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TECHNICAL REPORT

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Process management for avionics – Highly severe stress tests for operating margins identification and robustness improvement of avionics equipment – Application guidelines

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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**PROCESS MANAGEMENT FOR AVIONICS –
HIGHLY SEVERE STRESS TESTS FOR OPERATING MARGINS IDENTIFICATION AND ROBUSTNESS IMPROVEMENT OF AVIONICS EQUIPMENT – APPLICATION GUIDELINES**

FOREWORD

IEC TR 62500 has been prepared by IEC technical committee 107: Process management for avionics. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
107/411/DTR	107/415/RVDTR

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 Technical Report 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- withdrawn, or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.

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INTRODUCTION

In an increasingly harsh economic context (higher performance requirements, shorter development cycles, reduced cost of ownership, etc.), consideration is given to rapid equipment maturity, preferably from its entry into service (EIS).

It is with a view to remedying shortcomings that "highly severe stress" tests for margins research and robustness improvement are considered in equipment design and development methods. The main underlying principle behind this type of test strategy is as follows: rather than reasoning in terms of conformity with a specification and applying tests in line with the specification requirements, it is on the contrary attempted to push the equipment to its operating limits by applying environmental stresses or stimuli, whose levels are higher than the specification requirements.

PROCESS MANAGEMENT FOR AVIONICS – HIGHLY SEVERE STRESS TESTS FOR OPERATING MARGINS IDENTIFICATION AND ROBUSTNESS IMPROVEMENT OF AVIONICS EQUIPMENT – APPLICATION GUIDELINES

1 Scope

This technical report considers the targets assigned to highly severe stress tests for operating margins research and robustness improvement of avionics equipment, their basic principles, their scope of application and their implementation process. It is primarily intended for avionics programme managers, electronic equipment project managers, designers, test managers, and dependability team.

This document provides guidance which can apply to all avionics programmes and is of primary interest to the original equipment manufacturers (OEMs) in charge of designing, developing and producing equipment built for these programmes, for obtaining early equipment maturity.

NOTE 1 Highly severe stress tests approach is often an industrial will in a global lifecycle cost effective approach (see the Introduction) and it is not required at certification level. Moreover, customers can potentially define, in contract clauses, in-service availability requirements, for example, from the entry into service (EIS) or in operation.

This highly severe stress tests approach is part of the avionics equipment design and development stage, and it can address stresses in mechanical, climatic, electrical, etc., domains.

NOTE 2 The principles and objectives described in this document can apply to all types of equipment used in systems developed in avionics programmes, whatever their nature (electronic, electromechanical, mechanical, electrohydraulic, electro-pneumatic, etc.) and whatever their size, from "low-level" subassemblies (circuit card assemblies (CCAs), mechanical assemblies, connectors, etc.) up to system level groups of equipment.

This document can be used in conjunction with IEC 62429, IEC 62506, or both, with regard to dependability aspects related to equipment consisting of hardware with embedded software.

NOTE 3 This document can provide an aid in an equipment definition justification process (see CEN-CENELEC prEN 9215) which can address:

- the development of a definition justification dossier (DJD) by bringing data related to equipment margins and to decisions; or
- the justification of potential future changes made at equipment definition, for example when processing cases of electronic component obsolescence.

For the purpose of this document, if the term "deficiency" is used alone afterwards, it is stated as "built-in deficiency" or "weak point" and encompasses the concept of "deficiency and associated potential malfunction or failure" (see 3.1.1).

Although developed for the avionics industry, this document can be used by other industrial sectors at their discretion.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 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:

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

3.1.1 built-in deficiency

fault, flaw, imperfection, shortcoming or abnormality, often called weak point, in the design or in the manufacturing processes of an item, which can potentially lead to a malfunction or a failure and cause the item not to operate or function correctly

Note 1 to entry: Deviation from state-of-the-art design rules or inaccurate manufacturing process control can constitute risks and be, for example, at the origin of equipment built-in deficiencies. These built-in deficiencies are usually considered as weak points.

Note 2 to entry: The correction of a built-in deficiency goes in the direction of improving operating margin and robustness of an item, and so in the direction of improving its early maturity.

Note 3 to entry: A built-in deficiency is usually latent (present or potential but not obvious or not explicit or dormant) and manifests itself in operating time or certain conditions.

3.1.2
destruct limit

point from which an item breaks and suffers permanent and irreversible damage

Note 1 to entry: The destruct limit is above (beyond) the operating limit. The stress level leading to the destruct and the permanent and irreversible damage is in excess of the one characterizing the operating limit of an item. The item no longer functions, even the stress level is reduced and returned to below the one characterizing the operating limit.

3.1.3
highly severe stress test

test during which the equipment or some of its parts are submitted to environmental or operating condition or stress that is increased progressively to values far in excess of the specified values, up to the operating limit of the equipment

3.1.4
intermittent

occasional or irregular

Note 1 to entry: An intermittent malfunction or failure occurs occasionally or at irregular intervals.

Note 2 to entry: Intermittent malfunction or failure can occur at stress level in excess of the specified operating limit of an item where the item functions with nominal load. The purpose of highly severe stress tests approach is to precipitate the potential built-in deficiencies (at design or manufacturing processes level for example) into intermittent or permanent malfunctions or failures to investigate them and seek corrective actions.

Note 3 to entry: Intermittent malfunction or failure origin can sometimes be detected by applying an additional specific low stress level (vibrations for example) during a function test.

3.1.5
intrinsic limit
point below which an item, a material or a technology keeps its intrinsic properties or characteristics, with respect to given condition(s) (for example, temperature, vibration, electrical voltage, etc.)

Note 1 to entry: For example, melting temperature of a plastic, maximum junction temperature of a semiconductor, yield strength of an alloy, etc., are intrinsic properties or characteristics of these materials or technologies.

Note 2 to entry: This limit, whether or not destructive, is an absolute barrier.

3.1.6
maturity
state of an item whose functional and operational performance can be considered stabilized with respect to the specification

Note 1 to entry: Maturity is usually the result of a gradual process of eliminating built-in deficiencies still present at the item level and its associated processes (manufacturing processes for example).

3.1.7
operating limit
point at the boundary of the operation area of an item where it still operates or functions correctly and beyond which it no longer operates or functions correctly

Note 1 to entry: The operating limit defines the maximum range of correct operation area of an item, and it is usually characterized by stress level above which the item no longer operates or functions correctly. Usually, for determining this stress level, the stress level at which the item no longer operates or functions correctly is reduced to verify if the function of the item resumes; if the functionality resumes at the reduced stress level, then this stress level characterizes the operating limit.

Note 2 to entry: The operating limit can correspond to the intrinsic limit of a technology. In this case, this is the maximum range of operation which can be reached by the equipment.

3.1.8
operating margin
difference between the operating limit and the nominal operating level under specified stress levels

3.1.9
robustness
property of an item having reduced sensitivity of its performance under, for example, the environmental conditions, to components variations, or to drifts in its manufacturing processes

Note 1 to entry: Robustness is usually the result of actions taken to obtain sufficient operating margins while at the same time reducing all forms of variability.

3.2 Abbreviated terms

CCA	circuit card assembly
CDR	critical design review
EIS	entry into service
EMC	electromagnetic compatibility
ESD	electrostatic discharge
ESS	environmental stress screening
LCD	liquid crystal display
MTBF	mean operating time between failures
OEM	original equipment manufacturer
PCB	printed circuit board
PDR	preliminary design review

RTV rapid temperature variation

TTM time to market

4 Highly severe stress tests for margins research and robustness improvement – Approach

4.1 General

With regard to the initiative for obtaining early equipment maturity, the approach based on highly severe stress tests for operating margins research and robustness improvement consists in submitting an equipment or some of its component parts to environmental or operating stresses, or both, which are gradually raised to values in excess of the specified values until the equipment operating or destruct limits are reached.

Instead of reasoning in terms of conformity with the specification (which is representative of the equipment real lifecycle or mission profile), the highly severe stress tests approach aims, indeed, on the contrary with a view to obtaining robust and mature equipment, to push the equipment to its operating limits or potentially to its destruct limits in order to:

- detect potential intermittent or permanent malfunctions or failures that were not foreseen before the tests;
- reveal, identify and then, depending on margins targets if defined, correct built-in deficiencies which can lead to intermittent or permanent malfunctions or failures; and
- explore available margins and improve, if needed, these margins through appropriate actions, for example, on the equipment design itself or the manufacturing processes.

Equipment operating margin targets are often defined to orientate the highly severe stress approach.

NOTE For example, if not specified by the customer, an operating margin target of 5 °C can be defined with regard to the specified low operating temperature, $T_{\text{op-low}}$, of an equipment; so, in this case, the highest level of stress is limited to $T_{\text{op-low}}$-5 °C. The equipment operating margin target can also be defined according to the industrial usage or application domain or by experience feedback.

Usually, the highly severe stress tests activity is part of a global lifecycle cost effective approach and is formalized with its general objectives and principles in quality system procedures or other specific summary documents, allowing effective coordination and OEM executive officers' support.

Annex A, Figure A.1, provides a typical flowchart related to the highly severe stress tests approach.

4.2 Objectives

The main objectives of the approach include:

a) achieving, in a relatively short time, an early equipment maturity by improving its robustness toward the specification;

b) taking, from the first prototypes, full advantage of technologies and manufacturing processes, by:
   - eliminating, for example, design and manufacturing processes built-in deficiencies;
   - researching operational limits or destruct limits in operating and environmental conditions more severe than the specified ones;
   - considering operational margins allowing to:
     - satisfy, for example, potential technologies or manufacturing processes variations (which can lead later to potential malfunctions, failures or specification non-conformities);

- establish design provisions for potential future specific changes, for example, to facilitate (if possible) minor specification evolution or management of electronic component obsolescence with potential alternatives, in particular, with regard to future equipment maintenance management;

c) contributing potentially to the lifetime of the equipment in service through its conditions of use;

d) contributing to specify optimal or more accurate environmental stress screening profiles;

e) reducing the global costs of ownership (see Clause 11).

NOTE These objectives rely, as mentioned in 4.1, on:

- detection of built-in deficiencies as early as possible (so that they can be more easily corrected without excessive cost), as these deficiencies can be present, for example, in design errors or imprecise controls of the manufacturing processes;
- exploration of the operating limits once built-in deficiencies have been eliminated or corrected; these limits can be pushed back through design changes, for example, when the margins with regard to the specified operating range appear insufficient or inadequate.

4.3 Considerations

A highly severe stress test can be characterized as follows:

- A highly severe stress test is a proactive type of test: it is considered as a "tool" to support the design and development of the equipment, and its manufacturing processes implementation. It usually leads to engineering activities aimed at understanding the potential observed malfunctions or failures mechanisms and the built-in deficiencies origins which caused them, in order to consider then the corrections technically and economically feasible; these corrections enable to eliminate or correct built-in deficiencies, or at least to delay significantly their manifestation with regard to the margins which are considered acceptable. The highly severe stress test is "proactive" in that it encourages these engineering actions at the earliest stage in equipment development.
- A highly severe stress test is not a conformity test: through the desire to explore the margins and expand them if necessary, the highly severe stress test looks above all to reveal the equipment built-in deficiencies and their associated malfunctions or failures when working beyond the specifications. It is, therefore, the opposite of a conformity test, which aims to ensure that the equipment performance is correct when it is subjected to the specified operating and environmental conditions.
- A highly severe stress test is not confused with a "conventional" accelerated lifetime test: the purpose of an accelerated lifetime test is in fact to predict the evolution of the behaviour of an equipment in its operational conditions of use, by subjecting it to stresses that are harsher than the values expected during its lifetime profile. To do this, the "conventional" accelerated lifetime test relies on analytical equipment failure mode acceleration models, which is not the case with the highly severe stress test.
- A highly severe stress test does not produce reliability measures: as the highly severe stress test works outside the specified domains, the analytical acceleration models can no longer apply to the domains explored. Furthermore, it is very hard to involve the "time" factor given the very short duration of the test. The result is that as things currently stand, the highly severe stress test cannot be used to estimate equipment reliability or lifetime characteristics in the specified conditions of use.

4.4 General principles

As a "tool", the highly severe stress tests aim – through application of stresses going beyond the specification or simply not specified – to stimulate potential built-in deficiencies in the equipment design and in its manufacturing processes. Revealing these deficiencies, and the associated operational malfunctions or failures, is thus an opportunity to improve the equipment or processes more quickly than with a traditional approach, leading to an expansion of the operating margins and contributing to greater maturity.

It is understood that in a highly severe stress tests approach, the stresses are applied to actively stimulate the potential weak points of the equipment and its processes and are not, therefore, designed to simulate the conditions of use of the equipment during its lifetime or mission profile. These stresses are applied either alone or sometimes combined, exceeding the values expected during the lifetime of the equipment, until reaching the equipment operating limit and potentially the equipment destruct limit, or the intrinsic limit set by the technologies. This implies gradually eliminating the various barriers preventing this limit from being reached and which are due to the existence of any built-in deficiencies still present. An essential goal of the highly severe stress tests is precisely to reveal the existence of these deficiencies, to eliminate or correct them and to restore operating margins if needed.

NOTE 1 Some stresses can be chosen according to potential weak points which are identified initially.

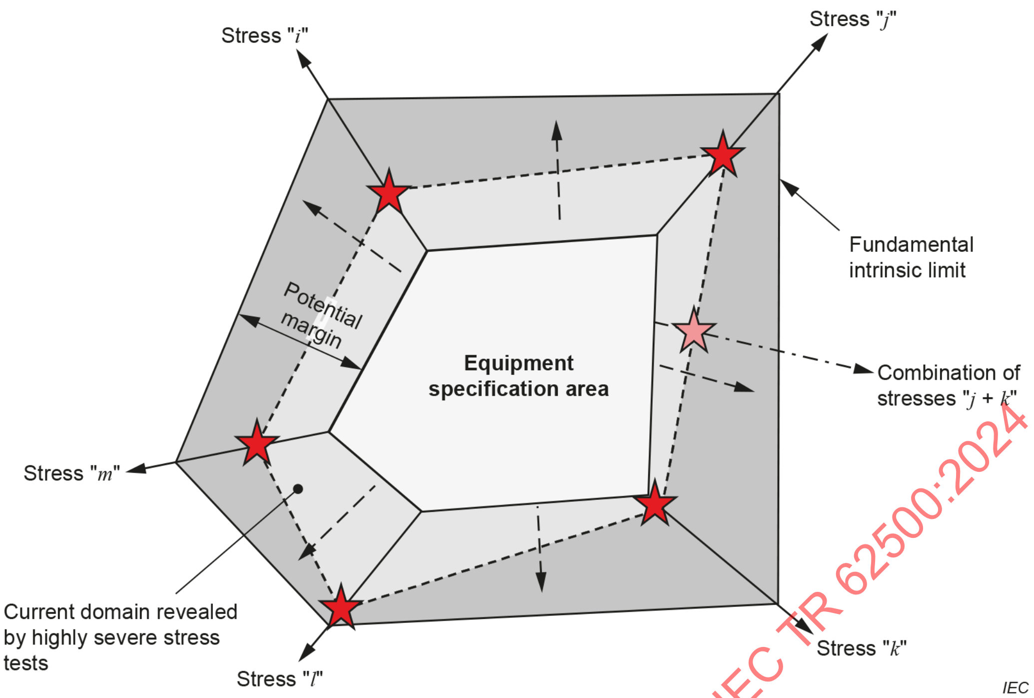
Among the reasons which justify the desire to correct built-in deficiencies, the following can be mentioned:

- the experience gained by OEMs which use highly severe stress tests shows that most problems detected during these tests would appear and be detected in the field if the built-in deficiencies revealed by these tests are not eliminated or corrected;
- experience shows that built-in deficiencies can often be located and can be eliminated or corrected or attenuated both easily and economically (for example: inadequate footprint of an electronic component package leading to poor solder joints, inadequately tightened screw, electronic components mounted on vibrating parts of a CCA, CCA inadequately fastened in an equipment subject to vibrations, etc.).

Because of its damaging nature, the principle of the highly severe stress test is often thus a cultural change in relation to the traditional approach whose main aim is to ensure the conformity of equipment performance within the specified conditions. As shown typically in Figure 1, the accelerated stress test aim is no longer to show that the equipment is in conformity, but to prove that exploration has been conducted beyond the specified frontier in order to clean the equipment of built-in deficiencies limiting its potential robustness, potentially going up to the intrinsic limit set by the technologies.

NOTE 2 Performing a highly severe stress test does not lead to over-sizing or over-design. The ultimate purpose of the accelerated stress test is to track down and eliminate built-in deficiencies, which by principle are, for example, the result of non-compliance with, or ignorance of, the state-of-the-art rules or good practices (in design and manufacture). These actions are, therefore, dedicated to eliminating built-in deficiencies, contributing to improving the operating margins and obtaining higher robustness. Generally speaking, one does not attempt to push back the fundamental limits of the technologies, components or materials, which would call into question the design and development choices, entailing probably significant additional investment and time.

NOTE 3 An important aim of a highly severe stress test is to eliminate the weakest links in the product, making all parts equally strong or robust in relation to the environmental loads and satisfying the operating margins target, To avoid overdesign the aim is not to make the whole product as strong as possible since that would most likely increase costs and weight for example but each malfunction or failure observed is carefully investigated and evaluated to determine if it can occur in the field; the reason is that the highly severe stresses can activate malfunctions or failure modes and the aim is that they do not occur in the field.



Key

- Specified domain: described in the equipment specification.
- Technological area: this corresponds to the ideal equipment, designed and produced without error, but which represents the intrinsic limit of technologies, and defines the maximum operating margin with respect to the specification.
- Domain revealed by the highly severe stress tests: this corresponds to the real limits of the equipment, as revealed by the highly severe stress tests. The stars bordering this domain correspond to built-in deficiencies detected, causing the equipment to cease to operate or function at this stress level. The limits reached can potentially correspond to destruct limits.
- Growth in operating margin by gradually increasing the stresses and correcting the built-in deficiencies revealed.
- Built-in deficiencies (to be detected and eliminated or corrected).

Figure 1 – Typical exploration of margins using a highly severe stress tests approach

4.5 Example of the limitations of highly severe stress tests

Despite its efficiency and speed, the highly severe stress tests method has, nevertheless, some limitations which can, in certain cases, require to consider first specific testing or specific checking of equipment components.

In practice, and independently of the parameters that highly severe stress tests do not address by their very nature (such as electrostatic discharges (ESDs), sealing, etc.), they provide relatively few information about the robustness of equipment that can change over time as a result of internal physical-chemical reactions for example.

The issue of electro-migration in ceramic capacitors is considered as an example of such a limitation:

- This effect causes, ultimately, capacitors to fail as a result of short-circuiting, which can take two weeks or two years to occur, depending on their design, their manufacturing process and the environmental conditions under which they are used.
- Highly severe stress tests of a new manufactured equipment cannot always reveal this type of fault, because at the time of testing, the ceramic capacitor complies fully with its specification and these tests only marginally accelerate the latent electromigration effect.
- In this example, at in-coming stage, integrity check of the supplied capacitors can considerably reduce the risk involved. Such check usually involves specific humidity and temperature testing of ceramic capacitors, using test conditions which can be impossible to reproduce with tests at the finished equipment level.

On the basis of this example, OEMs' feedback and experience enable the OEMs design authority, or the program or project manager for example, to decide whether the highly severe stress tests defined in the design and development phase, or the screening tests defined in the production processes, are sufficient. If not, OEMs can design, evaluate and implement additional filters to achieve the desired degree of robustness.

5 Industrial domains covered by highly severe stress tests

The highly severe stress tests can apply, beyond avionics, to all industrial sectors and to various equipment categories (for example: electrical, electronic and electromechanical equipment), provided that the most pertinent stresses (mechanical, climatic, electrical, etc.) are used with respect to the composition of the equipment (electrical, electronic, mechanical parts, etc.).

In some cases, the highly severe stress tests are not suitable for small equipment or very large equipment; IEC 62506 can provide information.

The equipment is able to be monitored for function during the highly severe stress tests either continuously or during pauses in the step stress process.

6 Highly severe stress tests in the equipment lifecycle and associated stages

6.1 General

To ensure optimum efficiency, the highly severe stress tests approach fits into the equipment lifecycle potentially at different stages and it is preferable to consider it as far upstream as possible in the lifecycle and the decision-making process, keeping in mind that the later a problem is detected and a change is late, the higher the cost is.

The highly severe stress tests approach therefore entails availability of equipment for the tests (prototypes for example) (see 6.2).

6.2 Design and development

The highly severe stress tests are an essential activity of the design and development stage in view of early equipment maturity from the EIS.

These tests are usually implemented on equipment which is operationally representative of the final equipment. This includes at least:

- very close definition and configuration of the final equipment;
- production processes closely representative of the series production ones.

Highly severe stress tests are usually considered as a supplement to the equipment validation and verification processes for addressing the equipment robustness improvement and margins identification.

NOTE 1 The objectives of the validation and verification processes, as well as associated activities are indeed to ensure that the requirements identified in the technical specifications are correctly implemented and satisfied in the design, meeting the needs of the customer. This is also to ensure that the manufactured equipment comply with the technical specifications.

NOTE 2 Sometimes, according to the technical innovation or complexity, at risk or critical functions, sub-assemblies or assemblies can be prototyped; specific highly severe tests can be applied to anticipate the final design, allowing very early to highlight potential weaknesses or to validate technical or technological choices or processes.

6.3 Qualification

The results of the highly severe stress tests contribute usually to the decision-making for determining whether the equipment is able to undergo qualification.

6.4 Production

The results of the highly severe stress tests can be an input for defining the profiles to be applied in the environmental stress screening or burn-in program in production (IEC 62506, IEC 61163-1 and IEC 61163-2 can also provide information).

During the production stage, periodic highly severe stress tests can also be considered on samples in order to assess or check variability of manufacturing processes, procured parts, etc., and to make potential adjustments. In this case, a risk analysis is usually performed previously as a trigger to determine the need of a periodic highly severe stress tests campaign during this stage.

6.5 Operation and maintenance

In the operation and maintenance stage, highly severe stress tests can be used for example to:

- investigate, confirm or reveal potential drifts at components or manufacturing processes level, etc.;
- validate change in suppliers, etc., in addition to usual activities to demonstrate compliance (for example, alternative PCB manufacturer demonstration process); and
- validate minor design evolution due to potential functional specification change, or to a management of electronic components obsolescence (for example, consideration of an alternative source with potentially electrical or physical characteristics slightly different), in addition to usual activities to demonstrate compliance (for example, equivalent or alternative components demonstration process).

7 Planning and management of highly severe stress tests

7.1 General

The highly severe stress tests constitute:

- a major activity in the equipment design and development stage (see Clause 6), in the same way as the qualification tests;
- an activity involving many equipment programme representatives (from design, industrialization, production) whose work is usually managed by a coordinator, guaranteeing correct progress of the tests and their successful completion; and
- a demanding activity in terms of test means and tools, human resources, equipment, etc.

In this respect, and in the same way as the qualification tests, this activity is considered and planned in the upstream phases of the equipment design and development project or programme, and is then closely monitored.

NOTE Ensuring the availability of a significant number of equipment samples for the highly severe stress test early in the project or programme is an important task.

Setting up a managed highly severe stress tests approach allows to deal with the risk of late equipment maturity and lack of equipment robustness.

7.2 Planning of highly severe stress tests and budget consideration

At the equipment project or programme level, the highly severe stress tests are taken into account by establishing a highly severe stress tests plan dedicated to the equipment maturity perspective (see 8.4).

The budget which is necessary for conducting the tests campaign is also planned; the information identified in the test plan (see 8.4) is considered as an enabler for defining the budget.

NOTE The budget is usually defined carefully as it allows to conduct the activity itself properly and it is often compared with the cost of non-quality and "non-maturity" (for example, MTBF not achieved, late re-design, retrofits, potential delay penalties, OEM poor image and loss of credibility, etc.) for demonstrating its interest.

These planning actions are usually under the responsibility of the highly severe stress tests coordinator.

7.3 Management of highly severe stress tests

Once the highly severe stress tests have been planned (see 7.2), the coordinator ensures that the associated process runs smoothly. This includes in particular:

- availability of test means and tools, human resources, equipment, etc. according to the test plan (see 8.4 and 8.5.2), including availability of resources from external test laboratories;
- information, and training if needed, of the human resources involved;
- management of the test implementation which includes management of potential built-in deficiencies and associated malfunctions or failures, root causes analysis, associated decisions, potential corrective actions and records of the events (test report) (see 8.5.3 to 8.5.5);
- schedule monitoring, knowing that significant drift can lead to extra costs, to the process not being conducted with the necessary stringency being potentially cut short;
- escalating of potential risks, if some are identified (see 8.5.5), to project or programme management;
- budget monitoring, knowing that the pertinence of the approach is based on its economic interest (see 7.2);
- recording of experience feedback (capitalization), including technical results and achievements acquired throughout the test campaigns, schedule and budget synthesis, etc. (see 8.5.5 and 9.2).

8 Typical methodology for implementing highly severe stress tests

8.1 Basis for an effective approach

To be effective and profitable, the highly severe stress tests approach relies on a structured methodology which is clearly understood by the team of representatives who conduct the test campaign and is supported by the OEM executive officers.

The team will have a thorough technical knowledge and know-how with regard to the equipment, its definition and configuration, its potential reactions to the stresses to be applied in order to be able to detect and understand the built-in deficiencies and their potential associated malfunctions or failures found, to determine the root causes and to decide on what action is taken. Technical knowledge and know-how will usually serve to identify in advance before the tests campaign: potential deficiencies or weak points and their potential associated expected malfunctions or failures; they allow to determine which will or will not be possible to reveal and activate, and to determine the most appropriate stresses for this activation.

Thus, for each equipment, the approach includes these main steps:

- identification of potential deficiencies or weak points, if any (see 8.2);
- selection of applicable stresses (see 8.3);
- preparation of the test plan (see 8.4); and
- tests implementation, including root cause analysis and corrective actions approach with regard to potential built-in deficiencies and report (see 8.5).

The step related to identification of potential built-in deficiencies or weak points is normally used as it usually favours a proactive highly severe stress tests approach and effectiveness in efforts and costs. But it cannot be considered before selecting and implementing stress tests if time for testing is constrained for example and if potential risk on efforts and costs is assumed.

8.2 Identification of equipment potential built-in deficiencies/weak points

8.2.1 General

A key step in running a highly severe stress tests approach is to investigate first, in advance, if there are potential weak points at the equipment level (design, manufacturing processes, for example), which can constitute risks and lead to the most expected built-in deficiencies.

Identifying potential deficiencies reinforces the pertinence of the highly severe stress tests, given that it is attempted to use stresses which allow effective stimulation of their malfunctions or failure mechanisms.

8.2.2 Sources of information and data for identification of potential built-in deficiencies or weak points

For identifying potential built-in deficiencies or weak points, different sources of information and data can be analyzed such as:

- equipment specifications, which include electrical and mechanical characteristics and refer usually to electrical and environmental constraints, and related standards, etc.;
- mission profile;

  NOTE 1 For example, with regard to the equipment mission profile, the nature of potential significant functional stresses (for example: on-off cycles, electrical network variations, etc.) and environmental stresses (for example: heat, cold, thermal cycles, humidity, vibrations, shocks, etc.) to which the equipment will normally be submitted in its future operating conditions, along if possible with their quantification in terms of levels, transition variation, frequency or duration can allow to target potential deficiencies or weak points.

- equipment definition dossier which includes bill of materials, CCAs dossiers, mechanical structure dossier, etc.;
- equipment manufacturing dossier which includes CCA manufacturing dossiers, processes, controls, etc.;
- simulation results (electrical, thermal, mechanical, stress-damage modelling, physics of failure, etc.) achieved during the design and development stage;
- key characteristics related to the manufacturing means and associated processes, which often are under control;

- FMEAs carried out at equipment design and manufacturing processes level, which identify potential failure modes, their causes, effects, severity ratings and occurrence ratings;
- experimental plans oriented towards the design choices or innovative technologies (for example, electronic components including packages assembly or soldering, manufacturing technologies and processes, etc.) and the results of which can indicate that some of the characteristics observed (for example, linked to the materials, technologies, attachments, mounting or assembly techniques), are particularly sensitive to certain environmental stresses;

  NOTE 2 For example, design innovations or technological innovations can be considered as likely to present a high risk of built-in deficiencies and their associated malfunctions or or failures, especially as low, no experience feedback or sufficiently well documented test results are available.

- feedbacks coming from previous highly severe stress campaigns, previous qualification campaigns and in operation of similar equipment with potentially:
  – the most frequent built-in deficiencies and associated malfunctions or failure types already observed, their mechanisms, causes or origins;
  – the environmental conditions or relevant constraints which favoured the observed built-in deficiencies and associated malfunctions or failures, if reported.

Performing detailed analysis of such information and data allows to identify and list the potential built-in deficiencies or weak points which are in principle the most vulnerable, the potential nature of their malfunctions or failures, and then to identify the stresses most likely to stimulate these weak points (see 8.3).

NOTE 3 In addition to the test team, experts can be involved considering their high technical knowledge, know-how and experience (for example, electronic components experts, materials or manufacturing technologies experts, EMC experts, etc.).

NOTE 4 If a serious deficiency or weak point is identified and can "mask" other weaknesses, the weak element will be strengthened by ruggedizing it (for example, shock absorber for LCD screen with regard to vibrations or shocks and gluing of heavy capacitor) before launching a campaign of accelerated stress tests (see 8.4 and 8.5.2).

8.2.3 Specific consideration of parameters related to intrinsic limits

Major parameters, and their values, related to intrinsic limits of materials, technologies, etc. will be identified in order to clearly identify the technological domain in which the equipment operates (see Figure 1) and what can (or cannot) be improved in the equipment. For example, operational temperature range and maximum junction temperature of electronic components belong to the technological domain and are related to the limit of technologies (see 3.1.2).

That data can be used for contributing to the equipment measurement instrumentation configuration (see 8.4.2 j)) and for potentially leading to the highest level of stress to be applied before the end of highly severe stress tests.

8.3 Selection of applicable stresses

8.3.1 General

Referring to the objectives of highly severe stresses (see 4.2), an effective method is to draw up a table (see Annex B), in which the columns correspond to the various potential built-in deficiency or weak points and the rows correspond to the stress types (for example, random vibrations, heat, cold, thermal cycles, on-off cycles, etc.), and then to tick boxes as appropriate. There is no point in listing all the foreseeable stress types and to consider then only those which are applicable for the highly severe stress campaign.

8.3.2 Stress types

Stress types are selected as:

- they are considered for having in principle the highest potential and ability to stimulate the potential built-in deficiencies or weak points (due to their nature or their level) and their relationship with the equipment lifecycle or mission profile;
- their constraints, although rarely present in the nominal equipment operating conditions, are believed to have a significant impact on activation of potential built-in deficiencies and associated malfunction or failure mechanisms related to the weak points of the equipment;
- they have proven, by experience, their effectiveness in revealing usual or specific built-in deficiencies and associated malfunctions or failures on similar equipment types.

The preparation of the table is under the highly severe stress tests coordinator's responsibility with the support of the project or programme representatives who are involved.

If combined stresses (two or more stresses at a time) are considered, Table B.1 (Annex B) is updated accordingly.

NOTE The application of combined stresses can lead to a synergy of effects for activation of certain built-in deficiency and associated malfunction or failure mechanisms; this can be the case, for example, when vibration cycles are combined with thermal cycles, or electrical on-off cycles combined with temperature. Nevertheless, this combination of stresses can lead to potential concerns with regard to the root cause analysis and corrective action process; see 8.4.3.2 for more considerations.

8.4 Test plan and preparation of the tests implementation

8.4.1 General

The test plan is established under the highly severe stress tests coordinator's responsibility and contains all information and recommendations necessary for carrying out the tests and correctly interpreting the results. It constitutes a guide and any deviation or adaptation is recorded.

Usually, the test plan is "frozen" or approved, for example, by the OEM design authority or the programme or project manager. It is usually available for the customer upon request or it can be approved by the customer if required by the contact, for example.

At the same time as the test plan is established, the actions to prepare the tests implementation are conducted such as booking the availabilities of test resources including those of external test laboratories if needed, specification and development of test-benches, specification and development of specific test software, etc.

For the purpose of this document and to facilitate the user understanding, considerations are included in the test plan contents and associated items, allowing an easier preparation of the tests implementation.

8.4.2 Test plan contents

The test plan usually contains the following:

a) Concise description of the equipment under test: equipment description, both physical and functional (dimensions, weight, number and type of CCAs (CPU, power supply, etc.), backplane if any, utilization, etc.) and main technologies (at electronic, mechanical, thermal, manufacturing processes level, etc.);

b) List of documents or data relevant and being available:

- equipment specifications, qualification requirements, applicable standards, lifecycle or mission profile;
- definition dossier;
- configuration;
- other documents or data.

c) List of identified potential risks, for example:

- limitations set by budgets, human resources, availability of human or test resources, or deadlines;
- impacts on safety of equipment, environment and operators during testing;
- other risks.

d) List of major parameters and their values, related to intrinsic limits of materials, technologies, etc. which can influence the equipment measurement instrumentation configuration (see 8.2.3 and 8.4.2 i)) and potentially the highest level of stress to be applied (see 8.4.2 m));

e) Estimated number of equipment to be used: experience of previous tests campaigns can serve as an input for determining the number of equipment which is necessary to achieve the tests campaign. In practice, this number is justified by the replacement (spare parts or repair) of faulty equipment, components or sub-assemblies or assemblies in order to continue the test campaign.

NOTE 1 Due to the cumulative effects and the potentially destructive nature of tests, it is often proposed to consider a set of at least three equipment for conducting a highly severe stress campaign and, preferably if the budget permits, at least one equipment per highly severe stress type plus at least one spare.

If the budget, including the price of the equipment allows (see 7.2), it is always relevant to repeat the tests campaign on one additional set of equipment. This improves the representativeness of the "built-in deficiency - stress" combination.

f) Human resources: identification of OEM team, including the highly severe stress tests coordinator and the project or programme representatives who are involved (designers and design managers, technical specialists or experts (EMC specialist or expert for example), industrialization and manufacturing specialists and managers, etc.).

g) List of test resources (test means, tools, etc.) needed for performing the tests. This list includes:

- test means used to apply the stresses (for example: thermal chamber, mechanical shaker, anechoic chamber, electric disturbance generator, lightning generator, etc.) which includes:
  – OEM in-house test means;
  – external test means with test laboratories if needed; the conditions in which these organizations work is then defined and planned;
- tools needed for the equipment to operate, be monitored, etc.; this includes, for example, test-bench, etc.;
- stress measuring tools.

NOTE 2 All test means and tools used for stress tests, measurements, etc., are calibrated.as usually defined in the OEM quality system.

The test-bench, which allows to put the equipment in a monitoring environment, is defined, specified, developed and accepted. It can:

- be automated or semi-automated;
- include resources and functions (for example: electrical signal generators, measurement instruments, processing unit, power supply, connecting cables, etc.);

- simulate the functional environment of the equipment during the test, for example, by generating at equipment input signals, stimuli in accordance with the specification (amplitude, frequency, waveform properties, etc.), and measuring equipment output signals and verifying potential by calculating their compliance with the specification;
- exchange information and data with the equipment embedded monitoring software with regard to the supervision of the equipment internal functional resources (see 8.4.2 l)), and provide status related to the equipment operation.

The test-bench for the highly severe stress tests can be common with the one for qualification; in this case, potential specific needs are included in a common specification.

h) Description of the interfaces or plates which are needed between test resources and equipment and potential adaptations or modifications to be made to the equipment; this can be necessary to ensure that the stresses are correctly applied to the equipment and to allow optimum transfer of the applied stress. Adaption or modification to the equipment's mechanical structure can include, for example:

- additional openings to allow air to pass;
- removal of packaging covers;
- inhibition of thermal protection systems;
- openings for the passage of probe or sensor cables installed inside the equipment (see 8.4.2 i)).

These needs can be defined, specified, developed and accepted if they do not already exist. They can be common with the ones for qualification; in this case, potential specific needs are included in common specifications.

i) Description of potential needs for ruggedizing some identified equipment weak elements or parts before testing (see 8.5.2).

j) Equipment instrumentation configuration: in order to measure and control the levels of stresses, the equipment when submitted to the highly severe stress tests is instrumented with probes and sensors. This instrumentation (for example, thermocouples, accelerometers, strain gauges, etc.) allows effective measurement of the equipment response to the stresses. Installation of this instrumentation is usually defined on the basis of the risk analysis, technologies intrinsic limits, and simulation results and targets the weakest points which have been identified to follow their behaviours face to the tests. Some probes or sensors can be installed inside the equipment, at specific parts for measuring stress levels transferred.

k) Definition of the correct functional or operating states: they allow an unambiguous declaration of whether or not the equipment operation is altered by applying the stress. Definition of criteria determining continuation or cessation of tests with the process being iterative.

l) Description of the equipment embedded monitoring software: this software allows permanent functional monitoring of the equipment under stress tests in order to detect and record any built-in deficiency and associated malfunction or failure.

NOTE 3 In some cases, continuous functional monitoring cannot be possible during the highly severe stress tests; so, for example, a functional test can be performed while the stress level is kept constant for a short time.

This software, which can be used in lieu of the equipment embedded application software, allows continuous functional monitoring of the equipment under stress test in order to detect and record any built-in deficiency and associated malfunction or failure. So in this way, it ensures in particular continuous surveillance of the correct activities and integrity of the internal electronic functions (for example, read or write in memories, input or output signals, etc.); it usually communicates with the test-bench with regard to the supervision of the equipment internal functional resources.

The equipment embedded monitoring software is defined, specified, developed and accepted if it does not already exist.

It can be common with the monitoring software used for qualification; in this case, potential specific needs are included in a common specification.

The monitoring software specification and development can be based on data coming from the testability analysis, which is usually carried out during the equipment design and development stage at equipment and embedded electronic functions level. Indeed, testability analysis allows to:

- verify the test capabilities including accessibilities for test of the embedded electronics, and if needed, to propose recommendations with the aim of reaching the maximum test coverage;
- provide data for tests that can be considered in various test situations according to their needs (for example, for qualification and highly severe stress tests monitoring, production stress screening monitoring, equipment built-in test in operation).

m) Description of the tests: each test is described, sometimes based on existing standards, in a specific paragraph which includes:
   - the type of stress or combination of stresses, and the associated resources used;
   - the running order in which the stress is applied;
   - the test set up procedure, if needed (for example, EMC tests related to conducted emissions where the installation of power cables or signal cables out of the equipment can be critical for the test representativeness); the characteristics of progressive step sequences when gradual severity levels are applied;
   - the levels of stress at the various steps;
   - the characteristics of each step (including, for example, duration of the plateau state, slopes, etc.);
   - the actions to be performed at each step (for example: external equipment inspection, measurements via the instrumentation, etc.);
   - if applicable, the highest level of stress that can be applied to the equipment, in accordance, for example, with the parameter and their values related to intrinsic limits (see 8.4.2 d)) or operating margin targets (see 4.1);

n) detailed flowchart of the highly severe tests campaign and associated schedule (including task links, forecast durations, etc.).

8.4.3 Specific considerations

8.4.3.1 Running order

Particular attention is paid to the test running order, according to the types of stresses and the potential identified built-in deficiency and potential associated malfunction or failure. The test running order is not random but follows a logic which moves to the next more "aggressive" stress type. In addition, the procedure for the highly severe stress tests leads usually to increase the amplitude of each stress type by progressive steps, revealing the deficiency and associated malfunction or failure up to potential destruct.

For example, with electronics equipment, this principle is applied to define the running order of stresses; operation at a high temperature is generally more damaging than at a low temperature, so the tests will be running at low temperature before running at high temperature.

8.4.3.2 Combined stress tests

As mentioned in 8.3, combined stresses (for example, vibration cycles combined with thermal cycles, electrical on-off cycles combined with temperature) can lead to a synergy of effects for activation of certain malfunctions or failures mechanisms. This can be useful as the reaction of the equipment cannot be the same as with a succession of single unit stresses. Nevertheless, the concern lies often in the difficulties to understand the origin of a malfunction or failure, or potentially of several simultaneous malfunctions or failures, to identify the root causes (for example, a solder joint failure at an electronic component when vibrations and thermal cycle stresses are combined) and to determine the appropriate corrective action, leading often to additional time or delay or extra cost.

Care is usually taken to apply a first stress at its maximum no-failure level previously determined, and the other stress is then incrementally applied until it reveals malfunction or failure, or up to the level reached with the single unit stress. Such an approach with combined stress tests can minimize the above concern and make the research of the origins and root causes of malfunctions or failure and built-in deficiency easier.

If considered and if time, budget, etc., allow, the combined stress tests are carried out after the unit stress tests, allowing an optimal coverage of tests.

8.5 Tests implementation

8.5.1 General

Annex A, Figure A.2, provides a typical flowchart related to the highly severe stress tests implementation.

8.5.2 Checks before tests

Checks are made before launching the tests campaign and usually before some test types (thermal, mechanical tests, for example).

This includes:

- availability of equipment, test means, tools including test-benches, interfaces between equipment and test means (for example, attachment plate for mechanical stress, air flow plate for climatic stress, etc.);
- potential adaptations or modifications of the equipment for correct exposure to the stresses using potential interfaces, and for installation of the instrumentation;
- potential modifications of the equipment with regard to ruggedizing some identified weak elements or parts, for example, the gluing of a heavy capacitor, etc. (see 8.4.2i));
- instrumentation: attachment of sensors and probes, etc. on, or in, the equipment;
- installation of the equipment on the mounting interfaces usually used between the test means and the equipment;
- check on the equipment operation, including that adaptations or modifications made to the equipment or the instrumentation have not altered the equipment operation.

NOTE With regard to the installation of the equipment, since the normal fastening points can contain vibration dampening devices, it is sometimes necessary to fasten the chassis of the equipment directly to the vibration table to allow the vibrations to propagate into the equipment during the test.

8.5.3 Stresses application

The stresses are applied to the equipment with a step stressing method, as described in the test plan. In principle, the starting value of each stress is close to the specification value if any, and this value is increased in successive increments, the level of which is defined in the test plan. When a malfunction or failure occurs at a given value of the applied stress, the test is temporarily interrupted to analyze the root cause of the malfunction or failure and built-in deficiency origin (see 8.5.4).

Additional test investigations can be conducted for bringing more context details to the root cause analysis, for example:

- if the function returns when the stress level is decreased the malfunction or failure (intermittent or permanent) is classified as a functional failing; it can be an operating limit if any corrective action is, or can be, applied after the analysis;
- if the function does not return when the stress level is reduced, the malfunction or failure is classified as a breaking. It can be a destruct limit if any corrective action is, or can be, applied after the analysis.

Participation of the designers including hardware and software specialists as well as manufacturing specialists is justified for a quick evaluation of the importance of the malfunction or failure and built-in deficiency detected, as well as to identify the root cause and to define a corrective action.

Once the corrective action has been implemented, the equipment has been repaired or a workaround solution has been found (for example, a specific temporary protection for an electronic component, reinforcement of an electronic component attachment, etc.), the test continues, once again stepping up the stress level until the higher operating limit is reached. This means that one does not simply look for the first event impacting the equipment operating limit, but one aims to go further, possibly up to the destruct limit or the intrinsic limit, insofar as the test resources so allow.

Contrary to the equipment qualification, an equipment will not accumulate several aggressive highly severe stress tests (for example, thermal followed by mechanical) in order to find more easily the root cause of a malfunction or failure and the built-in deficiency origin, and not to influence the margin research.

In any case, the test is finished when:

- the destruct limit or the intrinsic limit is reached; or
- an operating margin is considered sufficient.

Figure 1 illustrates these test termination conditions.

8.5.4 Root cause analysis, corrective actions

The tests are conducted as described in the test plan. When running the test plan, usually the tests are interrupted as soon as a malfunction or failure occurs.

An initial technical analysis is made with regard to the root cause.

This is based on a necessary detailed description of the event. Additional verification can be needed to verify that the malfunction or failure disappears when the revealing stress level returns to a lower level (case of operating limit, or intermittent malfunction or failure) or does not disappear (case of destruct limit); this can make the technical analysis more complex (see 8.5.3).

This technical analysis leads to typical situations such as:

- root cause including built-in deficiency origin, is easily identified (for example: manufacturing process not followed, obvious deficiency or weak point of an electronic component package, etc.), and corrective action defined and applied, potential repairs are made and the test restarts with the same equipment;
- root cause is difficult to identify and an in-depth malfunction or failure technical analysis is carried out:
  - the root cause is then identified. The possible corrective action is applied and the test is restarted with the repaired or the corrected original equipment, or another equipment corrected as applicable;

– the root cause is not formally identified and deeper technical analysis is carried out. According to the malfunction or failure type, the criticality level of its manifestation, the potential duration envisaged for the additional technical analysis, etc., can be decided under the highly severe stress tests coordinator's responsibility to leave the equipment as is or to replace it by a new one and to restart the test. The malfunction or failure technical analysis can continue in parallel and potential corrective actions are applied later. Nevertheless, in the option where the failed equipment is replaced by a new one, the test is restarted from the beginning with the initial stress level but the new equipment will have normally the same limitation as the previous one as the root cause is not yet formally identified and the corrective action not yet applied; so this option is not suggested. If the decision is to leave the equipment as is, some tests can be limited or temporarily removed. In any case, the decision and the process followed are described in the test report. In some cases where the failed equipment is needed for malfunction or failure deeper analysis, the highly severe stress tests coordinator can decide to temporarily suspend the continuation of the stress test which caused the malfunction or failure and to continue the test campaign with a new equipment but for another type of stress test.

Usually, in case of equipment repair in the course of the test, the test restarts at the stress level which revealed the malfunction or failure.

The malfunction or failure and built-in deficiency technical analysis is, thus, to identify all the root causes in order to define and implement the necessary corrective actions, insofar as these causes actually correspond to a clearly identifiable deficiency. As applicable, these corrective actions can result, for example, in a simple replacement of an unsuitable electronic component or reinforcement of the attachment of an electronic component (potentially heavy such as coil, transformer, capacitor, etc.), or mechanical reinforcement of a CCA, cable fixing or thermal dissipation improvement at a hot spot level due to a high power electronic component, or in a change at a manufacturing control process level.

Pursuing the highly severe tests after the corrective actions have been applied, allows to:

- check that the operating or destruct limits of the equipment have indeed been pushed back;
- check that the modifications introduced have not generated new problems which could challenge the previous limits.

Corrective actions can lead to changes at design level and to the definition dossier, the manufacturing processes and to the manufacturing dossier.

8.5.5 Test report

The test report is essential to record the information, events and data all along the tests campaign, and contributes to the experience feedback.

A computer database can allow to facilitate the recording and the issue of the report, and to capitalize the global OEM experience on the highly severe stress tests topic (see 9.2).

The content of the test report includes:

- "frozen" or approved test plan (see 8.4.1);
- any deviation or adaptation to the "frozen" or approved test plan;
- reference of the equipment (part number, serial number);
- identification of equipment family if any;
- description of the tests performed (see 8.4.2), identification of resources used (references of test means, test benches, etc.), and dates and locations of tests;
- built-in deficiencies, root causes, corrective actions:

  - detailed descriptions of built-in deficiencies and malfunctions or failures observed (including for each of them the equipment serial number) and corresponding measured stress values;
  - results of technical analysis and root cause of the built-in deficiencies and malfunctions or failure;
  - corrective actions, for example, repairs made, the components, subassemblies or assemblies replaced or other workaround solutions employed;
- maximum levels reached;
- the identification of the operating limits and the potential destruct limits as well as potential intermittent malfunctions or failures. The difference between these limits and the specification indicates the margins;
- operating margins obtained;
- residual built-in deficiencies, weak points or residual risks if any.

If residual built-in deficiencies/weak points and/or residual risks are identified, especially when the highly severe stress tests objectives have not been reached (for example, due to insufficient test resources, etc.), they are carefully described within the test report and then escalated to project or programme management.

9 Taking advantage and using experience gained with highly severe tests

9.1 General

Analyzing the results of the highly severe stress tests allows to gain experience. The OEM can take advantage of this experience and use it for:

- creating or enhancing an experience database;
- checking the effectiveness of the applied highly severe tests with regard to the wish of determining equipment operating margins and improving the equipment robustness;
- enhancing procedures and quality systems, including, for example, updates of design rules, manufacturing process control criteria, etc.;
- contributing to defining environmental stress screening for production;
- checking the effectiveness of the highly severe tests with regard to the experience and the equipment maturity, if feedback related to the equipment life has been registered;
- moving OEMs' culture forward.

9.2 Creating or enhancing a database

Experience is usually capitalized in a computer database where a specific dossier is open for each equipment at the beginning of the tests campaign and is updated on an ongoing basis during the campaign itself and potentially during the equipment life.

For each equipment, the dossier includes the contents identified for the test report (see 8.5.5), and the assessments related to schedule and budget (for example, as initially forecasted and as achieved with synthetic main drivers).

For consistency, the database can be enriched for each equipment by records of feedbacks related to the equipment life. This includes potential incidents or events (built-in deficiencies, malfunctions or failures) identified during series production, entry into service, operation, etc. This allows to analyze the effectiveness of the highly severe stress tests campaign (see 9.5) and to prepare future highly severe stress tests campaigns with other equipment.

This record process is optional but is strongly suggested in an OEM continuous improvement approach.

9.3 Enhancing procedures and quality system

As the equipment was designed, developed and manufactured in accordance with the current procedures and quality system, the results and experience brought by the highly severe stress tests can offer the opportunity to update and improve the procedures and quality system. This can, for example, include:

- rules and processes for choosing electronic components, materials, etc.;
- design rules (PCB place and route rules, circuit card mechanical strengthening, etc.); and
- manufacturing technologies, qualification processes (identification of process key characteristics, process control criteria, for example).

9.4 Contribution to environmental stress screening (ESS) definition

9.4.1 Reminder of ESS purpose

Environmental stress screening (ESS) is an operation applied to equipment in production to reveal and detect early latent breakdowns before final acceptance and delivery to the customer. It can be conducted on 100 % of all manufactured equipment or on a sample in the case of large volumes with process control.

ESS is usually carried out by applying, under monitoring, thermal, or vibration, or both, and electrical (on-off cycles, for example) stresses.

The limits for the stress screening are usually chosen to be at slighter lower stress levels as the operating limits; IEC 62506 can provide information.

NOTE ESS profiles are often defined on a "historical" approach based on ESS experience feedback and profiles already implemented on similar equipment. Highly severe stress test results can contribute to potential improvement.

9.4.2 Contribution of highly severe stress tests

Having conducted highly severe stress tests on the equipment during its design and development stage gives a clearer picture of its limits (operating or destruct) and its potential residual built-in deficiencies or weak points which are considered at risk (see 8.5.5).

So this can provide opportunity with regard to a "historical" ESS approach. Results of the highly severe stress tests can allow to improve the effectiveness of ESS by targeting, for example, the potential residual deficiencies or weak points, or through a tightening (choice, severity) of the stresses, or both.

NOTE Nevertheless, it is checked that the ESS is efficient and does not consume usable life of an equipment as its role is to eradicate early deficiencies, malfunctions or failures (at electronic components, PCB, solder joints, etc. level) and to detect manufacturing process quality issues while not significantly reducing the life of the equipment. In this sense, for example, an equipment can be exposed several times to the selected screening stresses and duration; if the equipment is still functioning afterwards the risk of life time reduction can be assessed and acceptance depends on the results and expected target. A theorical life time reduction assessment based on equipment qualification can also be considered.

9.5 Checking the effectiveness of the highly severe stress tests with regard to the experience and the equipment maturity by correlation with feedbacks

In order to check the effectiveness of the highly severe stress tests with regard to the equipment maturity, a comparison of the events encountered during the life of the equipment (production, entry into service, operation, etc.) is done with the results of the tests performed. This is facilitated if these events have been recorded within the experience database for each equipment (see 9.2).

The following cases can occur:

- built-in deficiencies and malfunctions or failures revealed during the highly severe stress tests and then corrected, no longer appear;
- built-in deficiencies and malfunctions or failures which appear in operation were seen during the highly severe stress tests and intentionally not dealt with. A case-by-case in-depth technical analysis is done;
- built-in deficiencies and malfunctions or failures which appear in operation were not seen during the accelerated stress tests. An in-depth technical analysis for determining the root causes is performed and can lead to a new series of adapted or more pertinent highly severe stress tests, potentially to corrective actions, and identification in the OEM experience feedback.

The in-depth technical analysis can determine that the root causes are due to specific quality or reliability issues, attributable for example to an electronic component or PCB lot. This has no direct link with the highly severe stress tests process and a specific and relevant corrective action plan is carried out (for example, with the supplier or manufacturer, with the equipment manufacturer in charge of the ESS, etc.).

The whole action can potentially allow to update, for example, the highly severe stress tests approach, procedures and test plans of future campaigns.

9.6 Moving OEM's culture forward

The highly severe stress tests approach can be adopted by each OEM and then refined, taking into account its experience with the objective to obtain a mature equipment from its entry into service. This often takes place in an OEM continuous improvement or progress, preventive or proactive attitude and customer satisfaction approach supported by the OEM executive officers.

10 Responsibilities and relationships

10.1 Customer/OEM relationship

10.1.1 Responsibilities

OEM design, development and production processes are usually described in the OEM's quality system; this includes the highly severe stress tests approach. The OEM is responsible for defining, preparing and implementing the highly severe stress tests, and recording the results, even if some tests are carried out at external test laboratories, for example.

Highly severe stress tests approach can be:

- an OEM's own preventive or proactive initiative to obtain margins, provisions and early equipment maturity in an optimum global time and effective cost search;
- a means for the OEM to satisfy potential customer contractual requirements such as equipment availability from the EIS or in operation.

In any case, the OEM is responsible for assessing the pertinence of the margins obtained after the tests.

10.1.2 Contractual requirements

The customer expresses its contractual requirements in the equipment specification or in the contract document.

Obligation of results or obligation of means are two opposite ways:

- Obligation of results: the customer defines maturity related requirements (for example: availability target value at EIS or in operation, first-fit removal rate, MTBF, etc.). The OEM is then totally responsible for defining and implementing the highly severe stress tests.
- Obligation of means: in this case, the customer can impose clearly its highly severe stress tests approach to obtain the assurance of a minimum level of robustness (for example, methodology, types of stresses, etc.). In this case, the OEM proposes a preliminary test plan, defining the schedule (in accordance with the equipment development cycle) and the associated structure of the future test report. It can also propose the way of managing residual risks, potential constraints (economic and calendar) with regard to the tests. A preliminary customer approval is usually obtained from the customer concerning the highly accelerated tests programme.

Usually, the customer requires an obligation of result and not obligation of means. As part of the equipment design and development stage (see Clause 6), the highly severe stress test plan is established and it is usually available before the design and development reviews (for example: preliminary design review (PDR), critical design review (CDR)), in particular if equipment maturity related requirements are defined by the customer.

According to the customer requirements expressed in the equipment specification or contract document, the test plan (see 8.4) and the test report (see 8.5.5) can be part of the formal deliverables or available upon request.

10.2 OEM and external test laboratories relationship

The OEM is responsible for the complete highly severe stress test approach even if tests are conducted outside its facility with external test laboratories.

The external test laboratories can assist the OEM when defining the test means or tools, etc.

When tests are conducted at an external test laboratory facility:

- the test laboratory and the OEM jointly agree with the whole or part of the test plan and with the test resources configuration, before the tests launch;
- the test laboratory records and synthesizes all data related to the different test phases (stress, levels, durations, measurements, technical events observed, etc.);
- the test laboratory records and reports any built-in deficiency, malfunction or failure to the OEM for disposition. This can include, for example, technical investigations and root causes analysis, corrective action proposals, repair proposals, workaround solution proposals, etc., according to the content of the order or contract;
- the test laboratory identifies in the test report any deviation or adaptation between the test plan and the tests conducted to ensure the traceability of the test conditions and the test results (see 8.5.5).

The OEM is responsible for recording the whole information within the experience database.

11 Costs and savings

11.1 General

The profitability of the highly severe stress tests lies essentially in the gains obtained by early equipment maturity by treatments of weaknesses, identification of margins and provisions for managing later potential design changes (for example, minor specification evolution, electronic components obsolescence management, PCB manufacturer change, etc.), which usually offset the expenses of conducting these tests. For example, a design defect detected and corrected late in the equipment lifecycle incurs considerable extra costs or concerns such as:

- potential delay in time to market (TTM) or poor EIS;
- technical and economical credibility and confidence with the customers, poor brand image; or
- recovery operations and equipment retrofits.

The economic analysis therefore establishes the difference between, for example:

a) costs of the equipment "non-maturity" which include in particular (see 11.2):
   – costs due to delayed equipment time to market (TTM) or poor EIS;
   – costs of in-service built-in deficiency processing and in-service recovery operations and equipment retrofit;
   – costs linked to the damaged brand image;
   – other costs;

and

b) expenses generated by implementing the highly severe stress tests, including mainly (see 11.3):
   – engineering for highly severe stress tests preparation;
   – highly severe stress tests implementation which includes:
      - test means, tools and services; and
      - human resources and services;
   – weakened, damaged or destroyed equipment.

11.2 "Non-maturity" costs

11.2.1 Cost due to delayed time to market (TTM) or poor entry into service (EIS)

11.2.1.1 Delayed time to market (TTM)

Nowadays, time to market (TTM) for any equipment is a major factor with regard to the performance and benefit of a company, especially in highly competitive sectors where the technologies evolve rapidly. This is why the TTM date has become essential for an equipment under development.

Experience shows that the targeted TTM date, set when the equipment project is initialized, and the equipment EIS are usually at risk due to potential development difficulties or potential insufficient maturity, or both. The highly severe stress tests approach, considered in the equipment development schedule, allows to mitigate the TTM and EIS risk, to secure in addition the rest of the equipment life (for example, tolerance to manufacturing process variations, etc.), and to avoid immediate financial losses.

The commercial life of an equipment, or in general all types of products, is usually characterized by three main stages:

1) "growth" after EIS with mass production volume growing quickly; then
2) "maturity", period of varying length, where the mass production volume is stable; finally
3) "decline" where the mass production volume decreases due to other higher-performance products reaching the market, for example.

Figure 2 describes typical marketing stages of a product with time. Curve (1) corresponds to an ideal product marketing, with a product launching on the market on time. The total production level then reaches the planned target and the profitability of the product is reached. Curve (2) illustrates a delayed product TTM leading to losses in production volume with respect to market demand, and therefore, in profitability.

Generally speaking, a delay in TTM can lead to the following possible cases:

- The product belongs to a captive market and sales will reach the targets, but later than expected. The financial losses affect the "growth" period and, thus, the commercial forecast.
- The product is on an open competitive market. All market shares not occupied from the beginning will be lost permanently and the total level of sales will be lower, in direct proportion to the length of the delay. If the delay is too high, placing the product on the market can even be compromised and the product cannot be marketed.

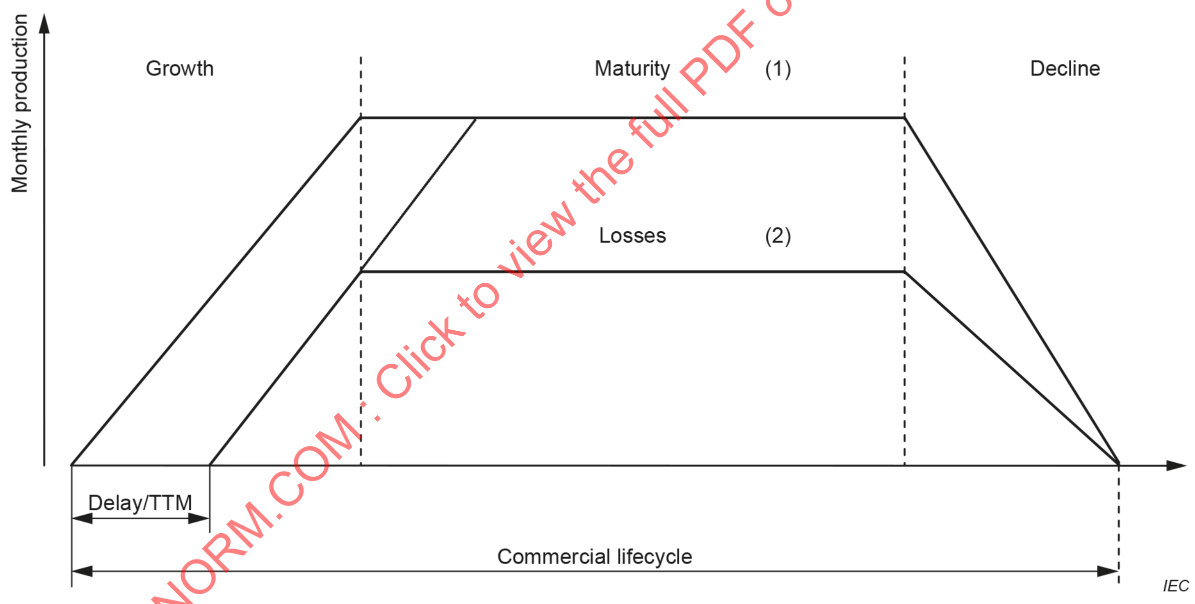


Figure 2 – Typical marketing stages of a product with time

11.2.1.2 Case of poor entry into service (EIS)

A poor equipment EIS in the "growth" stage is characterized by a low operating availability value of the equipment after its deliveries. The economic impact is all the more significant that the equipment ramp-up is rapid.

A poor EIS most often comes with built-in deficiencies processing, recovery operation and equipment retrofit, and leads to inevitable associated costs (see 11.2.2 and 11.2.3), and likely issues all along the equipment programme.