
Draft for Development

Methods of equipment reliability testing

Projet à développer
Méthodes d'essai de la fiabilité de l'équipement

Entwurf zur weiteren Ausarbeitung
Prüfverfahren für Gerätezuverlässigkeit

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This publication is not to be regarded as a British Standard.

It is issued in the Draft for Development series of publications and is of a provisional nature because further evidence is required before the tests described could be incorporated into a British Standard.

It is recommended that it should be applied on this provisional basis so that information and experience of its practical application may be obtained. Those who use it are urged to write to BSI giving details of their experience in applying this publication. Constructive proposals for improvement and comments on reliability growth and growth programmes will be welcomed.

The intention is to publish a British Standard when sufficient knowledge and experience is accumulated. Moreover, such knowledge and experience will be helpful to the UK participation in the preparation of a corresponding international document in IEC/TC 56.

The British Standards Institution request that, because of the provisional nature of the publication, its reference number should not be marked on products.

Foreword

This Draft for Development has been prepared under the direction of the General Electrotechnical Engineering Standards Committee.

The tests given in this draft are not intended to replace existing functional and environmental tests. They apply to all types of equipment such as electronic, electro-mechanical and mechanical. The term equipment is used here to cover equally a complete system or its sub-assemblies. The distinct purposes of equipment reliability testing are as follows.

(a) *Reliability determination test.* To determine the value of a reliability characteristic of the equipments tested,

NOTE. Analysis of existing data may also be used for reliability determination.

(b) *Reliability growth test.* To expose and eliminate weaknesses, usually carried out as part of the development process.

(c) *Reliability compliance test.* To show whether or not the value of a reliability characteristic of the developed equipments complies with the specified reliability requirements.

The essential difference between growth testing on the one hand, and compliance and determination on the other, is that in the first case corrective modifications during the programme are essential while in the second case they are not expected.

In practice, there may be a slight overlap between the above purposes. A growth programme may permit

approximate estimates to be made of a reliability characteristic while compliance and determination tests may well reveal weaknesses which lead to corrective actions outside the test programme.

Reliability testing is costly both in time and money. It is therefore important at the inception of a project and well before any particular programme, to consider the following factors:

- (1) the consequences, both in manufacture and in use, of inferior equipment reliability (including economic and safety considerations);
- (2) the cost of reliability testing;
- (3) the minimum cost effective time required for testing;
- (4) the possibility of obtaining reliability improvement or assurance by alternative means;
- (5) the cost and availability of sample equipments of the required design standard;
- (6) failure definition.

Due to the complexity and variability of most equipments and their applications, agreement between reliability characteristics obtained from laboratory reliability testing and those of other equipments in actual use may not be exact. Great care should be taken in the extrapolation of the results of a reliability compliance or determination test to other equipment populations, other environmental conditions and other periods of operation.

NOTE. This Draft for Development contains some information which already appears in DD 13.

Draft for Development

Methods of equipment reliability testing

1. Scope

This Draft for Development gives general principles as well as methods and procedures for equipment reliability determination, growth and compliance testing. It also provides guidance on how a reliability test procedure document should be prepared before commencement of tests for each particular programme.

2. References

The titles of the standards publications referred to in this Draft for Development are listed on the inside back cover.

3. Definitions and symbols

For the purposes of this Draft for Development the definitions given in DD 12 apply.

3.1 Symbols. Some of the symbols used in appendix D are defined as they occur, otherwise the symbols used throughout this Draft for Development are as follows:

- a is the ratio of total failures to relevant failures
- C is the contingency factor
- D is the discrimination ratio (general) being the ratio of the 'specified' to the minimum acceptable value of the reliability characteristic
- D_m is the discrimination ratio associated with mean time between failure (m.t.b.f.) ($D_m = m_0/m_1$)
- D_R is the discrimination ratio associated with success ratio ($D_R = \frac{1 - R_1}{1 - R_0}$)
- F_m is the total potential number of systematic failure types
- F_s is the number of distinct systematic failure types
- H is the maximum number of operating hours per week, per equipment
- h is the intercept value of the accept and reject lines on the vertical axis of the sequential test diagram (see figure 31 of appendix C)
- K is the average down time per failure (in calendar time)
- M is the number of equipments tested
- m is the mean time between failures (m.t.b.f.) (general)
- m_0 is the specified value of m.t.b.f.
- m_1 is the minimum acceptable value of m.t.b.f.
- m_c is the cumulative m.t.b.f.
- m_d is the instantaneous m.t.b.f. at test time T_d

- m_F is the mean time to failure (m.t.t.f.)
- m_i is the instantaneous m.t.b.f.
- n_f is the fixed number of trials required for acceptance
- n_s is the accumulated number of trials in a sequential test plan
- n_t is the number of trials at truncation
- R is the true value of success ratio
- R_0 is the acceptable value of success ratio
- R_1 is the unacceptable value of success ratio
- r is the number of relevant failures
- r_{Re} is the number of failures for rejection
- r_t is the number of failures at truncation
- S is the growth slope
- s is the slope of accept and reject lines in the sequential test diagram (see figure 30)
- Z is the programme duration (in calendar time)
- T is the accumulative operating time at any point in a test programme
- T_d is the accumulative operating time at an arbitrary datum point in a test programme
- α is the (nominal) producer's risk, i.e. probability of rejection when $m = m_0$ or $R = R_0$
- β is the (nominal) consumer's risk, i.e. probability of acceptance when $m = m_1$ or $R = R_1$
- λ is the failure rate
- τ is the time constant of F_s versus T curve

4. Reliability test plan

While this Draft for Development does not attempt to present a fully standardized reliability test plan, nevertheless the general guidelines given in the foreword should be followed as far as they apply in each case. Guidelines are given in greater detail below.

4.1 The reliability characteristic. It is important to define the reliability characteristic (and, if required, also the confidence levels) to be used as criteria. The reliability characteristic may be expressed variously as:

- (a) failure rate, mean time between failures, mean time to first failure, or other parameters of the distribution of times to or between failures;
- (b) success ratio for a given time interval or number of operations.

4.2 The correct stage for the programme

4.2.1 Determination testing. Determination testing may be a simple and short test programme inserted at an early stage in the development to determine the capability of realizing the specified characteristic. It will indicate whether or not a growth programme is likely to be required and if so it will indicate the value of the characteristic at which it will start and the extent of growth required. The programme must of necessity be short, to avoid delay to the start of any growth programme and hence the accuracy of determination of the characteristic will not, nor need be, high at this early stage.

4.2.2 Growth testing. A reliability growth programme is essentially a development exercise and will be expected to give rise to corrective actions involving changes under one or more of the following headings:

- (a) equipment design including types of components or parts and loading or utilization of components or parts;
- (b) specifications and drawings;
- (c) production planning and processes;
- (d) commissioning and acceptance testing;
- (e) packaging and storage;
- (f) equipment usage;
- (g) planned maintenance actions.

The programme should therefore be phased with the above activities in order to bring the maximum and most widespread benefit within the framework of the schedules which govern them.

Although it is desirable to start a growth programme as early as possible in development, it should be borne in mind when testing early equipment that it may differ significantly in design from the final design and production standard. In these circumstances there are two possible courses of action:

- (1) to use a sequence of equipments, of advancing standards, starting as soon as any hardware is available;
- (2) to adopt equipments of one standard which appears to provide the best compromise between the conflicting demands stated above.

4.2.3 Compliance. Since compliance testing should take place late in development or during pre-production or full production, corrective modifications, if found necessary at that stage, are difficult or even impossible to carry out.

Compliance testing has the purpose of formal confirmation and assurance that the reliability objective has been achieved and should, therefore, preferably take place at a time when design, development and production have become stabilized as far as possible.

4.3 Number of equipments to be tested. It is axiomatic that the more equipments that are tested, the more representative they will be of the general population, that, reliability growth will be wider in its influence and that there will be greater confidence in the results of compliance testing. Any major design error will probably manifest itself even in one equipment, but more marginal

and random failures will be dependent upon variability and ageing of components, which will follow a distribution throughout the population of equipments. For a given number of equipment-hours there are two extreme choices; to test one equipment for a long period or to test several equipments for the shortest possible period.

The latter choice would give the most representative result but is usually much more costly. Although the equipments may be saleable after the test (if necessary) after reconditioning the additional costs of the test facilities may be prohibitive. The m.t.b.f. will also determine the length of test, the higher the m.t.b.f. the larger the number of equipments needed to give a programme of practicable length which will often offer practicable costs, since equipments of high m.t.b.f. may be small and relatively inexpensive. The following considerations will determine the number of equipments tested:

- (a) the representative nature of the sample;
- (b) availability of equipments for test;
- (c) availability of test facilities;
- (d) cost of running the test;
- (e) the m.t.b.f.;
- (f) the cost per equipment.

A compromise should be found in each individual case.

For avionic equipment in growth programmes 5.3 shows that a suitable operating time may be 2500 h to 3000 h per equipment and for the equipment-hours required this could then determine the number of equipments to be tested. For determination and compliance testing it is important that the test time should not be influenced by initial failure effects which could still be present even after a previous burn-in. Therefore a minimum of about 1000 h per equipment is probably desirable. Also any substantial wearout failures should be discounted in a sequential test plan based upon a constant failure rate. Normally the early failure period will be the more important factor with electrical and electronic equipment and wearout with mechanical items, the relative content of each may well influence the number of equipments to be tested.

4.4 The test conditions. To be realistic, test conditions should always represent a combination of environmental stresses.

4.4.1 Initial operation. Prior to the formal test programme, the equipments should be preconditioned for the following purposes:

- (a) in a growth programme, to identify any environment-dependent failure patterns;
- (b) in compliance or determination tests, to complete screening or burn-in and achieve the constant failure rate upon which the standard statistical test plans are based;
- (c) to prove the environmental and test procedures.

In (a) the preconditioning may commence under room conditions followed by each type of environment separately in order to observe the effect of each.

In (b) the screening procedure should be the same as that which is intended for production equipment.

4.4.2 Regular test conditions. Definition of the conditions should include:

- (a) the maximum and minimum values of electrical, mechanical, thermal and other environmental conditions and their duration in each cycle*;
- (b) the average rate of change of temperature and the stabilization required;
- (c) the frequency and points in the cycle of switch ON (or start) and switch OFF (or stop);
- (d) the duty cycle, i.e. the ratio of ON to OFF time;
- (e) the mode or modes of operation and the times spent in each.

4.5 Operation and monitoring

4.5.1 Pre-test adjustments and observations. Adjustments and calibrations should be carried out before the start of regular testing, if convenient during the initial operation (see 4.4.1). During this period it may also be necessary to observe the changes in measured parameters with environment with a view to setting limits to apply to these environments during regular testing.

4.5.2 Operation. During the ON time, the equipment should operate continuously in the most realistic manner practicable, in order to exercise all the essential functions and components or parts and so to stimulate any latent failures. If there is more than one functional mode then these should all be excited in a sequence and a time-shared cycle which are typical of normal use. Manual controls should be operated regularly and realistically. Any functions having a purely protective, emergency, safety or self-testing role should also be exercised periodically, preferably during the monitoring routines described in 4.5.3.

One-shot devices will require special consideration in each individual case.

It is usual, but not essential, for the operational cycle to coincide in time with the environmental cycle. The equipment ON periods then correspond to warm-up and upper temperature and vibration or other mechanical environments and OFF periods to cooling and lower temperature. In such a way the extreme combinations are simulated (see figure 1 for a typical environmental and operational cycle).

4.5.3 Monitoring. The sensitivity and promptness of detection of failure, and hence the quantitative reliability

indicated by the programme, are dependent upon the thoroughness and frequency of monitoring of the performance of the equipment. In all forms of test programme, therefore, monitoring should be as comprehensive and frequent as practicable within the framework of the environmental conditions and the manning available.

Monitoring can take the following forms:

- (a) continuous, or repetitive in an unbroken sequence;
- (b) periodic routines (e.g. hourly, daily, weekly);
- (c) initial and final, i.e. at the start and finish of the programme and perhaps at significant intermediate stages.

The method may be automatic (employing facilities either separate from or built-in to the equipment under test) or manual. Continuous surveillance is nearly always automatic, whereas the other forms of monitoring may be either automatic or manual. Due to the increased speed, automation normally allows more complete monitoring within a given period, but test personnel are always needed when manual adjustments or visual observations are to be made.

4.5.4 Accumulation of operating time. The operating time (or ON time) of the equipment is an essential parameter in all types of programme. For economy, both in programme time and cost, a maximum accumulation of ON time in a given period should be the aim and this can be achieved in the following ways:

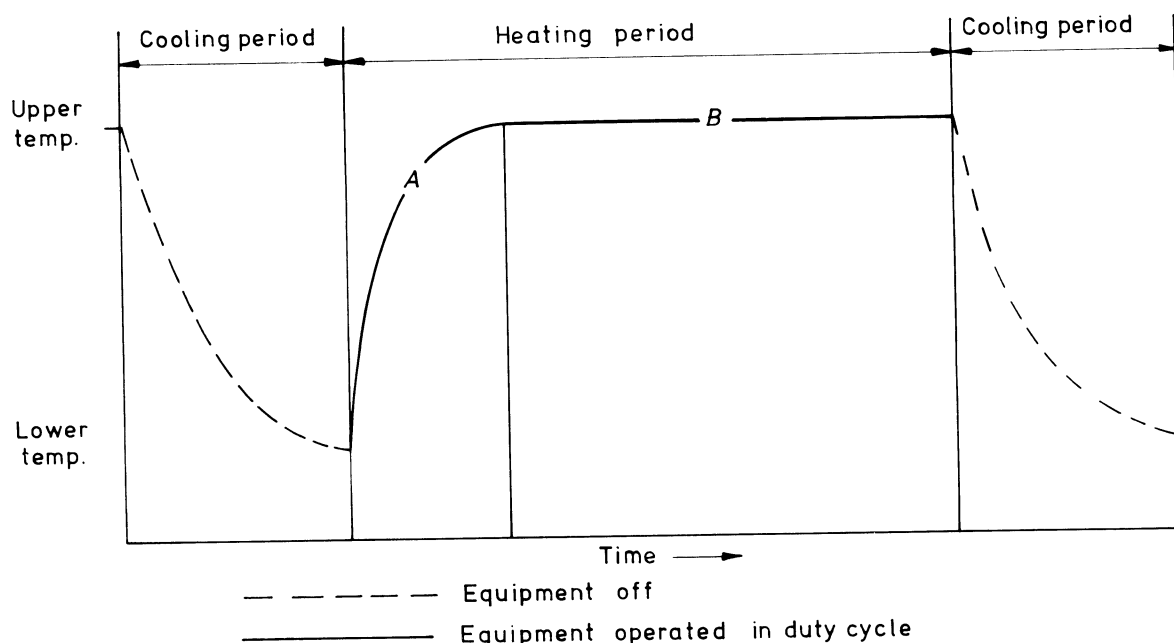
- (a) minimizing OFF time periods, subject to the requirements of the low temperature cycle (see figure 1) and the intended use of the equipment;
- (b) minimizing down-time, by efficient diagnosis and repair and by satisfactory maintenance of the environmental facilities, test equipment and other ancillaries;
- (c) operation, wherever safety and adequate supervision permit, for 24 h daily and 7 days weekly.

4.6 Processing of failures

4.6.1 Definition of failure. The reliability test procedure document relating to a particular programme should state the definition of failure to be used. It is desirable that such definitions be given in their practical interpretation for the purposes of the programme envisaged.

4.6.2 Classification. Clause 3 of BS 4200 : Part 6 : 1971 gives guidance on classifications and categories of failure.

*These should be the 'operating' and not necessarily the storage extremes. Appendix A gives guidance on environmental loads.



where

A is the time for equipment to stabilize at upper temperature

B is the time for stabilized operation at upper temperature

Figure 1. Typical environmental and operational cycle

Typical examples of categories of failure are given diagrammatically for a typical situation in figures 2 and 3. The purpose of dividing failures into such groups is to decide upon their relevance or otherwise in respect of:

- (a) corrective actions (see figure 2);
- (b) compliance or determination criteria (see figure 3).

These may both be of concern in all the types of test programme here being considered. However, a particular failure may be classified differently in the same programme for the distinct purposes above.

The classification 'unacceptable failure' may be used for a failure for which a single occurrence results in a 'reject' decision in a compliance test, thereby overriding the normal decision criteria (see 4.7). A typical example is a failure which affects safety.

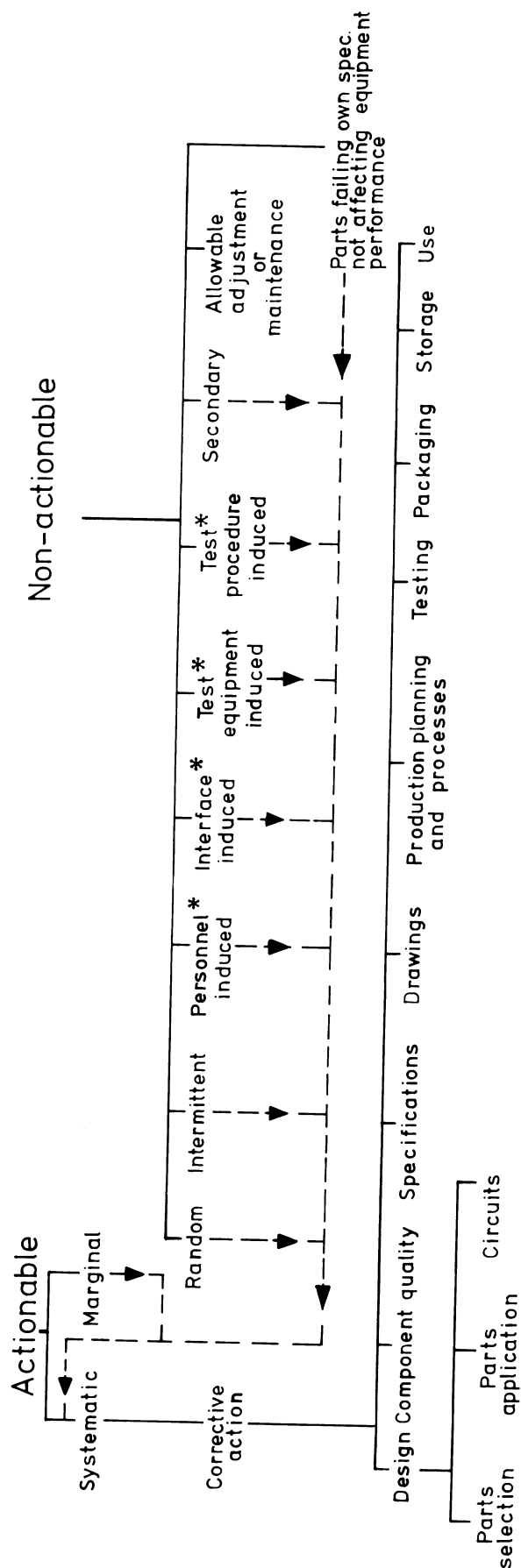
Initially a provisional classification may be made from first impressions. This may need to be modified after a full investigation or if new evidence comes to light.

The accuracy of a classification will always be dependent upon the completeness of detail of the circumstances of failure and upon the thoroughness of later investigation. However, engineering judgement will usually also play a part. Subject to the agreement of all parties concerned, classification should be performed by an engineer of adequate experience.

In a compliance test, scheduled maintenance procedures should be detailed in the test procedure document, together with any components or parts, whose planned or permitted replacement, will not count as relevant failures.

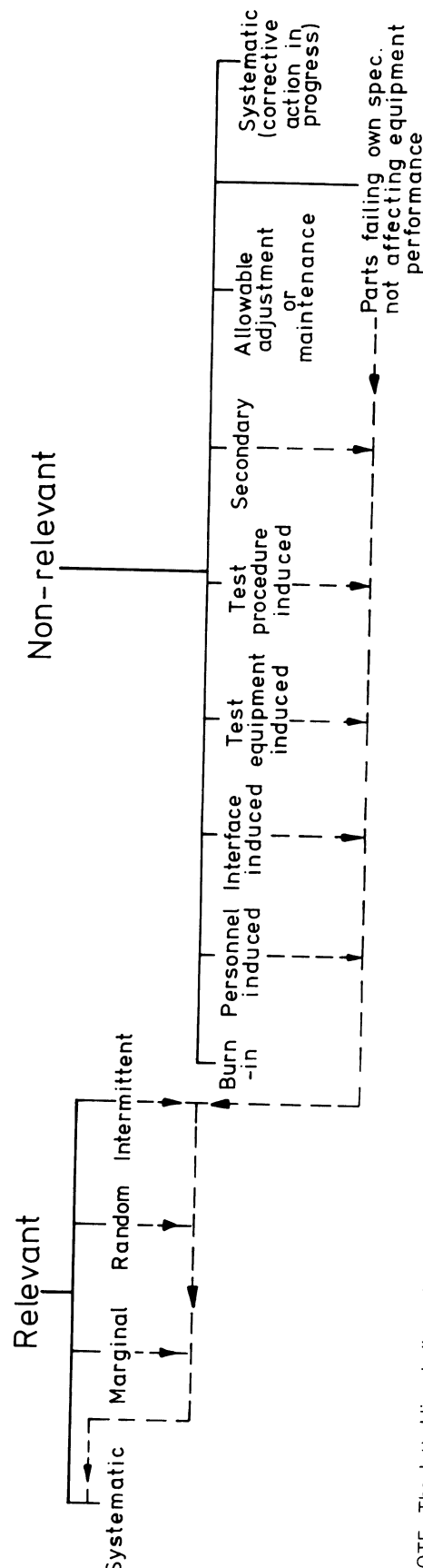
4.6.3 Investigation. Investigation of a failure may take the following forms.

- (a) Testing followed by physical dissection and examination of a failed component or part, either by the manufacturer of the component or of the equipment.
- (b) Confirmation by measurement as well as by calculation of the most severe conditions (mechanical, electrical, thermal and environmental) which the failed component or part could experience in use.
- (c) Where a failure is induced by one particular environment only, a special separate investigation in that environment should be made.
- (d) Continuation of the normal test programme but with closer monitoring of the stresses on a component or part that has previously failed or of a sub-unit or module in which it is contained. For intermittent failures, attempts to render them permanent and hence more readily investigated, by the application of more severe environments or more intensive conditions of use, e.g. by repeated ON, OFF switching or 'stop and start'.



NOTE. The dotted lines indicate the direction of possible subsequent changes in category in the light of later information.
*In some cases these may be actionable in the appropriate areas.

Figure 2. Typical example of categories of failure for purpose of corrective actions



NOTE. The dotted lines indicate the direction of possible subsequent changes in category in the light of later information.
*In some cases these may be actionable in the appropriate areas.

Figure 3. Typical example of categories of failure for purpose of compliance and determination testing

4.6.4 Corrective action. Effective and prompt corrective action is essential in the promotion of reliability growth. This requires:

- (a) an organizational feedback loop to convey the necessary information and recommendations to those responsible for implementing them;
- (b) An engineer whose task it is to set priorities and to initiate an investigation and to follow up corrective actions through the feedback loop to their satisfactory conclusion and to ensure continued adequate functioning of the loop.

Fuller details of such a system are given in clause 2 of BS 4200 : Part 6 : 1971.

4.7 Statistical plans for compliance tests. These test plans provide straightforward and unambiguous criteria for decisions on compliance or non-compliance with specified reliability requirements. Fuller details are given in appendices B and C. The plan is dependent upon the relationship of relevant failures and equipment operating hours and makes it clear, at any stage of the programme, which alternative courses of action will apply, i.e., to accept, to reject or to continue testing.

Sequential test plans are always characterized by four basic parameters:

- (a) the specified (or contractual) value of the reliability characteristic (see 4.1);
- (b) D , D_m or D_R ;
- (c) α ;
- (d) β

Note that $D > 1$ and with a characteristic such as failure rate that increases with decreasing reliability the ratio must be inverted. Between the two values connected by the ratio D there is, therefore, a range of uncertainty within which the equipment is neither 'acceptable' nor 'unacceptable'. While the equipment appears from testing to be within this range no decision can be reached and the course of action is 'continue testing'.

It is also fundamentally important in sequential testing that risks of unfair rejection and acceptance shall be agreed both by the manufacturer (or producer) and by the customer (or consumer).

Table 1 shows the concepts involved in sequential testing, α and β are the risks associated with true values lying just on the limits related by the ratio D .

If the true value lies outside these limits then the risks of unfair rejection or acceptance are respectively lower, but still finite. For a good chance of acceptance, therefore, the true value should lie well beyond the specified (or acceptable) characteristic and this further reinforces the desirability already stated of a prior determination or growth programme. The O.C. curves (or approximate points) in appendices B and C show the probability of acceptance as a function of 'true' values.

Figure 4 shows a typical sequential test plan with an arbitrary staircase plot added. If a marginal equipment should persist in the 'continue test' region, then at a suitable point the test is terminated by truncation lines that force an 'accept' or 'reject' decision. The truncation point is positioned so that the risks are not substantially affected.

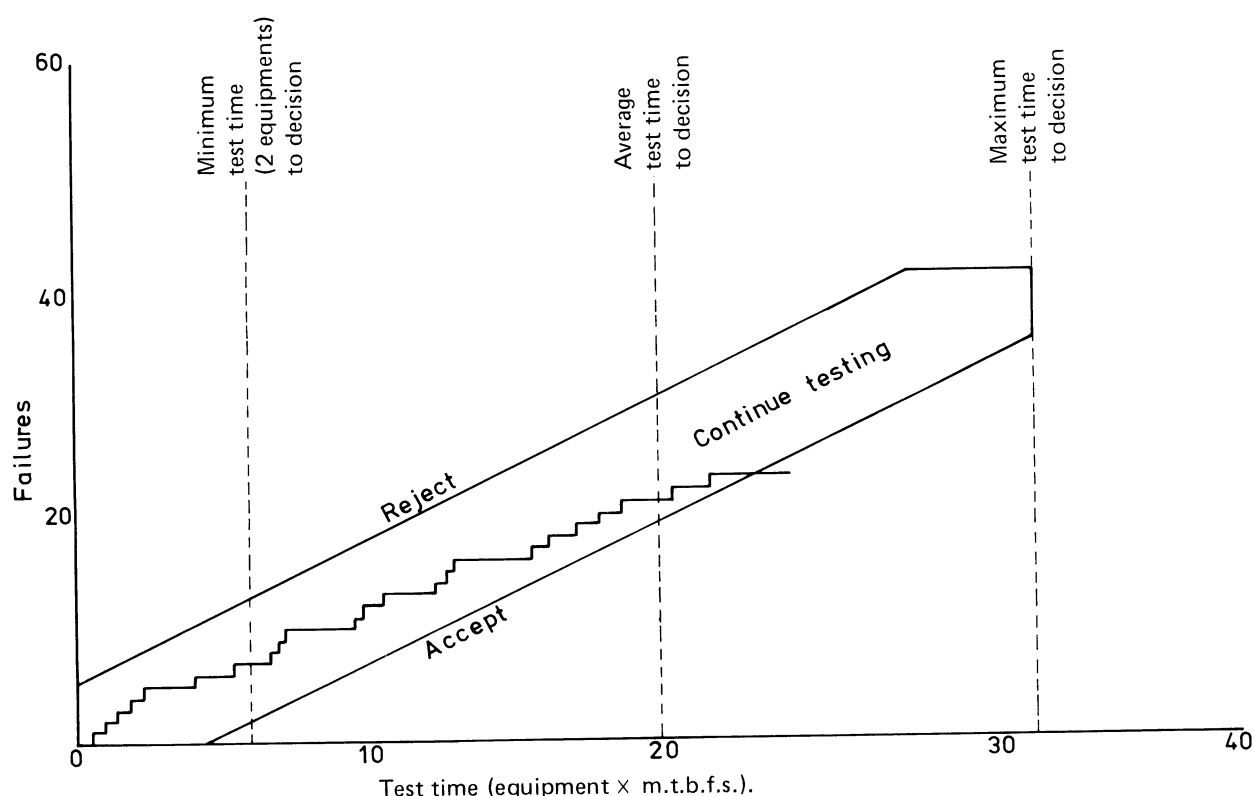


Figure 4. Typical sequential test plan

5. Laws governing reliability growth

5.1 Prediction of growth. In a programme of approximately 1000 h or more per equipment, the process of growth has been found to follow, with adequate accuracy, the Duane model, which is described by the following expression:

$$\frac{m_i}{m_d} = \left(\frac{[T]}{[T]_d} \right)^S \quad \dots (1)$$

or the alternative forms:

$$T = T_d \left(\frac{m_i}{m_d} \right)^{1/S} \quad \dots (1a)$$

$$T = T_d \left(\frac{\lambda_d}{\lambda_i} \right)^{1/S} \quad \dots (1b)$$

where

m_i is at test time T

NOTE. m_d , λ_d and T_d relate to a datum point early in the test programme (commonly 100 h).

λ_i is the failure rate at test time T and is equal to $1/m_i$

λ_d is equal to $1/m_d$

The test time is the aggregate of that of the equipments undergoing test all of which are assumed to run as nearly as possible concurrently throughout the programme.

Table 1. Concepts involved in sequential testing

Situation	Specific levels of reliability characteristic
Genuinely acceptable (Risk of rejection $< \alpha$)	Ratio D { ‘Specified’ or ‘acceptable’ value (risk of rejection = α) ‘Minimum acceptable’ value (risk of acceptance = β)
Range of uncertainty	
Genuinely unacceptable (Risk of acceptance $< \beta$)	

where

α is the producer's risk

β is the consumer's risk

D is the discrimination ratio

When m_i and T are plotted on log-log axes the model takes the form of figure 5. The time taken to reach any value of m_i can be predicted from equation (1a) or figure 5, with a knowledge of m_d at time T_d and S . These are best determined from past experience, but the following are fairly typical ranges of values for avionic equipment:

m_d at 100 h = 0.1 m_0 to 0.2 m_0

where m_0 is the value of m_i from a theoretical prediction (an agreed figure or one derived from an accepted prediction procedure).

$S = 0.4$ to 0.5 .

For given values of T_d , m_d/m_0 and S , the test time required to reach m_0 is independent of the value of m_0 .

The ratio of m_d to m_0 is a measure of the reliability of the initial design, while S is a function of the test environment and the efficiency and speed of detecting and correcting actionable failures. Both are of importance to the achievement of the reliability goal. Maximizing reliability in the initial design should receive special attention as it is less costly than improvement in subsequent testing, however, experience suggests that, as m_d/m_0 is increased, S will fall somewhat.

5.2 Monitoring reliability growth and achievement.

A diagram such as figure 5 cannot conveniently be plotted to monitor progress during a test programme because the instantaneous m.t.b.f is not readily determined with any degree of confidence. However, appendix D shows that by integration the following expression is derived from equation (1):

$$m_i = \frac{[m_c]}{1 - S} \quad \dots (2)$$

m_c is readily derived from test data at any point by dividing all relevant* failures into total test time. Thus m_c is represented by the lower line of figure 5, parallel to the line representing m and separated from it by the interval $\log(1/(1 - S))$. m_c can be readily plotted from experimental data as the test proceeds and when enough points have been plotted to give a reasonable straight line and an estimate of S , the upper line can be drawn to allow m_i to be estimated†.

It has been found that a satisfactory straight line cannot be drawn until at least 500 h per equipment have been completed (though this will of course depend upon the actual m.t.b.f). Below this there may be fluctuation in m_c due to the relatively small numbers of failures. In addition there may be an initial effect as shown by the dotted line in figure 5, where m_c drops before it begins to show linear growth. This occurs if the burn-in effect is still evident and it inflates the subsequent apparent growth. The rate of growth is obviously affected by the time cycle of corrective actions, which is composed of:

- the time taken for an inherent weakness to manifest itself;
- the time for diagnosis, investigation and modification action;
- the time before the beneficial effects of such corrective action produce evidence of growth.

*As defined by figure 3 which is slightly different from figure 2.

†Only the data obtained under the regular test environment should be plotted (i.e. not including the pre-conditioning described in 4.4.1). The 'burn-in' effect in the early period can produce a spurious appearance of reliability growth. In plotting, give most weight to later points, which contain most data.

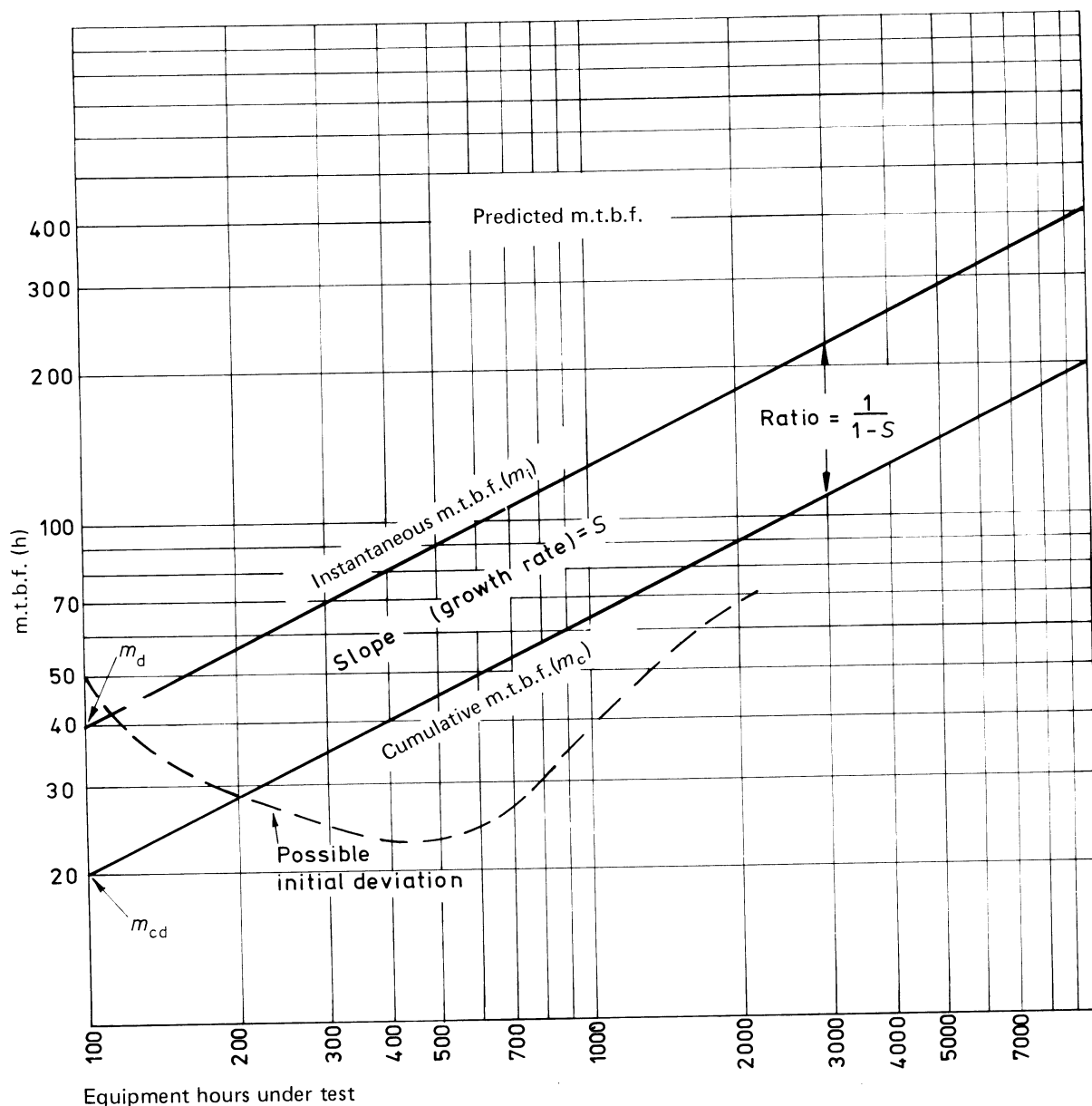


Figure 5. Typical Duane plot of reliability growth

The sum of these times (expressed in terms of test time) may commonly be of the order of 500 h per equipment, which explains the delay before growth becomes apparent. At the end of the test programme, the final instantaneous m.t.b.f. can be estimated from the upper line though,

even if all modifications have been incorporated, the time lag in the appearance of growth will hide the current situation. If upward extrapolation is made to compensate, this presupposes that the later modifications have been successful and produce no side effects.

5.3 Appearance of systematic failure types. Figure 6 shows a typical graph connecting cumulative systematic (i.e. repetitive or by nature liable to be repetitive) failures and test time for one equipment. This relationship has been found to be exponential and of the form:

$$F_s = F_m (1 - e^{-T/\tau})$$

where

τ is the time constant

400 h has been experienced in one case of avionic equipment, but the value of τ is likely to be dependent upon both magnitude of m.t.b.f. and severity of test environment.

If the constant is 400 h, by 1000 h over 90 % of the potential (non wear-out) types of failure will be known and by 2000 h over 99 %. There is therefore little new knowledge to be gained from testing beyond 2000 h, except on wear-out characteristics of components of limited life, but further time is needed to prove the effectiveness of modifications and to demonstrate the resultant growth. Therefore, probably 2500 h to 3000 h per equipment is the limit of meaningful testing, allowing for the time lag previously mentioned. A programme of growth to reach the theoretical m.t.b.f. prediction is possibly about 12 000 equipment-hours, based upon $S = 0.4$ and $m_d = 0.15 m_0$, hence four or five equipments would be the ideal number. Often this number of equipments is not available for reliability testing, but such equipments with their enhanced reliability could be made available, after reconditioning, for other purposes. The cost of the equipments themselves need not then be reckoned as a part of the testing costs. The greater number of equipments tested will make the programme more representative and the growth achieved will be wider in its influence.

It is emphasized that this is purely an example from experience of testing of avionic equipment and may not apply to other types of equipment or environment.

6. Length of programmes

The predicted calendar time of a test programme has to allow for the expected down-time involved in waiting, diagnosis, repair and modification. This is based upon the total number of failures, which can be easily derived from the cumulative m.t.b.f. in the case of a growth programme and from the predicted m.t.b.f. in compliance and determination programmes

6.1 Growth programmes. The following expression (from in appendix D), gives the expected programme time for T equipment-hours of testing, with an achieved instantaneous m.t.b.f. of m hours:

$$Z = CT \left(\frac{1}{MH} + \frac{[aK]}{m_i (1 - S)} \right) \text{ weeks}$$

The above equation assumes that down-time will be consecutive even when two or more equipments are unserviceable together. In a practical situation of this kind, some of the waiting time on one equipment could be profitably used in servicing the other equipment so that the effective value of K could be reduced. Further economies in down-time would result if there were enough technical effort to service more than one equipment simultaneously.

An allowance should be made for additional failures due to wear-out if this is likely to have a significant effect.

The calendar period given by the above equation is for testing only and to obtain the length of the total programme, periods for preparation and for reporting should be added.

6.2 Compliance and determination programmes.

The same general method as for growth programmes may be employed, except that the reliability is assumed constant (apart from the effects of any expected wear out, which must be taken into account). In a sequential compliance test, the maximum down-time will depend upon the number of failures at the truncation point,

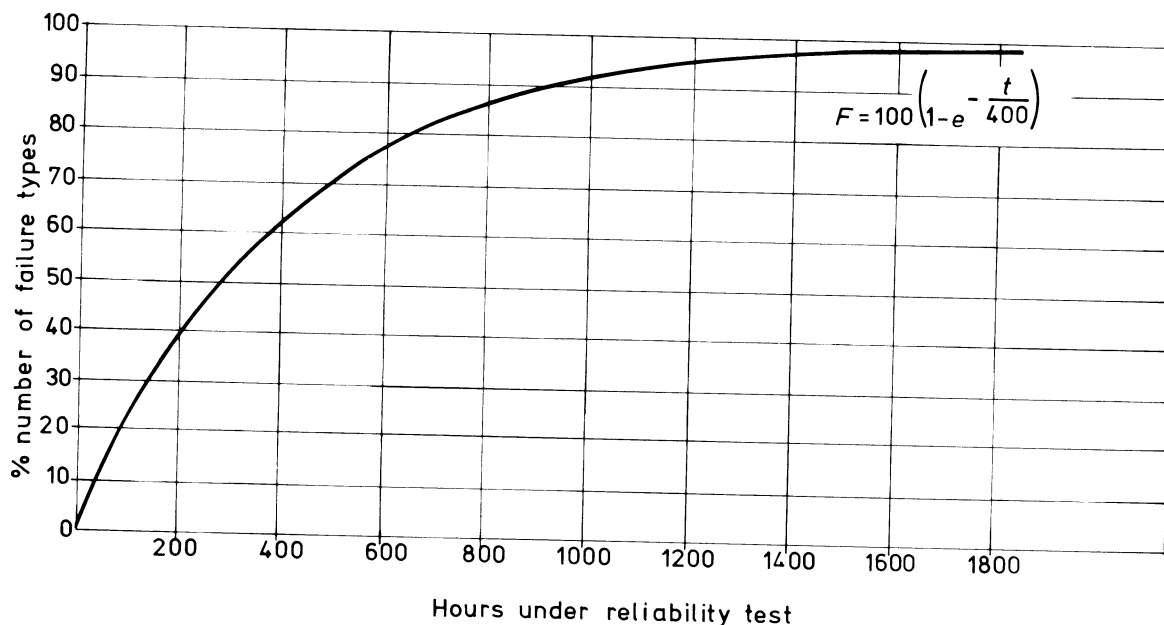


Figure 6. Typical plot of systematic failure types

as detailed in appendices B and C. Alternatively the 'expected' number of failures may be used as a basis, if some risk of a longer programme is admissible. For determination testing the maximum or expected number of failures should be calculated from the estimated reliability and total equipment-hours.

The programme time is then given by:

$$Z = CT \left(\frac{1}{MH} + arK \right) \text{ weeks}$$

7. Test reports

The format, scope and issue of reliability test reports should be agreed prior to the commencement of any reliability test. Where the test is being carried out in response to a contract requirement, then the contract should also contain a statement on the requirements of the test reports.

7.1 General. There are three basic types of report which should be prepared during the course of a reliability testing programme.

(a) *Test logs and data records.* These are continuous records which contain details of the day-to-day happenings on the reliability programme. They will not in general contain specific details of occurrences (such as failures) but will contain references to other forms of records and reports, e.g. failure reports.

(b) *Failure reports.* These reports are made to detail the nature of actions and recommendations taken on specific failure occurrences.

(c) *Summary reports and final reports.* These reports are published at specific points in the reliability test programme and summarize the results obtained up to that point. They will also summarize all failure information.

7.2 Test logs and data records. One document should be established for each test item. The chronological data should be recorded at defined times and after each failure and should be of sufficient detail to provide an accurate historical record of all pertinent happenings during the test.

Test logs and data records should include the following information.

(a) *Equipment identification.*

- (1) Equipment name, type and serial number (including sub-systems);
- (2) model build or modification state;
- (3) name of manufacturer.

(b) *Chronological recording for each observation and action.*

- (1) Date and time of the observation or action;
- (2) environmental conditions;
- (3) relevant performance parameter conditions;
- (4) comments on any out-of-specification conditions;
- (5) elapsed time meter reading;
- (6) names of personnel involved;
- (7) other comments.

7.3 Failure report. A report should be made on each failure and contain the description of the failure, the result of the failure analysis and the actions taken concerning the equipment and the components or parts.

Originators and detailed contents should be as given in 7.3.1 to 7.3.3.

7.3.1 From the test operator

(a) Failure identification.

- (1) Date and time of failure;
- (2) serial number of the test item;
- (3) assembly, sub-assembly and component or part involved;
- (4) operating conditions at the instant of failure;
- (5) environmental conditions at the instant of failure;
- (6) elapsed time meter reading;
- (7) name of test operator.

(b) Failure symptom on equipment performance.

- (1) Parameters exceeding specified limits;
- (2) instruments used for indicating the failure.

(c) References to related failure reports.

(d) Opinion concerning the classification of the failure.

(e) Recommended corrective action.

(f) Any other relevant data.

7.3.2 From the repairing personnel

(a) Failure confirmation.

- (1) Method and instruments used;
- (2) observations and comments.

(b) Repair description.

- (1) Actions taken;
- (2) on-time of the equipment during the repair;
- (3) date, time and duration of repair;
- (4) organization responsible and name of the person responsible for carrying out the repair.

(c) Replacement identification for each component or part replaced.

- (1) Location of circuit position;
- (2) name of the component or part;
- (3) type designation and characteristics;
- (4) name of manufacturer.

(d) Opinion concerning the cause and classification of the failure.

(e) Recommended corrective action.

(f) Any other associated modifications carried out at the time of repair.

(g) Any other relevant data.

7.3.3 From the failure analysis personnel

(a) Analysis of the replaced components or parts.

- (1) Visual examination and initial measurements;
- (2) analysis description (physical, chemical, etc.);
- (3) results;

- (4) date of analysis;
- (5) organization and name of the person responsible for carrying out the analysis;
- (6) equipment used during the analysis.

(b) Analysis of conditions influencing the failure.

(c) Cause and classification of the failure.

(d) Recommended corrective action.

(e) Any other relevant data.

7.4 Summary reports and final reports. These documents should contain summarized information on all failures and the test results to date. Failure data and relevant test time should be traceable to the originating test log and failure reports.

Summary reports and final reports should contain the following information:

(a) General information.

(1) Equipment identification;

(2) reference to the detailed reliability test specification and test conditions.

(b) Chronological summary of all the relevant failures.

(1) Calendar time to failure;

(2) failure classification;

(3) reference to failure report;

(4) test item serial number;

(5) accumulated number of relevant failures;

(6) accumulated relevant test time.

(c) Summary of all the non-relevant failures.

(1) Failure classification;

(2) reference to failure report.

(d) Plots and values presenting the results of the statistical treatment (including any reliability growth).

(e) Final conclusions and proposed actions to be taken if applicable.

Appendix A

Test conditions

This appendix expands the subject of test conditions as given in 4.4 and shows the principles which should govern selection of environmental and operating cycles in pre-conditioning, burn-in, growth and compliance or determination tests. It is normal that the design specification for any project should include a statement of the applicable environmental extremes and that these (or their more typical equivalents) should be used as a basis for the test environments. However, the specified environmental conditions appropriate to utilization (including on, off and standby periods) should apply. Those pertaining to storage, which are often more extreme, would not be relevant.

Figure 1 shows a basic temperature and operating cycle, in which the constituent time periods may be set to suit the required conditions. Although it has become customary in reliability testing to utilize only high and low temperature environments and in some cases also vibration, there is no reason why other environments (e.g. humidity, low air pressure and bumping), if they are appropriate and frequently experienced in use, should not be applied.

It is important to note, however, that reliability testing does not dispense with the need for prior testing at the extremes of all the specified environments to verify the capability of the equipment in withstanding them, at least for short periods. Reliability testing differs from this testing in that it adds the factors of long term exposure to the environments and equipment operation in a realistic duty cycle.

A.1 Initial operation

A.1.1 Pre-conditioning in a growth programme. The most dominant failure types are expected to be the first to appear in a growth programme and it is desirable therefore to identify and remedy them quickly before the later appearance of more obscure types, which may require more time-consuming investigations. The types appearing early may also be environment dependent, i.e. they disappear on removal of a particular environment and hence will require investigation while in that environment.

Therefore, for ease of identification of such failure types, the environments to be used in the subsequent growth programme (see A.2.1) should be applied singly at their extreme values for approximately 100 h each (or longer if needed for investigations). At the same time the equipment should be operated according to the normal use condition appropriate to each environment concerned.

A.1.2 Screening or burn-in. In order to eliminate initial failures in the shortest possible time, this process should be as severe as the design specification will allow. It may, therefore, be slightly harsher than the more typical conditions which are likely to be prescribed for the subsequent compliance or determination tests (see A.2.1). However, it will normally employ the same types of environment and cycling, coupled with equipment operation in a typical on-off duty cycle.

The need for screening or burn-in is likely to be greatest for electrical or electronic equipment which shows the most pronounced premature failure period. The fall in

failure rate which accompanies screening may be gradual or sudden but as many as 300 operating hours may be required for reasonable stabilization. Shorter periods (commonly 150 operating hours including all operating time under bench conditions) may, however, be adopted as a compromise. The usual requirement that the screening used before compliance or demonstration testing must be identical with that applied to every equipment in production will be an important consideration in determining the most economic and practicable procedure. For equipments which are predominantly mechanical or electro-mechanical, screening periods of 25 to 50 operating hours may be adequate.

A.2 Regular test conditions

A.2.1 Growth programmes

A.2.1.1 Sources of degradation. As with screening, such programmes have the purpose of stimulating latent failures and hence the environmental and operating conditions should be as severe as the design specification will allow. The most common influences of degradation leading to failure are as follows:

- (a) *high temperature.* Acceleration of chemical deterioration or embrittlement through dehydration;
- (b) *low temperature.* Mechanical fatigue, with fracture or rapid wear due to operation under the excessive loads imposed by stiffening of flexible materials, differential contraction, increased viscosity of lubricants and progressive embrittlement of materials;
- (c) *heat shock.* Sudden and extreme thermal stressing;
- (d) *temperature cycling.* Repeated expansions and contractions, which lead to fatigue, breathing and to moisture penetration;
- (e) *humidity.* Accelerated ingress of moisture through seals, which leads to corrosion and breakdown of electrical insulation;
- (f) *low air pressure.* Mechanical stressing and electrical breakdown;
- (g) *vibration or bumping.* Repeated mechanical shocks causing fatigue;
- (h) *stop/start or on/off.* Repeated heavy starting loads causing fatigue or electrical switching transients causing breakdown.
- (j) *electrical supply fluctuation.* Reduced life of some components through excessive voltages.
- (k) *normal operation.* Progressive wear and tear or acceptable degradation.

A.2.1.2 Combined environments. Combinations of two or more of the above environments will often be more severe in their effects than in isolation. However, they should only be combined in a testing situation where this is expected to occur in practical use.

A.2.1.3 Cycling and fatigue. Cycling between extremes, 'stop/start' or 'on/off' and bumping or vibration are important in the element of mechanical fatigue which they introduce, and the 'pumping action' which in some cases may stimulate ingress of humidity. It should be noted that mechanical fatigue in sound materials may require millions of cycles, but where there is a potential weakness earlier failure will occur.