation methods	EN 61710	-
IEC 62429	-	Reliability growth - Stress testing for early failures in unique complex systems	EN 62429	-

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	8
2 Normative references	8
3 Terms, definitions, symbols and abbreviated terms.....	9
3.1 Terms and definitions.....	9
3.2 Symbols and abbreviated terms	11
4 General description of the accelerated test methods.....	12
4.1 Cumulative damage model.....	12
4.2 Classification, methods and types of test acceleration	14
4.2.1 General	14
4.2.2 Type A: qualitative accelerated tests	15
4.2.3 Type B: quantitative accelerated tests	15
4.2.4 Type C: quantitative time and event compressed tests.....	16
5 Accelerated test models	17
5.1 Type A, qualitative accelerated tests.....	17
5.1.1 Highly accelerated limit tests (HALT)	17
5.1.2 Highly accelerated stress test (HAST)	21
5.1.3 Highly accelerated stress screening or audit (HASS or HASA).....	22
5.1.4 Engineering aspects of HALT and HASS	23
5.2 Types B and C – Quantitative accelerated test methods.....	23
5.2.1 Purpose of quantitative accelerated testing.....	23
5.2.2 Physical basis for the quantitative accelerated Type B test methods.....	23
5.2.3 Type C tests, time (C_1) and event (C_2) compression	25
5.3 Failure mechanisms and test design	27
5.4 Determination of stress levels, profiles and combinations in use and test – Stress modelling	27
5.4.1 General	27
5.4.2 Step-by-step procedure	28
5.5 Multiple stress acceleration methodology – Type B tests.....	28
5.6 Single and multiple stress acceleration for Type B tests.....	31
5.6.1 Single stress acceleration methodology	31
5.6.2 Stress models with stress varying as a function of time – Type B tests	38
5.6.3 Stress models that depend on repetition of stress applications – Fatigue models.....	40
5.6.4 Other acceleration models	41
5.7 Acceleration of quantitative reliability tests.....	42
5.7.1 Reliability requirements, goals, and use profile	42
5.7.2 Accelerated testing for reliability demonstration or life tests.....	44
5.7.3 Testing of components for a reliability measure	55
5.7.4 Reliability measures for components and systems	56
5.8 Accelerated reliability compliance or evaluation tests.....	57
5.9 Accelerated reliability growth testing	58
5.10 Guidelines for accelerated testing	59
5.10.1 Accelerated testing for multiple stresses and the known use profile	59
5.10.2 Level of accelerated stresses	59
5.10.3 Accelerated reliability and verification tests	59

6	Accelerated testing strategy in product development	60
6.1	Accelerated testing sampling plan.....	60
6.2	General discussion about test stresses and durations	60
6.3	Testing components for multiple stresses.....	61
6.4	Accelerated testing of assemblies	61
6.5	Accelerated testing of systems.....	61
6.6	Analysis of test results	62
7	Limitations of accelerated testing methodology.....	62
Annex A	(informative) Highly accelerated limit test (HALT)	63
A.1	HALT procedure.....	63
A.2	HALT step-by-step procedure	63
A.3	Example 1 – HALT test results for a DC/DC converter.....	65
A.4	Example 2 – HALT test results for a medical item	65
A.5	HALT test results for a Hi-Fi equipment	67
Annex B	(informative) Accelerated reliability compliance and growth test design	68
B.1	Use environment and test acceleration	68
B.2	Determination of stresses and stress duration.....	68
B.3	Overall acceleration of a reliability test.....	69
B.4	Example of reliability compliance test design assuming constant failure rate or failure intensity	70
B.4.1	General	70
B.4.2	Thermal cycling	71
B.4.3	Thermal exposure, thermal dwell	72
B.4.4	Humidity	72
B.4.5	Vibration test	73
B.4.6	Accelerations summary and overall acceleration.....	73
B.5	Example of reliability compliance test design assuming non-constant failure rate or failure intensity (wear-out)	75
Annex C	(informative) Estimating the activation energy, E_a	76
Annex D	(informative) Calibrated accelerated life testing (CALT)	78
D.1	Purpose of test	78
D.2	Test execution	78
Annex E	(informative) Example of how to estimate empirical factors	80
Annex F	(informative) Determination of acceleration factors by testing to failure	83
F.1	Failure modes and acceleration factors	83
F.2	Example of determination of acceleration factor	83
Annex G	(informative) Median rank tables 95 % rank	87
Bibliography		89

Figure 1	– Probability density functions (PDF) for cumulative damage, degradation, and test types	13
Figure 2	– Relationship of PDFs of the item strength versus load in use	18
Figure 3	– How HALT tests detect the design margin	19
Figure 4	– PDFs of operating and destruct limits as a function of applied stress	20
Figure 5	– Line plot for Arrhenius reaction model	35
Figure 6	– Plot for determination of the activation energy.....	36
Figure 7	– Bathtub curve	

Figure 8 – Test planning with a Weibull distribution.....	50
Figure 9 – Example of a test based on the Weibull distribution.....	51
Figure 10 – Life time and "tail" of the failure rate or failure intensity	52
Figure 11 – Reliability as a function of life time ratio L_V and number of test items	53
Figure 12 – Nomogram for test planning	54
Figure A.1 – How FMEA and HALT supplement each other	63
Figure C.1 – Plotting failures to estimate the activation energy E_a	77
Figure E.1 – Weibull graphical data analysis	81
Figure F.1 – Weibull plot of the three data sets	84
Table 1 – Test types mapped to the item development cycle	14
Table A.1 – Comparison between classical accelerated tests and HALT tests	63
Table A.2 – Summary of HALT results for a DC/DC converter	65
Table A.3 – Summary of HALT results for a medical system	66
Table A.4 – Summary of HALT results for a Hi-Fi equipment.....	67
Table B.1 – Environmental stress conditions of an automotive electronic device	70
Table E.1 – Probability of failure of test samples A and B	81
Table F.1 – Voltage test failure data for Weibull distribution.....	83
Table G.1 – Median rank tables 95 % rank.....	87

INTERNATIONAL ELECTROTECHNICAL COMMISSION

METHODS FOR PRODUCT ACCELERATED TESTING

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at <https://patents.iec.ch>. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 62506 has been prepared by IEC technical committee 56: Dependability. It is an International Standard.

This second edition cancels and replaces the first edition published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) references have been updated;
- b) symbols have been revised;
- c) errors in 5.7.2.3 and Annex B, mainly, have been corrected;
- d) calculation errors in the examples of Annex B and Annex F have been corrected.

The text of this International Standard is based on the following documents:

Draft	Report on voting
56/2000/FDIS	56/2016/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Many reliability or failure investigation test methods have been developed and most of them are currently in use. These methods are used to either determine product reliability or to identify potential product failure modes, and have been considered effective as demonstrations of reliability:

- fixed duration,
- sequential probability ratio,
- reliability growth tests,
- tests to failure, etc.

Such tests, although very useful, are usually lengthy, especially when the product reliability that has to be demonstrated is high. The reduction in time-to-market periods as well as competitive product cost, increase the need for efficient and effective accelerated testing. Here, the tests are shortened through the application of increased stress levels or by increasing the speed of application of repetitive stresses, thus facilitating a quicker assessment and growth of product reliability through failure mode discovery and mitigation.

There are two distinctly different approaches to reliability activities:

- the first approach verifies, through analysis and testing, that there are no potential failure modes in the product that are likely to be activated during the expected life time of the product under the expected operating conditions and usage profile;
- the second approach estimates how many failures can be expected after a given time under the expected operating conditions and usage profile.

Accelerated testing is a method appropriate for both cases, but used quite differently. The first approach is associated with qualitative accelerated testing, where the goal is identification of potential faults that eventually can result in product field failures. The second approach is associated with quantitative accelerated testing where the product reliability may be estimated based on the results of accelerated simulation testing that can be related back to the use of the environment and usage profile.

Accelerated testing can be applied to multiple levels of items containing hardware and software. Different types of reliability testing, such as fixed duration, sequential test-to-failure, success test, reliability demonstration, or reliability growth or improvement tests can be candidates for accelerated methods. This document provides guidance on selected, commonly used accelerated test types. This document should be used in conjunction with statistical test plan standards such as IEC 61123, IEC 61124, IEC 61649 and IEC 61710.

The relative merits of various methods and their individual or combined applicability in evaluating a given system or item, should be reviewed by the product design team (including reliability engineering) prior to selection of a specific test method or a combination of methods. For each method, consideration should also be given to the test time, results produced, credibility of the results, data required to perform meaningful analysis, life cycle cost impact, complexity of analysis and other identified factors.

In this document the term "item" is used as defined in IEC 60050-192 covering physical products as well as software. Services and people are however not covered by this document.

METHODS FOR PRODUCT ACCELERATED TESTING

1 Scope

This document provides guidance on the application of various accelerated test techniques for measurement or improvement of item reliability. Identification of potential failure modes that can be experienced in the use of an item and their mitigation is instrumental to ensure dependability of an item.

The object of the methods is to either identify potential design weakness or provide information on item reliability, or to achieve necessary reliability and availability improvement, all within a compressed or accelerated period of time. This document addresses accelerated testing of non-repairable and repairable systems. It can be used for probability ratio sequential tests, fixed duration tests and reliability improvement/growth tests, where the measure of reliability can differ from the standard probability of failure occurrence.

This document also extends to present accelerated testing or production screening methods that would identify weakness introduced into the item by manufacturing error, which can compromise item reliability. Services and people are however not covered by this document.

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.

IEC 60050-192 – *International Electrotechnical Vocabulary (IEV) – Part 192: Dependability*, available at <http://www.electropedia.org>

IEC 60300-3-5, *Dependability management – Part 3-5: Application guide – Reliability test conditions and statistical test principles*

IEC 60605-2, *Equipment reliability testing – Part 2: Design of test cycles*

IEC 60721 (all parts), *Classification of environmental conditions*

IEC 61123:2019, *Reliability testing – Compliance test plans for success ratio*

IEC 61124:2023, *Reliability testing – Compliance tests for constant failure rate and constant failure intensity*

IEC 61649:2008, *Weibull analysis*

IEC 61709, *Electric components – Reliability – Reference conditions for failure rates and stress models for conversion*

IEC 61710, *Power law model – Goodness-of-fit tests and estimation methods*

IEC 62429, *Reliability growth – Stress testing for early failures in unique complex systems*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-192 and the following apply.

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

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

NOTE Symbols for reliability, availability and maintainability measures follow those of IEC 60050-192, where available.

3.1.1

activation energy

E_a

empirical factor for estimating the acceleration caused by a change in absolute temperature

Note 1 to entry: Activation energy is usually measured in electron volts per degree Kelvin.

3.1.2

detection screen

low stress level exposure to detect intermittent faults

3.1.3

event compression

increasing stress repetition frequency to be at considerably higher levels than it is in the field

3.1.4

highly accelerated limit test

HALT

test or sequence of tests intended to identify the most likely failure modes of the product in a defined stress environment

Note 1 to entry: HALT is sometimes spelt out as the highly accelerated life test (as it was originally named in error). However, as a non-measurable accelerated test, it does not provide information on life duration, but on the magnitude of stress which represents the limit of the design.

3.1.5

highly accelerated stress audit

HASA

process monitoring tool where a sample from a production lot is tested to detect potential weaknesses in a product caused by manufacturing

3.1.6

highly accelerated stress screening

HASS

screening intended to identify latent defects in a product caused by manufacturing process or control errors

3.1.7

item

subject being considered

Note 1 to entry: The item may be an individual part, component, device, functional unit, equipment, subsystem, or system.

Note 2 to entry: The item may consist of hardware, software, people or any combination thereof.

Note 3 to entry: The item is often comprised of elements that may each be individually considered. See "sub-item" (IEV 192-01-02) and "indenture level" (IEV 192-01-05).

Note 4 to entry: IEC 60050-191:1990 (now withdrawn; replaced by IEC 60050-192:2015) identified the term "entity" as an English synonym, which is not true for all applications.

Note 5 to entry: The definition for "item" in IEC 60050-191:1990 (now withdrawn; replaced by IEC 60050-192:2015) is a description rather than a definition. This new definition provides meaningful substitution throughout this document. The words of the former definition form the new Note 1 to entry.

Note 6 to entry: In this document people and services are excluded.

[SOURCE: IEC 60050-192:2015, 192-01-01, modified – Note 6 to entry has been added.]

3.1.8

life time

<of a non-repairable item> time interval from first use until user requirements are no longer met

Note 1 to entry: The end of life time is usually called failure of the component.

Note 2 to entry: The end of life is often defined as the time where a specified percentage of the components have failed, for example stated as a B_{10} or L_{10} value for 10 % accumulated failures.

3.1.9

precipitation screen

screening profile to precipitate, through failure, conversion of latent faults into revealed faults

3.1.10

step-stress test

test in which the applied stress is increased, after each specified interval, until failure occurs or a predetermined stress level is reached

Note 1 to entry: The 'interval' could be specified in terms of number of stress applications, durations, or test sequences.

Note 2 to entry: The test should not alter the basic failure modes, failure mechanisms, or their relative prevalence.

[SOURCE: IEC 60050-192:2015, 192-09-10]

3.1.11

test acceleration factor

ratio of the stress response rate of the test specimen under the accelerated conditions, to the stress response rate under specified operational conditions

Note 1 to entry: Both stress response rates refer to the same time interval in the life of the tested items.

Note 2 to entry: Measures of stress response rate are, for example, operating time to failure, failure intensity, and rate of wear.

[SOURCE: IEC 60050-192:2015, 192-09-09]

3.1.12

time compression

removal of exposure time at low or deemed non damaging stress levels from a test for the purpose of acceleration

3.2 Symbols and abbreviated terms

ADT	accelerated degradation test(ing)
AF	acceleration, acceleration factor
AF_{Test}	overall acceleration in a test
CALT	calibrated accelerated life testing
B_{10}	life time, the time where 10 % of the items have failed
C	confidence
CD	compact disc player in a HiFi equipment
DL	destruct limit
DSL	design specification limit
FIT	failure in time (failure per 10^9 hours)
HALT	highly accelerated limit test
HASA	highly accelerated stress audit
HASS	highly accelerated stress screening test
HAST	highly accelerated stress test
L	load
L_v	life time ratio
LDL	lower destruct limit
LDT	lower destruct temperature
LOL	lower operating limit
LOT	lower operating temperature
LRTL	lower reliability test limit
MTBF	mean operating time between failures
MTTF	mean operating time to failure
OL	operating limit
OVL	operation vibration limit
P_A	acceptance probability
PDF	probability density functions
PWB	printed wiring board
$R(t)$	reliability as a function of time; probability of survival to the time t
RTL	reliability test level
S	strength
SL	specification limit
SPRT	sequential probability ratio test
t_0	time denoted time 0
t_L	a specified time, e.g. life
THB	temperature humidity bias test
TTF	time to failure
UDL	upper destruct limit
UDT	upper destruct temperature
UOL	upper operating limit
UOT	upper operating temperature

URTL	upper reliability test limit
UUT	unit under test
VDL	vibration destruct limit
$\lambda(S)$	failure rate as a function of a stress
$\lambda(t)$	failure rate as a function of time

4 General description of the accelerated test methods

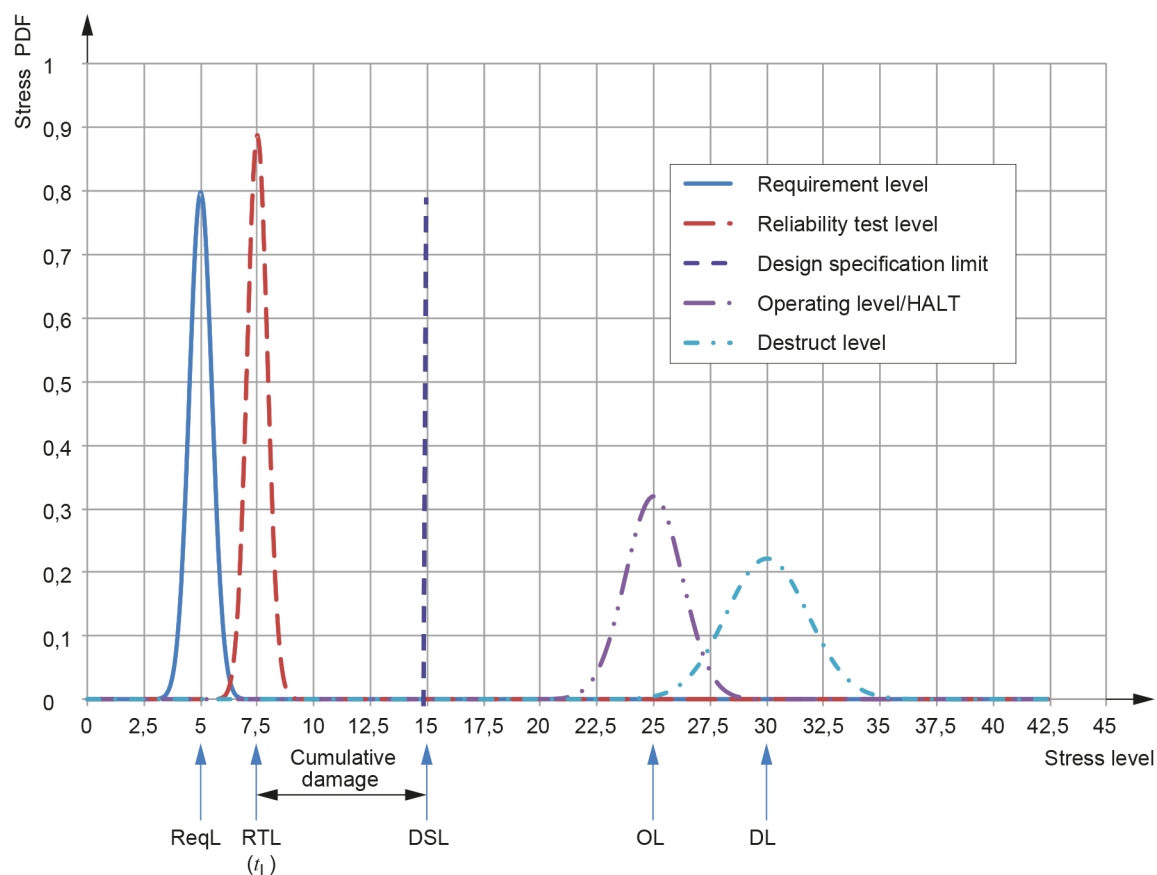
4.1 Cumulative damage model

Accelerated testing of any type is based on the cumulative damage principle. The stresses of the item in its life cause progressive damage that accumulates throughout the item life. This damage can, or not, result in an item's failure in the field.

The strategy of any type of accelerated testing is to produce, by increasing stress levels during testing, cumulative damage equivalent to that expected in the item's life for the type of expected stress. The determination of item destruct limits, without reliability estimation, provides information on whether there exists a sufficient margin between those destruct limits and item specification limits, thus providing assurance that the item will survive its predetermined life period without failure related to that specific stress type. This technique can, but not necessarily, quantify a probability of item survival for its life, and just provides assurance that the necessary adjustments in item strength would help eliminate such failure in item use. Where sufficient margins are determined unrelated to the probability of survival, the type of test is qualitative. In tests where this probability of survival is determined, the magnitude of the stress is correlated to the probability that the item would survive that stress type beyond the predetermined life, and this test type is quantitative.

Figure 1 depicts the principle of cumulative damage in both qualitative and quantitative accelerated tests.

In Figure 1, for simplicity, all stresses, operating limits, destruct limits, etc. are shown as absolute values. The specification values for an item are usually given in both extremes, upper and lower, thus the upper and lower (or low) specification limit, USL and LSL with the corresponding design limits (DSL), UDL and LDL, the upper and lower operating limits, UOL and LOL, and also the reliability test limits, URTL and LRTL. The rationale is that the opposite (negative stresses), can also cause cumulative damage probably with a different failure mechanism, thus the relationship between the expected and specified limits can be illustrated in the same manner as for the high or positive stress. As an example, cold temperature extremes can produce the same or different failure modes in an item. To avoid clutter, the positive and the negative thermal or any other stresses are not separately shown in Figure 1, thus the magnitudes of stresses are either positive or negative, and thus represented as absolute values only as upper or lower limits.



IEC

Figure 1 – Probability density functions (PDF) for cumulative damage, degradation, and test types

The graph in Figure 1 shows the required strength of an item regarding a stress for the duration of its life time, from beginning of life (e.g. time when the item is made), t_0 , through the end of life, t_L . The strength and stresses in tests are also assumed to have a Gaussian distribution.

The different types of accelerated tests can now be illustrated using Figure 1 as a conceptual model.

Functional testing is carried out within the range of the requirement specification and at the level of the specification. In this area no failures should occur during the test; design is validated to allow operation within the upper and lower specification limits. Accelerated testing of Types B and C (4.2.3 and 4.2.4), i.e. accelerated degradation testing (ADT) or cumulative damage testing can be illustrated as the distance between the design specification limit (DSL) and the level where the reliability demonstration test should be performed (RTL). When the degradation reduces the performance below the requirement specifications, the item can be declared as failed, if this behaviour is defined as a failure. When testing the item at time t_0 no failures should be expected for stress levels up to and including the design specification limit (DSL).

The item design specification should take into consideration certain degradation during the item's life which is resultant from the cumulative damage of the stresses expected in life, thus its limit is the design specification limit (DSL) which is higher than the requirement limit (RL) in order to provide the necessary margin. After item degradation resultant from the cumulative damage caused by expected stresses, the reliability test provides information on the existing margin between the test level (the remaining strength) and the requirement. This margin is a measure of reliability at the end of required period, t_L .

The ultimate strength of the design is considerably higher than the design specifications and this is the level determined in the qualitative accelerated test where the goal is to identify design weaknesses which can compromise item reliability, i.e. the weaknesses that can occur in the item's life span, as the item degrades. Thus, the strength in the qualitative test is demonstrated at operating limit (OL).

The destruct limit is above (beyond) the operating limit, and is denoted as DL. This is where a permanent failure is observed. If the OL or DL are close to the DSL or the standard deviation of the OL or DL distributions are high, then the test will indicate a potential weakness in the design as indicated in Figure 1.

Item reliability is a function of time, usually predetermined life time, t_L .

The cumulative normal distribution of the margin (difference of stress means divided by their common standard deviation) between the specified strength (use conditions) which is represented by the requirement and the reliability test level (RTL) determines item reliability. The test level and its duration are chosen so as to cause cumulative damage during testing corresponding to the degradation due to cumulative damage in the item's life span. The calculated value produces the item required reliability, which is then a quantitative measure.

A summary of listed tests and the mapping of their applications to the item life cycle is presented in Table 1.

Table 1 – Test types mapped to the item development cycle

Type	Design	Integration	Validation	Acceptance	Manufacturing	Services
A Qualitative	FMECA	HALT			HASS/HASA	
	Maturity Building		Maturity Confirmation			
B & C Quantitative			Reliability Growth Test	Reliability Qualification Test	Reliability Production Acceptance Test	
	Maturity Assessment					
Product Breakdown structure Opportunity	Type B/C : Component					
	Type A: Component	Type A : Assembly an/or Subsystem				
		Type B/C : Assembly	Type B/C : System			

Table 1 provides the users of this document a synthesis in order to get a better understanding of the different methods as and when required during the whole life cycle of the item.

4.2 Classification, methods and types of test acceleration

4.2.1 General

Based on the cumulative damage model, the information expected from the test and the item use assumptions, the accelerated test methods may be divided into three groups:

- Type A: qualitative accelerated tests: for detection of failure mode or phenomenon;
- Type B quantitative accelerated tests: for prediction of failure distribution in normal use;
- Type C: quantitative time and event compression tests: for prediction of failure distribution in normal use.

4.2.2 Type A: qualitative accelerated tests

Type A accelerated tests are designed to identify potential design weaknesses and also weaknesses caused by the manufacturing process. They can therefore be induced at levels considerably higher than OL, as shown in Figure 1. The goal of this type of test is not to quantify item reliability, but to induce or precipitate, during the test, the item's overall performance issues which are likely to take place in the field some time during the item's life time and result in an item failure. Improvement of the item design or manufacturing processes is executed to preclude those failures, producing a stronger or more robust item, expected to be more reliable in the field even under extreme or repetitive stresses as outlined in the design specifications.

Type A tests may be applied also to detect other weaknesses or latent failures not only for reliability but also for other dependability attributes.

Item development processes using this type of test increase item reliability through the mitigation of failure modes and by increasing item robustness without demonstrating a reliability target or measuring reliability improvement. These tests are often made with such high stress levels that, ideally, failures should be observed (DL in Figure 1) well beyond design specification limits. The purpose is to identify the failure modes, the weak links in the design and the margin between the functional limits, operating limit (OL) and the destruct limit (DL), as shown in Figure 1. The margin between the specification limit and the operating limit ensures that the weaknesses are identified in HALT (see 5.1.1) and are not expected to occur as failures during the expected item life, t_L .

NOTE Other tests of type A are marginal tests and overstress tests.

4.2.3 Type B: quantitative accelerated tests

Type B tests use cumulative damage methods to determine item reliability projected to the end of the expected item life. The necessary margin between the expected cumulative damage and the requirement produces a reliability measure. These tests are then accelerated to achieve the required cumulative damage in considerably shorter time than the item's expected life. Type B accelerated tests use quantifiable acceleration factors which are based on the physics of specific failures (or failure modes) and provide a relationship between the exposure time to the specific stresses during testing and in use environment. The failure, or failure mode distribution, is determined from information gathered through separate accelerated tests. Such test information provides the basis for a functional life model and can be used to quantify test acceleration for various reliability calculations, as necessary and applicable. In this way, item reliability can be estimated through estimation of the reliability or probability of occurrence of individual failure modes for any level of expected stresses. If necessary for data analysis using other test types (e.g. reliability growth or reliability demonstration tests), the determined test acceleration factor can be used to recalculate times to failure data from accelerated tests so as to represent times to failure occurrences in the use environment, and use the results for reliability calculations. In Figure 1, these tests are shown as reliability test levels (RTLs).

Another way of getting information from this type of test is to test to failure samples of items for the specific failure modes and the specific environments. This permits determination of applicable failure distributions and appropriate acceleration factors which can then be used for calculation of the probability of occurrence of the particular failure mode. This information can be useful for future tests as well as WeiBayes tests (1 parameter Weibull; see IEC 61649). The stress level of the Type B tests can be illustrated in Figure 1 as being higher than the requirement, but below the stress level that would be applied in HALT. The stress level can be between the design specification limit and the stress level of DL. The duration of the stress application shall be sufficient to cause cumulative damage with a margin over the cumulative damage produced by the expected life stresses during the item life.

Test time reduction is often achieved through an increase in operational or environmental stress beyond those specified for use. The increased level of these stresses produces a cumulative damage effect equivalent to that expected in the item life, but in a considerably reduced time period.

The accelerated degradation test (ADT) is a method where the degradation of an item is measured as a function of time or stress cycles. The degradation is plotted and extrapolated until the parameter reaches an unacceptable level (failure). This method is very useful for failures that are not sudden failures, but develop gradually. The stress levels applied in the test may be the nominal or worst case operating limits expected in the field use or the test may be accelerated by increasing test stresses as described in [1]¹.

4.2.4 Type C: quantitative time and event compressed tests

4.2.4.1 Use of Type C tests

Type C tests are mostly used for estimation of the life time of components where wear-out in active use is the dominating failure mode, for example switches, keyboards, relays, connectors or bearings. The data from these tests are often analysed using the Weibull distribution, and often in the form of the so-called "sudden death test" (see IEC 61649).

Type C time compression tests are also often used to identify:

- system integration issues (such as software and hardware integration or interaction);
- failure modes that are specific to the operating state, for example operating cycles for any mechanical and electrical cycling event;
- failure modes specific for environments where the range of stress is broad, but there is a threshold defined such that stress exposures below the threshold will not contribute significant damage to the item.

With the time compressions or event compression, the stress is accelerated by the duration or frequency of its application but not by the increase of its level.

Each of the above accelerated test methods is further described in Clause 5.

4.2.4.2 Time compression

Time compression is a test acceleration that can be applied in some circumstances, where the tests take into consideration only the time that an item is actually operational or operating in a state that produces significant damage (also known as removal of "non-damaging exposures"). The circumstances in which this type of acceleration may be applied are those where the operational stresses and their cumulative damage are significantly higher than those in other operational modes, for example non-operational or standby. To apply this rationale, the accumulated damage during the lower stress periods should be insignificant compared with the damage accumulated during the high stress periods, which physically will possibly not be easily justified (see IEC 60605-2).

4.2.4.3 Event compression

When a stress is repetitious, such as ON/OFF cycling, then the test can be accelerated by speeding up the repetition of stress (event compression). This is especially useful in cases where the test cannot be accelerated by increasing the stress level itself. In this manner, the number of operations remains the same as does the effect of the cumulative damage. Care should be taken that the higher repetition rate of the stress does not cause failure modes that would not occur in normal operation. Examples are self-heating in a plastic part, vibrations that do not dampen out before the next load and software sequences that do not finish before the next signal.

¹ Numbers in square brackets refer to the Bibliography.

5 Accelerated test models

5.1 Type A, qualitative accelerated tests

5.1.1 Highly accelerated limit tests (HALT)

5.1.1.1 General

Each type of commonly applied accelerated test method is presented in this document with its advantages, disadvantages and necessary application cautions.

Type A tests are not only the classical HALT but there are also other highly accelerated test types such as the autoclave, thermal shock, marginal tests, over-stress tests and other quantitative accelerated tests (see JESD47B [2] and [3]).

NOTE 1 A classical HALT uses only thermal and vibrational stresses.

The model shown in Figure 1 illustrates the relationship between the specifications, the design limits and the test strategies of the HALT.

NOTE 2 The acronym HALT was inadvertently spelt out in the past as highly accelerated *life* test. By its nature of being a qualitative accelerated test, however, HALT does not measure the life of an item, even though the term "life" is implied by ensuring that the failures in HALT would not be experienced in the life of the tested item. The test effectively tests the strength limits of an item, thus the word "limit" is appropriately used in the spelt-out acronym.

When reliability demonstration or reliability growth tests are accelerated, there is a need to demonstrate a margin between the cumulative damage induced by the applied stresses during testing and the cumulative damages caused by stresses expected to take place during the life, or any other predetermined time for which reliability is to be demonstrated. The favourable test results for the applied margins provide information on item reliability in that predetermined time as expressed by strength versus stress criteria. Demonstrated strength is shown through the test results, while reliability is the complement of the area common to both, load and strength curves, shown in Figure 2 (the area common to both stress and strength distributions are associated with the probability of failure of the item; the larger this area, the greater the probability of failure will be).

In Figure 1 the requirement specifications are translated into design specifications. The figure further illustrates how the design margin is verified by the HALT.

In order to estimate the margin between the design specifications and the unit under test (UUT) it is necessary to increase the stress levels until failure occurs during Type A tests. The margins verified in these tests are illustrated by a HALT operating stress limit (OL), as well as a destruct limit (DL). This also indicates the margins for the variations in the materials and manufacturing processes during manufacturing.

5.1.1.2 Main principles of HALT

The methodology of HALT is to quickly precipitate failures to identify and mitigate design weaknesses in an item in order to increase robustness during the item field use. This type of accelerated test is not intended to measure, but to increase item reliability through the elimination of failure modes with the lowest margin between the field stress (load) and item strength (Figure 2 and Figure 3). This type of accelerated test only identifies potential failure modes and guides the development and improvement processes for the chosen stressors. It is from the experience of HALT that most products are very robust for the applied stresses, but that a few components or design details are significantly weaker than the rest. The idea of a HALT is to find those few components or design details and make them as strong as the rest of the item.

Figure 2 illustrates the interference between the strength and stress distribution. It is assumed that the stresses in the field from different applications, climatic conditions, etc. can be modelled by a load distribution. It is shown here as a normal distribution. The strength of the items will vary due to variations in raw materials and manufacturing processes. This can be modelled by a strength distribution which in Figure 2 is also shown as a normal distribution.

The area common to both load and strength distribution is associated with the probability of item failure. The larger this area, the greater the probability of failure will be. The graph in Figure 2 shows the classical design margin, stress versus strength criteria, but in the context shown in 5.1.1.2, it does not account for the cumulative damage model; therefore, it is applicable to the initial short duration test that would measure the ultimate strength of the item design. Also, if the extensive item quality control maintains a very narrow strength distribution (which can be a very expensive and time consuming measure), then the distributions would not overlap, meaning that the field failures for the specific failure mode would be unlikely.

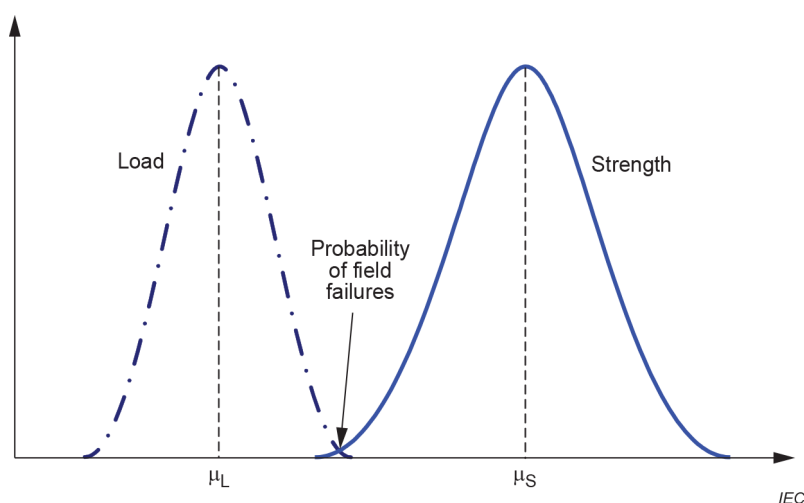


Figure 2 – Relationship of PDFs of the item strength versus load in use

Figure 3 illustrates the importance of design margins. The design margin not only have to cover the reduction in strength due to ageing, wear and fatigue, it also has to cover the variations in strength caused by the raw materials, components and manufacturing and assembly processes. Figure 3 a) illustrates a case of insufficient design margin, Figure 3 b) a case with sufficient design margin. The load curve illustrates the loads used during testing, representing the loads in the field. The strength curve is a PDF curve that covers all produced items from early test samples to mass produced items. The test samples are often manufactured in a special prototype test laboratory with optimum manufacturing conditions and maximum management attention. They are therefore typical of average strength or better (light blue circles). Later when the items are mass produced variations in strength from raw materials, components and manufacturing processes often cause the produced items to be of lower strength (the left "tail" of the strength distribution – the dark blue circles). When looking at the acceptance test of the design in Figure 3 a) the test level is H1 – the maximum stress expected in the field. The test samples (light blue circles) pass this test and the design is approved. However, once the mass production starts, some items in the left tail of the strength distribution (dark blue circles) are produced, and some of these cause failures in the field. In Figure 3 b) a HALT test is made on the design. Once the design survives the stress level H1 the stress is increased to H2, H3 and H4. In Figure 3 a) failure would be seen already at H2, had a HALT test been made, but in Figure 3 b) no failures are seen even at stress level H4. The conclusion is therefore that the design in Figure 3 b) has a sufficient margin, while the design in Figure 3 a) has an insufficient margin. This would not have been detected if a HALT test had not been made.

This is the rationale behind the application of tests such as step-stress tests and HALT, to ensure an appropriate margin over the expected stresses in life. In this way, these tests can be performed on a considerably smaller number of test samples than needed for conventional testing.

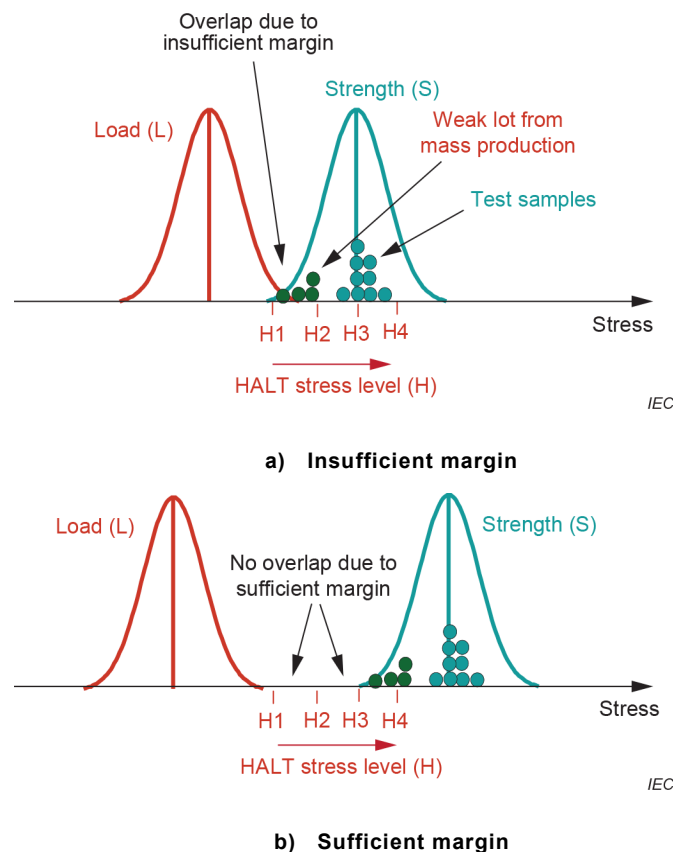


Figure 3 – How HALT tests detect the design margin

HALT is an explorative, qualitative design improvement test and should be accepted as such. It identifies the weakest link failure mode in the design for the related stress type(s). If this failure mode is related to the stress in the item use environment, the stress levels can only be estimated by an engineering judgement, considering the margin between the load and strength curves and including the additional margin for the expected variations in both the manufacturing process and the expected use environment. The comparison between HALT and a conventional accelerated test is illustrated in Table A.1. A step by step procedure can be found in Clause A.2 and examples in Table A.2, Table A.3 and Table A.4.

With the weakest link failing first, HALT is applied further to detect the second, third, and other consecutive weak links. This takes place until no more relevant failure modes are observed or until the technological limits of the tested system are reached.

HALT is designed to far exceed the item use environment as well as the design specifications. The stresses are applied in short durations, and the goal is to precipitate transition of faults into failures, and strengthen the item as much as it is economically and technically feasible. HALT identifies failure modes, but not their time dependency.

The UUT shall be functionally monitored during the test in order to detect the loss of its functions. If continuous monitoring is not possible, the item functions have to be tested while the stress level is kept constant. A typical procedure for a HALT is shown in Annex A.

The stress magnitude is not the focus of HALT; the real focus of an effective HALT programme is on item improvement activities and organizational response to failures. The item improvement should be continued to the point of a cost-effective rugged item where no part of the design is significantly weaker than the rest of the item. The goal is to keep improving the item to the level justified by the business case and utilization of cost-effective technology.

The operating and destruct limits for the item can be pictured as distributions on a stress axis, as illustrated in Figure 4, for both stress extremes, high and low (LOL, UOL, LDL, and UDL).

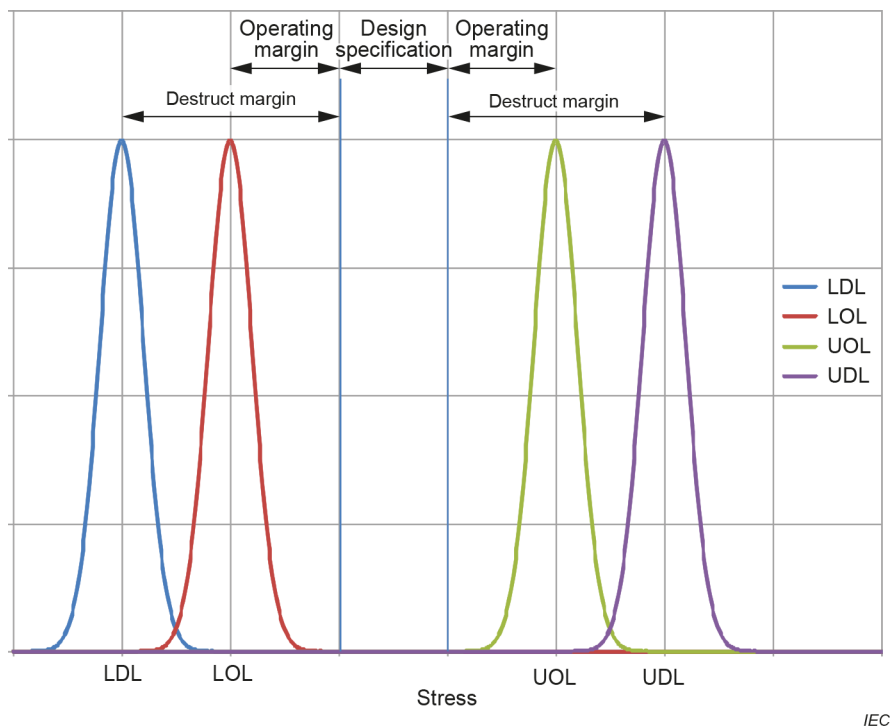


Figure 4 – PDFs of operating and destruct limits as a function of applied stress

Figure 4 is an example where both limits of the stress affect an item. This example can be the thermal stress where both, high and low temperatures, affect the performance of the item. It is possible that these effects will not be symmetrical, as the limits for high and low temperatures can be at a different distance from the nominal design stress. Even though these tests are performed on early prototypes they can provide information on design related failure modes. As shown in Figure 4, all of these limits can vary as indicated by the distributions. These distributions may have different standard deviations, and to determine HALT is to give an indication of the margins that allows the final item to accommodate these variations without failures in the field.

Even though Figure 4 depicts the temperature stress, other stresses may also be successfully applied in a HALT. In the case of other stress types, it is possible that lower limits will not exist as for example is the case for mechanical stresses, but they can exist with other stresses such as electrical stress and humidity.

5.1.1.3 Stress types and application

The primary or typically applied stresses in HALT are as follows:

- temperature;
- thermal cycling;
- vibration or shock;
- voltage;
- combination of vibration or shock and thermal cycling.

Other item-specific stresses can also be applied such as clock frequency for the microprocessor, voltage or power variations, contaminants or solvents, or a combination of these [3].

Verification of margins and item improvements made in response to HALT serve to increase the likelihood that the item will be robust and reliable in the field.

An example of typical stress levels is shown in Annex A. Ideally, the HALT stresses are applied as described in 5.1.1.2 until the predetermined maximum stresses are achieved. These maximum stresses are determined as follows:

- by the material limits and technological limits of the used materials and components;
- by the maximum stress achievable with the available methods and equipment.

It should be noted that the applied stress levels should not exceed the ultimate material limits where the physical or chemical characteristics can change.

It is normal to expect that there are some fragile elements in the UUT that are not designed for the stress levels normally applied in HALT. Those fragile elements should if possible be protected during HALT or disregarded in the test data evaluation. Fragile elements may be protected for example by applying cooling air to them, by isolating them against cold air, by suspending them outside the UUT in order to isolate them from vibration and shock or even by moving them outside the HALT test chamber and extending their connections to the rest of the UUT. Fragile elements that have been protected during the HALT test then have to be tested by a separate test for example a component test or a survival test.

Each failure observed during the HALT should be investigated and root cause failure analysis should be performed (see IEC 62740 [4]). If the identified failure mode is likely to occur in the field where the stress level is expected to be considerably lower than in a HALT, a corrective action should be proposed and implemented in accordance with engineering as well as management decisions.

5.1.2 Highly accelerated stress test (HAST)

This type of testing may be considered to be a cross between the qualitative, Type A, and quantitative, Type B, tests. This test type is very popular in the electronic components industry where it is widely used as a more efficient (shorter) alternative to the much longer temperature humidity bias test (THB), i.e. a pressure cooker test, which has a duration of 1 000 h. The stresses in these tests consist usually of temperature and humidity where corrosion of vias (metal conductors) in dies and thin film resistors can occur. The components are normally voltage biased during the test. Even though these tests do not yield numerical reliability estimates, they are used as effective re-qualification tests to provide certainty that reliability of the components is not compromised by any changes introduced in the components, see JESD22-A110 [5]. The duration of a HAST in the electronic component industry is usually about 100 h, and the stress levels for temperature and humidity are usually 130 °C and 85 % RH, respectively.

5.1.3 Highly accelerated stress screening or audit (HASS or HASA)

5.1.3.1 Applicability and principle of HASS or HASA

HASS and HASA are not classified as tests. Yet, both are included in this document because they apply accelerated stress for defect detection or screening. HASS is used for screening of production units using stresses considerably higher than those expected in normal use or in shipping, but with lower levels than those that can significantly reduce item life in the field. These levels are determined based on the finding from the HALT programme. The screening may be performed on all (100 %) production units or on a sample. The purpose of screening is to detect any latent manufacturing defects that would eventually appear in the normal use of the item. Detection of latent defects, followed by failure analysis and necessary corrective action (verified through a test designed to detect the specific failure mode), reduces the number of faults. The resulting field reliability improvement is due to the reduction in the number of field components with latent manufacturing defects and not due to a change in the inherent design reliability. HASS is ideally suited to pilot production or production ramp-up, i.e. when production rate is slow and 100 % screening can easily be accomplished. HASS may continue during normal production for very critical items that are manufactured in small volumes.

The stress levels in HASS or HASA are used for defect precipitation screening. The precipitation screen consists of combined stresses with their levels barely inside the operational limits. The purpose of this screen is to precipitate manufacturing defects into intermittent or permanent failures. To detect the failures, it is recommended to monitor the functions of the UUTs during screening as it is possible that some operational abnormalities will not be discovered in the post test operational checks. Further, it is not known when, during the precipitation screening, the possibly intermittent functional failure can be detected. The precipitation screen may combine several different stress types and stress levels. As with HALT, intermittent failures can be verified by using a detection screen (see Clause A.2, Step 4). Constant monitoring should provide functional coverage that is as complete as possible. Coverage and effectiveness of the monitoring should be optimized prior to beginning of the screen development process. The monitoring process should facilitate root cause analysis.

A typical precipitation screen itself will require a relatively short stress application time such as from 3 min to 1 h of stress. Additional time will be required for the test and monitoring equipment set-up.

HASA is a process monitoring tool where a sample from a production lot is exposed to the precipitation screen to detect possible defects. HASA is often performed before the production lot is released. HASA often supplants HASS when the manufacturing process reaches its maturity. HASA is further reduced and even eliminated when the effectiveness of production controls is established.

5.1.3.2 Selection of stresses and their magnitudes

Stresses should be selected so as not to compromise functionality, material properties, or the life of non defective hardware. The initial levels are determined from information gained in HALT.

The precipitation screen is performed with stress levels a little lower than the operating limits since the UUT have to be monitored for function during screening. Typically, the temperature stress is reduced by 5 °C and the vibration level by 2 g RMS (19,62 m/s²). Before the precipitation screen is used for HASS or HASA it should be verified that the precipitation screen does not significantly reduce the item life in the field. This can be tested, for example, by exposing one sample to the precipitation screen 10 times.

5.1.4 Engineering aspects of HALT and HASS

5.1.4.1 Advantages of HALT and HASS

The advantages of HALT and HASS are as follows:

- verified and selectively increased design margins for reliability improvement;
- sample size for determination of a specific failure mode is small;
- quick determination of dominant failure modes for specific stressors and easily combined stresses (the duration of the test is typically three days);
- efficient trade-off analysis information and determination of necessary corrective actions;
- quick verification of corrective actions;
- efficient short-term production screening;
- elimination of weak or defective components (HASS) from the main population (quality and reliability improvement).

5.1.4.2 Disadvantages of HALT and HASS

The disadvantages of HALT and HASS are as follows:

- a) possibility of stimulating failure modes that would not normally be observed in item use;
- b) potential for over-improvement of design margin (over-design);
- c) resultant reliability not known;
- d) no statistical confidence in the test result (over- or under-estimation of the design margins);
- e) testing does not address all interactive effects of multiple failure modes;
- f) impractical for very large items, very small items and items with diverse fragility;
- g) limited number of stress types (primarily temperature, vibration, shock and thermal cycling);
- h) inability to evaluate the design limits for a stress influenced by synergy with other stress types not provided by the HALT types.

5.2 Types B and C – Quantitative accelerated test methods

5.2.1 Purpose of quantitative accelerated testing

The purpose of quantitative accelerated tests is to estimate one or more measures of reliability, for example failure rate, probability of failure or survival, or time to failure (TTF). Often the purpose of quantitative accelerated testing is to determine the life time of components with a limited life (wear-out), or to determine (quantify) and improve the reliability of systems and components. For this, Weibull analysis is very useful (see IEC 61649).

5.2.2 Physical basis for the quantitative accelerated Type B test methods

5.2.2.1 General

The goal of Type B accelerated testing is to measure the reliability and verify acceptable reliability performance of the item within a short period of time. Thus, the goal in accelerated testing is to accelerate the damage accumulation rate for relevant repetitive stress and wear-out failure mechanisms (a relevant failure mechanism is one that is expected to occur under life-cycle conditions).

In order to accelerate tests, it is necessary to have a thorough understanding of the potential failure mechanisms and the operational and environmental stresses of the item or system. This can also be achieved through failure mode analysis of the designed item associated with the intended item usage profile, for example using an FMEA (see IEC 60812 [6]). Effective measures can then be taken not only to prevent their manifestation under predetermined life or usage stresses, but also to precipitate them effectively during accelerated testing for item improvement. Accelerated wear-out or reliability testing has been recognized to be a valuable activity to assess the reliability of high reliability electronics, electro-mechanical and mechanical systems. The application of elevated stresses is usually for the purpose of:

- a) making the design more robust and improving the manufacturing process through systematic step-stress testing and increasing the stress margins through corrective actions (reliability growth testing);
- b) conducting accelerated life tests in the laboratory to measure and verify in-service reliability.

The extent of acceleration, usually termed the acceleration factor (AF), is defined as the ratio of the life under use conditions to that under the accelerated test conditions. This acceleration factor is needed to quantitatively extrapolate reliability measures (such as time-to-failure and failure rates) from the accelerated test environment to the usage environment, with some reasonable degree of confidence. The acceleration factor depends on hardware parameters (e.g. material properties, item architecture) of the UUT, usage stress conditions, accelerated stress test conditions and the relevant failure mechanism. Thus, each relevant failure mode (assuming it is a result of one failure mechanism) in the UUT has its own acceleration factor and the test conditions (e.g. duty cycle, stress level, stress history, test duration) shall be tailored based on these acceleration factors.

The physics of failure approach means that each failure mode is addressed separately and the margin to the life time or to the required reliability is verified for each of them. With this approach, each of the failure modes has its own failure distribution and failure rate. In other cases, the result is combined to an estimated reliability for the whole item.

When planning a test the potential failure modes in the item should be listed. The test is then planned with stress levels and durations so that the failure modes should be observed in the test if they are present in the item. For this planning, empirical factors from previous items, from the component suppliers or from literature, can be used to estimate the acceleration factor of the test. After the test is performed the actual failure modes are known, and the test can be analysed for each failure mode separately. It is recommended to use a test set-up where the empirical factors can be estimated from the test itself. See Annex E and Annex F.

Type B tests can be run by increasing the level of a variety of loads such as thermal loads (e.g. temperature, temperature cycling, and rates of temperature change), chemical loads (e.g. humidity, corrosive chemicals like acids and salt), electrical loads (e.g. steady-state or transient voltage, current, power), and mechanical loads (e.g. quasi-static cyclic mechanical deformations, vibration, and shock impulse or impact). The accelerated test environment may include a combination of these loads. Interpretation of results for combined loads and extrapolation of the results to the life-cycle conditions requires a quantitative understanding of the relative interactions of the different test stresses and the contribution of each stress type to the overall damage.

5.2.2.2 Advantages of the Type B test

The acceleration stress test provides quantitative information on the reliability of the tested item:

- this test type can be designed
 - for selected failure modes (e.g. from FMEA) to assess, with reasonable confidence, overall reliability;
 - for combined stresses also to simulate the interactive effects of those stresses and a realistic assessment of the item reliability;

- an acceleration test can be effectively carried out to enable the test to represent cumulative damage in use.

5.2.2.3 Disadvantages of the Type B test

- A risk that the stress acceleration can exceed the physical properties of item materials and cause unforeseen damage.
- A risk that the acceleration of combined stresses can cause additional unforeseen damage to the item that would not have happened in actual use.
- The base line for accelerated testing is not a single stress but is generally a multiple stress that varies with user and location. It is necessary to take this into consideration when quantifying the results.

5.2.3 Type C tests, time (C₁) and event (C₂) compression

5.2.3.1 Type C₁ tests

5.2.3.1.1 General

Time compression is achieved by eliminating "OFF-time" (e.g. non-operating time or time with low stress levels) by compressing the duty cycle through addressing just the ON time. Furthermore, when items are exposed to a wide range of stresses, it is typical that the highest stresses (the primary stresses) will induce the most damage, and that there are some levels of usage stress that, compared to the primary stresses, are assumed to produce negligible damage. Any exposure below a chosen damage threshold stress can be assumed to produce negligible damage and can be eliminated from the test programme. This is particularly true for mechanical fatigue and is often applied in accelerated structural fatigue testing (see IEC 60605-2).

An example of duty cycle compression is when the test duration is 24 h per day, whereas the item in its actual use environment operates for only 8 h per day. This results in a time compression factor of 3. Each day of test time is equal to three days of actual use time.

5.2.3.1.2 Advantages of time compressed tests

Items with a minimal or short operating use time compared with calendar time can be tested within a very reasonable test time relative to its required life (e.g. office equipment, cars, harvesting machinery). For example, a snow plough is used only in one season, once a year, and only when there is a reasonable accumulation of snow to justify its use. Even when used, it is expected to be on for 2 h to 3 h on average. There are several primary damaging stresses such as vibration, stress in the motor, wear-out of blades. For the rest of the year, it is stored in a shed, and protected from extreme weather conditions. Thus a snow plough that has a required life of ten years, but effectively is used four times a month for three months, for durations of 2 h, can be tested for a required usage duration of 240 h. Therefore, a test of approximately 300 h would provide a good margin to prove the snow plough's reliability.

With a relatively short test duration at nominal stresses, there is no reason to increase the stresses, and therefore, there is no need to determine stress acceleration factors; otherwise there is a risk of overstressing the UUT.

5.2.3.1.3 Disadvantages of time compressed tests

Concentration exclusively on operational time means considering the operational environment only with its associated failure modes, while the failure modes occurring in the "non-operational" environments may be neglected. Such failure modes can even be more damaging to the item, since they are a result of stresses that are perhaps considerably lower than those when the item is in use, but are applied for a considerably longer time to produce the same or greater cumulative damage than the stresses applied in use.