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Reliability of Military Electronic Equipment

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Report by

Advisory Group on Reliability of Electronic Equipment,
Office of the Assistant Secretary of Defense
(Research and Engineering)

4 June 1957

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RELIABILITY OF MILITARY ELECTRONIC EQUIPMENT

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FOREWORD

The Advisory Group on Reliability of Electronic Equipment was established by the Research and Development Board as an agency of the Committee on Electronics on 21 August 1952. Its purpose was to monitor and stimulate interest in reliability matters and recommend measures which would result in more reliable electronic equipment.

The Advisory Group was continued under the Assistant Secretary of Defense (Research and Development), upon the abolition of the RDB in 1953, and it was re-established in 1954 as an agency of the Office of the Assistant Secretary of Defense (Applications Engineering). The purpose and membership remained essentially the same during these administrative changes.

In late 1955, it appeared that sufficient knowledge was available and sufficient interest aroused that specific steps could be taken toward quantifying reliability requirements and toward developing suitable tests to verify that such requirements are met. Consequently, a program of nine tasks in the areas of numerical reliability requirements, tests, design procedures, components, procurement, packaging and transportation, storage and operation and maintenance was established. A task group of people from the Military Departments and industry was assigned to each of the tasks early in 1956. These task groups were asked to submit their findings in the form of a report after they had considered all aspects of their assigned tasks.

This document is a consolidation of the nine task group reports and is issued at this time only for informational purposes. Methods of implementing the recommendations contained in this report are being studied by Department of Defense agencies.

The recipients of this report are urged to utilize any of this material that may be useful and appropriate to their activities.

J. M. Bridges
Chairman
Advisory Group on Reliability of
Electronic Equipment

CONTENTS

PROGRAM FOR AGREE

1. Develop minimum acceptability figures for reliability of the various types of military electronic equipment. These figures possibly may be expressed as "time between failures" or some other truly quantitative measurement. The basis upon which the figures are determined shall include the factors of operational mission requirements, maintenance, complexity, and such other factors as may be significant.

2. Develop basic requirements for tests to be accomplished on development models which will prove that the design is capable of meeting the minimum acceptability figure for reliability established for the equipment type. These tests shall be designed to be performed either in addition to, or in conjunction with, whatever performance evaluations are specified for the equipment.

3. Develop basic requirements for tests to be accomplished on pilot-production and on production models which will prove conclusively that the equipment will meet the minimum acceptability figure for reliability established for the equipment type. These tests shall be designed to be performed either in addition to, or in conjunction with, whatever performance evaluations and operational suitability evaluations are specified for the equipment.

4. Investigate and recommend methods of specifying development procedures to insure that equipment designs will have the inherent reliability required. Some factors which might be involved are: (1) theoretical reliability prediction, (2) thorough component selection, qualification, and application for specific circuit and environment requirements, (3) adequate signal levels and feedback, and (4) minimizing the effects of mechanical shock, vibration and temperature on critical components.

5. Establish criteria and methods for specifying the reliability of component parts and tubes in terms of failure rate as a function of time and environment. This is considered essential to a determination of the amount of improvement demanded in various components to meet the over-all reliability requirements of the various types of electronic equipments.

6. Study present procurement and contracting practices and regulations to determine their compatibility with reliability objectives. Make recommendations for specific changes as found necessary during the study. Some of the factors involved might be: (1) assessing the implementation of DoD Directive No. 1135.10, "Amplification of Policy Governing Award of Initial Production Contracts for Technical or Specialized Military Supplies," dated March 17, 1955, (2) methods of selection of contractors for development and production and the possibilities of including evaluation of the potential contractors' ability to produce reliable designs, and (3) evaluation of combined R&D production contracts, (4) in considering award to lowest bidder--the over-all cost including operation and maintenance might be considered (might be determined on basis of predicted reliability).

7. Investigate present practices of packaging for shipment and transportation methods and recommend specific improvements which will enhance reliability.

8. Investigate the effects of storage of electronic equipment upon reliability and recommend improvements where desirable.

9. Review present methods and procedures to assure that the reliability of equipment in service is kept up to the inherent design level. Factors which might be included are: (1) maintenance based on performance measurement rather than to meet rigid time schedules, (2) marginal testing, and (3) personnel training.

SUMMARY

In anticipation of the variety of interest prompting those who will study this document, the summary has been prepared to permit examination of the Task Group findings from three viewpoints. The first part divides the objective of specification, measurement and maintenance of quantitative reliability into the nine areas covered by the Task Group assignments. The second part provides a comparison of related recommendations and definitions and discusses the significance of the similarities or differences. The third part divides the Task Group recommendations into categories by the affected agency, termed "procurement agency," "contractor," "user" and "Department of Defense."

PART I

Task Group 1

Task Group 1 has developed minimum-acceptability figures for the reliability of various types of military electronic equipment, suitably expressed in terms of hours mean life (mean time between failures) to permit inclusion as contractual requirements. For shipborne equipment, the related value of percentage up time is also given. These figures were developed by determining the minimum acceptable probability of successful mission, tactical operation or controlling safety requirements through liaison with operational commands, followed by conversion via well-considered numerical importance factors to each equipment category required by the mission or operation under consideration. The coverage of types of missions and tactical operations for the three Services and categories of electronic equipment are representative and quite comprehensive, if not exhaustive.

Mean lives are presented in tabular form by equipment type, within equipment category, within Service branch. Certain equipment types appear in more than one tabular location with different mean life requirements. Accordingly, procurement agencies will face alternative decisions: to standardize on the longest mean life requirement or to procure given equipment types to different reliability requirements. The techniques employed for developing mean life requirements are fully explained by appendixes, thus permitting others to review the technique employed and extend it to additional equipment and tactical situations. The establishment of minimum-acceptability figures for reliability in terms of mean life is compatible with the findings of the other Task Groups.

Task Group 1 notes that large data-handling systems (SAGE, Naval Tactical Data System, Missile Master) have been omitted from consideration because of system complexity and recommends that future attention be given to them. By direction, missileborne electronic equipment is excluded. Security-sensitive equipment has been excluded, as well as noncombatant equipment, because of the complications that they would introduce.

While the Task Group, through manipulation of importance factors, has adjusted minimum mean life requirements for the various equipment categories which make up each weapon system, it urges that further adjustment should be considered by a more competent authority to take into account additional factors relative to items such as state of the art, compromised performance, cost, maintenance load and even test environment. The Group suggests that the tables, as presented, be adopted on the basis of being a first approximation (after a review of parameter), and that information feedback between tactical users, equipment manufacturers and procuring agencies be employed as the primary basis for any further adjustment of mean life requirements.

Task Group 2

The assignment of Task Group 2 was to develop basic requirements for tests of development models to prove that the design is capable of meeting the established minimum-acceptability figure for reliability of the equipment type. Accordingly, the Group proposes a test which balances economy of time and facility against the rigors of high accuracy and risk of wrong decision, and complete rules of procedure are set forth.

To assist in examining the propriety for augmenting the test developed pursuant to the objective, the Task Group paraphrased its assignment as a request to develop evaluation means to give assurance that unreliable equipment will not be released for pilot or production runs. This permitted the Group to consider recommendations for means of evaluating reliability other than by reliability tests, recommendations to improve the validity of reliability evaluation and recommendations for ways of improving reliability connected with such tests. The Group therefore recommends that, in addition to the proposed test, a review be made of the reliability prediction prepared during the determination of the development project's feasibility and that a review be made of the contractor's effort on component test to failure. The Task Group believes that the added review effort is needed since the failure-rate test alone should not be the basis of decision for the following reasons:

(1) The fact that the time and the number of models available for test are limited places broad confidence limits on results.

(2) The development models are not necessarily representative, as future production will undoubtedly be from different lots of parts and will be accomplished with different process controls.

(3) The failure pattern of the development models is not necessarily representative even if all lots are considered identical, since only a small number of the many possible component variations within the tolerance limits will occur in a few equipments.

To this end, then, the Group provides details for a careful review of reliability prediction, based on a review of paper design, and a program for component test to failure to identify failure modes and evaluate safety factors. Further, they recommend that a competent engineering failure analysis be mandatory for all test failures in order to initiate adequate corrective action. The Group recommends that all recommended reliability activity be supervised by an independent evaluation group that is not subject to the interests or prejudices of project personnel on the staffs of the contractor or procurement agency.

For the failure-rate test, the Task Group provides recommendations on the equipment characteristics to be measured, the number of models to be tested, the test environment to be employed, the proper definition of "failure," test-procedure criteria and data handling. All recommendations appear to be sufficiently detailed to permit their satisfactory implementation on the basis of the customary equipment specification, specified mean life (from Task Group 1), and the final report of Task Group 2.

Procurement agencies implementing these recommendations should (1) add a requirement that all design recommendations resulting from the test program be considered for incorporation into the product design and (2) prescribe a course of action in circumstances where development models fail to pass the test requirements, to the extent that they are judged unsuitable for pilot or production runs.

Task Group 3

In accordance with its assignment to develop basic requirements for tests of pilot-production and production models of electronic equipment which will prove conclusively that the equipment will meet the established minimum-acceptability figure for reliability of the equipment type, Task Group 3 submits specific testing methods, together with essentially all the details necessary for their implementation.

The recommended testing methods provide specific routines for (1) reliability index (mean life) evaluation of pilot-production equipment, (2) reliability index evaluation of production equipment and (3) longevity (the equipment's useful service life) evaluation of pilot-production and/or production equipment. The test routines permit, respectively, the establishment of (1) the equipment's capability of meeting a minimum reliability requirement, based upon the greatest economy with respect to the number of equipments tested and the testing time required, (2) statistically conclusive proof that an acceptable percentage of quantity-produced equipment meets a minimum [illegible]ility requirement, with maximum economy of testing cost and time and with op[illegible] "waiting time" for test results and (3) conclusive proof that equipment reliab[illegible]y does not degrade below a prescribed minimum level during the desired life of the equipment.

Testing procedures are developed so that they are reasonably immune to tampering by the contractor or by prejudiced testing personnel. By means of selected redundancies in data handling, the testing methods are rendered reasonably self-checking and immune to errors in data recording. Specific means for accomplishing the evaluations are in the form of detailed testing methods, circumscribed by complete rules for administration and procedure. The only elective parameters left to the procuring agency are those which identify minimum mean life and the extent of pilot production, relate conditions of equipment end use to the testing procedure and relate conditions of procurement volume and scheduling to the testing sequence. Factors that cannot affect evaluation conclusions but can affect testing convenience are left for election by the procuring agency or the contractor.

The Task Group's assignment requires that the proposed tests provide conclusive proof. The recommended tests establish proof to a degree of conclusiveness that is customarily accepted by established quality-control regimes. The Task Group has provided all necessary formulae to permit test revision so as to reduce the risk to the procurement agency and/or contractor to whatever degree is considered desirable to achieve such additional conclusiveness at added expense as may be necessary.

The Group recommends that trial implementations be run concurrently on both the proposed pilot-production and the production tests by selecting a varied group of procurement contracts on which the reliability tests may be made mandatory. It is further recommended that the test elections made by the procuring agency, the test programs made by the contractor and the ultimate findings be reviewed and compared with later field observations. If they are found satisfactory, then the testing requirements should be uniformly applied to all electronic procurement.

Task Group 4

The assignment for Task Group 4 was to investigate and recommend methods of specifying development procedures to ensure that equipment designs have the required inherent reliability. Suggested factors for considerations are (1) theoretical prediction of reliability, (2) thorough selection, qualification and application of components for specific circuit and environment requirements, (3) adequate signal levels and feedback and (4) reduction of the effects of mechanical shock, vibration and temperature on critical components to the lowest possible degree.

In compliance, the Task Group has submitted recommended development procedures in a military-standard format. The procedures divide the development program into (1) a feasibility study (Phase I) which includes theoretical reliability prediction and is terminated by a report and (2) the design and construction of prototype models (Phase II) in accordance with specified requirements for thorough selection, qualification and application of components in selected circuits and in anticipated environments, together with requirements for diligent appraisal to reduce the effects of mechanical shock, vibration and temperature.

While the proposed standard outlines explicit means for the treatment of failure rates on a quantitative basis in order to arrive at a numerical reliability prediction, the remaining development procedures are considered on a more qualitative than quantitative basis. The scope of coverage is comparatively comprehensive, although the treatment of each item considered is sufficiently abbreviated to make the specification useful for rapid reference.

Although Task Group 4 recommends that the Phase I report be found acceptable before the contractor is authorized to proceed with Phase II, the specification has been prepared in a fashion which permits beginning Phase II while awaiting approval of the Phase I report by the customer.

The Group emphasizes that the first step in developing reliable equipment is to make the contractors' engineers thoroughly familiar with the environment in which it is to be used; the expected maintenance conditions and operating problems.

The material submitted by Task Group 4 is in a form that is suitable for dissemination independently of the other Task Groups' findings.

Task Group 5

Task Group 5's assignment was to establish criteria and methods for specifying the reliability of component parts and tubes in terms of failure rate as a function of time and environment, since this is considered essential to a determination of the amount of improvement demanded to meet the over-all reliability requirements of electronic equipments. After careful study, Task Group 5 finds that present military component specifications do not assure the achievement of presently needed reliability levels. Component qualification approval results in only limited proof of component design capability and it provides no assurance of any determinable failure rate or component reliability at any level. Present military inspection practices in accordance with these specifications do not police reliability levels and they yield no data for reliability assurance.

Performance requirements of present military component specifications do not reflect present requirements for end use, and, with the limited information at hand, it is impossible to revise these specifications to reflect such a relationship in a statistically valid manner. Methods for environmental test of components, as contained in specifications MIL-STD-202 and MIL-E-1, do not permit the establishment of failure-rate data, nor do they correspond to anticipated environmental conditions. The failure rates of most present military components (and the materials of which they are composed) for single environments are generally unknown; they are entirely unknown for combined environments.

Government regulations on drafting component specifications must be amended before those specifications can establish reliability requirements based on failure-rate information. To be useful to the equipment designer, information on failure rates of components must include (1) the percent that fails per unit time, (2) the critical failure mode, or modes, or the parameter change to which this failure rate applies and (3) the relationship of this failure rate to environment.

Task Group 5 has provided a test procedure for determining the reliability of component parts and tubes, either in terms of failure rate, which may be used for equipment reliability calculation as recommended by Task Group 4, or in special parametric terms that apply to equipment reliability. The complete derivation of this procedure, from a statistical standpoint, is included.

The Group recommends that action toward achieving reliability of component parts and tubes be gr[illegible], beginning with temporary measures to maintain the present degree of inherent reliability through a more critical inspection procedure and through semiannual requalification with greater emphasis on reliability rather than quality. At the same time, new specifications should be prepared to require a sound evaluation of failure-rate versus severity of test. An attempt should be made to prepare a new standard set of test environments for all components. A new system should be developed to determine and identify approved suppliers, based on in-plant quality control, with a periodic redetermination of approval by a review of in-plant quality-control records. As part of a revised qualification approval, a large sample of the product should be tested to establish primary failure rates.

Task Group 5 further recommends that a permanent group, at Department of Defense level, be established and funded, that it be composed of personnel representing industry and the three Services in the fields of research, development, standardization, procurement and quality assurance and that this group be charged with the task of developing military component specifications, testing component parts for design capability and developing inspection methods. The group should accumulate usage reports, failure reports and reports on controlled experiments for use in monitoring the correlation between specifications, manufacturers' quality control and observed data, in order to control the continuation of each component manufacturer on the approved list. The work of Task Group 5 should be continued by a permanent committee of industrial and military representatives with policy-making power. This committee should review the present military effort to coordinate and eliminate duplication, make recommendations regarding the need for contracts to do specific outside work, establish means for disseminating information and establish policy for the creation of controlling documents companion to specifications which contain use and application notes for high reliability and special environments not covered by the specifications.

Task Group 6

The assignment to Task Group 6 was to study present procurement and contracting practices and regulations to determine their compatibility with reliability objectives and to make recommendations for specific changes as found necessary. The Group noted that some of the factors involved might be the following: (1) assessment of the implementation of DOD Directive No. 4105.10, "Amplification of Policy Governing Award of Initial Production Contracts for Technical or Specialized Military Supplies," (2) consideration of methods of selecting contractors for development and production and the possibilities of including an evaluation of a potential contractor's ability to produce reliable designs, (3) evaluation of combined R&D production contracts and (4) consideration of over-all cost, including operation and maintenance (on the basis of predicted reliability), when considering an award to the lowest bidder.

The Task Group is convinced that reliable electronic equipment cannot be procured unless the contracting officer can incorporate in his contract a comprehensive set of technical specifications which, if met, will produce the degree of reliability required. Task Group 6 finds that existing procurement laws and regulations are adequate and sufficiently flexible to permit the selection of fully qualified producers (with respect to reliability), especially if all procuring agencies uniformly interpret and implement existing guidance documents of the Department of Defense and the Office of Defense Mobilization. Thus, while not recommending any basic change in regulations, the Task Group does strongly recommend standardizing the interpretation of each clause in the <u>Armed Services Procurement Regulations</u> among all of the procuring Services.

The Group believes that procurement agencies can employ the findings of Task Groups 1 through 5--in the form of specifications--to procure reliable equipments. Procurement tools presently available to ensure improved reliability are: (1) the use of cost-type or redeterminable contracts during initial production runs, (2) an ability to contract for extensive tests during pilot runs and prior to full production, (3) careful selection of highly qualified contractors by using a procedure which evaluates the contracts' present and potential capabilities, (4) restriction of competition to planned suppliers, once the base has been established, (5) provision for operational tests, as needed, prior to acceptance and (6) provision in the production contract for a program of continued product improvement, based on controlled testing and field experience.

Task Group 7

Task Group 7 was charged with investigating present practices of packaging for shipment and transportation methods and recommending improvements where desirable.

Among the subjects investigated by the Group were: (1) the effect of closer relationship between equipment designers and packaging engineers, (2) the present shortage of information on cushioning to damped dynamic forces, (3) present programs to obtain better field data on the parameters of encountered shock and vibration during handling and transportation, (4) damage experienced by Service materiel during rough handling and transit because of lack of adequate blocking and bracing of equipment racks within the transportation media, (5) the development of specific test procedures to more clearly simulate transportation and handling environments and (e) general damage due to improper packaging and packing.

As a result of these investigations, the Task Group has made several recommendations: Working relations between the equipment designer and the package designer should be continued and improved. Emphasis on improving container design should be continued, with an effective feedback from present studies on encountered shock and vibration during handling and transportation. There should be improvement and enforcement of all requirements for blocking and bracing, as contained in all application rules, regulations and tariffs. The specification now in preparation covering test procedures for simulation of transportation and handling environments[1] should be completed as rapidly as possible. Finally, the Task Group recommends that close collaboration be maintained between the Government, the equipment designer and the container designer.

Task Group 8

Task Group 8 was asked to investigate the effects that storage has upon the reliability of electronic equipment and to recommend desired improvements. Based upon its study of failure-data records on equipment stored by eight agencies, the Task Group concludes that failures from storage are not significant in comparison with other failures.

The Group found that available data records were usually quite imperfect both with respect to identifying those failures specifically chargeable to storage and the number of equipment stored. In fact, the greatest bulk of data (from the Air Materiel Command), covering 100,000 failure reports, of which 454 were attributed to storage, contained no information on the total number of equipments from which the failure reports were drawn. Thus, it was necessary to estimate an over-all failure rate of 5 percent in order to deduce a quantity of two million equipments and to conclude that the probable storage failure rate was not more than 0.0225 percent. Summarized data from all eight sources, including the foregoing assumption, as well as others needed for statistical conclusions, indicate 920 failures from 2,449,772 equipments, which permits a statement of 90-percent probability that the storage failure rate lies between 0.035 and 0.040 percent.

The Task Group notes that there are considerable data in military files which, if converted to a standard form, could be machine-processed to yield improved statistical conclusions concerning failures resulting from storage. In fact, the analysis of such data would provide the principal justification for its past collection. The Group further notes that field inspection and maintenance provided to assure equipment operability, within performance limits, should include the regular submission of reports of findings as a basis for modifications in design and manufacturing.

On the basis of a portion of the data examined, the Group believes that, because of the variation in accuracy and precision of test equipment used in the field and in storage tests, a considerable percentage (at least 20 percent) of the rejection and acceptance decisions made are probably invalid. It is believed

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[1] Office of the Assistant Secretary of Defense (Supply and Logistics) Project No. 704-90.

that there is a basic lack of understanding on the part of management regarding the need for the valid and specific data that are required for reliability studies and estimates.

Even though deterioration in reliability during storage is not considered a significant problem, the Group makes the following recommendations:

(1) The apparently widespread philosophy that adequate and valid testing and reporting are not military functions of primary importance, even during peacetime, should be reviewed.

(2) Test and inspection requirements should be reviewed and amended to provide the data necessary for reliability studies, these data to be in a form convenient for reduction and analysis, and sufficient authority should be vested in quality-control organizations in all branches of the Service to ensure the proper collection of these data.

(3) A planned program for reducing and analyzing data now on file should be put into effect at an early date.

(4) A centralized working group with the Department of Defense should be established on a continuing basis to coordinate and evaluate reliability data from all sources to ensure proper and prompt action.

(5) The program proposed by Task Group 8 for recording all field test operations, even in the absence of failure, should be considered.

(6) The Advisory Group on Reliability of Electronic Equipment (AGREE) should consider a controlled experiment involving the storage and testing of a statistically significant sample of typical electronic equipments.

Task Group 9

Task Group 9 was charged with reviewing present methods and procedures to assure that the reliability of equipment in service is kept up to the inherent design level, and it was suggested that the following factors might be included: (1) maintenance based on measurement of performance rather than on meeting rigid time schedules, (2) marginal testing and (3) personnel training. Accordingly, the Group made a study of equipment maintainability, performance checking and performance standards, disposable modular units and test-equipment calibration, as well as supporting materials such as maintenance publications, manuals and handbooks. They also studied preventive maintenance and marginal checking, the shortage and training of Service technicians and the education of engineers. On the basis of these studies, the Group formulated a wide variety of recommendations.

The Task Group recommends that equipment contractors be required to demonstrate, by means of a prescribed test, that their equipments meet specified maintainability requirements prior to quantity production. Maintainability is defined as the reciprocal of mean net time to repair failures, where both the failures and the repairs take place under specified simulated field conditions. It is recommended that a study be made to evaluate an absolute average technician on a common basis. The Group also recommends that a figure of merit, termed "Operation Value," be computed for each equipment procurement program, taking into account maintainability, failure frequency (reliability index), recommended preventive maintenance and maintenance interval, operational checking and checking interval.

The Task Group recommends that a minimum number of performance indexes be standardized for each equipment class and that each equipment specification enumerate these indexes, with provision in equipment for checking them in the easiest and most rapid fashion. This would constitute the performance standard used for performance check after every maintenance operation. Test-equipment calibration centers should be established, and handbooks on test equipment should provide complete calibration information, with accuracy and precision stated in terms of standard deviation and maximum deviation over one year measured by specified means. All supporting facilities for new electronic equipment should be purchased concurrently, including test equipment and tools, test facilities, spare parts, publications and training material. Technical maintenance publications should be expanded by supplemental information; they should be written informally and well-illustrated and should cover broad principles of function, maintenance and operational use.

The Task Group recommends that preventive maintenance be limited to components and parts that obey a wear-out law of failure, as identified by supplemented equipment manuals prescribing preventive maintenance periods and procedures.

Whenever it is economically justifiable, marginal checking should be employed; in such cases, the equipment manufacturer should be required to furnish testing margins and testing frequencies. Marginal checking should be applied to transistorized equipment and analog devices as rapidly as research in these areas permits.

The Task Group's study of the shortage of Service technicians, with present emphasis on contract technicians, led to several recommendations. Until this Service shortage has been remedied, consideration should be given to mobilizing contract technicians in their present assignment in an appropriate status immediately upon declaration of a state of emergency. More emphasis should be placed on utilizing Service personnel for routine maintenance, and all possible steps must be taken to enhance the military career in order to reduce the high turnover rate of Service technicians. Because the long training times are resulting in the inefficient use of such technical manpower, the Task Group recommends that the Military Departments establish three levels of training, limiting the maximum time for training to about one-third of the remaining enlistment. The Military Departments should conduct conferences and symposia to stimulate the introspective examination and reappraisal of each Service's training effectiveness.

PART II

The similarities and differences of the Task Group recommendations indicate that there is a general agreement, not only on the basic philosophy but on the definitions used by the Task Groups.

All nine Task Groups uniformly interpreted the quantitative reliability requirements which appear in the first five Task Group assignments to mean the numerical probability of failure-free system or equipment operation during a described time interval under described conditions of performance and environment. While the precise definitions used by Task Groups 1, 3 and 8 differ slightly in wording, all acknowledge that reliability is a probability associated with a time interval. In addition, all the Task Groups agree that, under usual circumstances, this probability is calculable from a simple exponential function involving one variable, the duration of the time interval, and one constant (reliability index) variously termed "mean life" or "mean time between failure," or even inverted and described by the numerical reciprocal as "failure rate." Most important in this consideration is that this reliability index is a numerical constant that describes the probability of random failure and usually is not related to our implied meaning of an item's "life." Task Group 3 notes that, in all circumstances where the simple exponential function does not yield the correct probability, the error is in the safe direction, i.e., an equipment passing the prescribed acceptance tests may be more reliable than test results indicate. Furthermore, the equipment manufacturer can take steps to ensure the validity of the exponential function to minimize his risk.

Accordingly, the equipment user's desire for high probability of a failure-free mission has been translated by Task Group 1 into minimum acceptable values of mean life for the various equipment categories, and the tables of these reliability indexes set a measurable lower limit to quantitative reliability that can be used in procurement. These tables can be extended to cover all items not already tabulated, including one-shot, short-life devices such as missiles, as well as nonelectronic items. This would establish a lower limit to the reliability of the device which can be used for design as well as acceptance testing, even when testing is destructive.

Task Groups 2 and 3, which were assigned to devise tests that would establish capability and conclusive proof of minimum acceptable reliability, have prescribed testing routines to demonstrate that the reliability indexes of the tested equipment equal or exceed those minimum values specified. Aside from the question of the degree of test accuracy or confidence that must be achieved to establish capability or to establish conclusive proof, the foregoing discussion should point to a conclusion that tests of minimum reliability index are equivalent to tests of minimum reliability.

Task Groups 2 and 3 have chosen the same kind of reliability test, statistically termed "truncated sequential life test" but better described as an operating test whose duration should not significantly shorten the life remaining in the tested equipment. The only slight difference in the testing routines of the two prescribed tests is that a decision should be reached sooner with the Task Group 2 test than with the Task Group 3 test. This difference in test duration stems from the requirement to establish capability in the former case and to establish conclusive proof in the latter.

While these two Groups recognize that each must separately achieve a soundly chosen minimum test accuracy, both appreciate the cost in time and money involved in the additional testing not now prevalent in electronic equipment procurement. Each Task Group has made a judicious compromise between the economy of abbreviated testing and the accuracy of extended tests.

Tests for reliability index (mean life, etc.) call for operating equipment in an environment roughly simulating the conditions of its end use. Thus, from observation of failure frequency during test, inference is drawn regarding probable failure frequency during tactical use. The rules for treating test data are established by formalized statistical sampling theory. Fundamental to this approach is the principle that the accuracy of decisions based on such tests will improve as the quantity of pertinent data (number of observed failures) increases. An increase in data can be quickly obtained only by testing larger samples or by testing for a longer time. To keep sight of the limited decision accuracy available from tests kept within reasonable magnitudes, it is customary to describe such tests as having a specific confidence less than 100 percent.

How is a requirement for conclusive proof related to an accuracy or confidence less than 100 percent? It is acknowledged that such statements as "exactly three feet" or "precisely ten pounds" must be translated literally as requiring an infinite number of ciphers following the decimal point, whereas in practice there is usually an understanding as to how many significant figures are important to a dimension. Accordingly, we interpret "exact" in terms of a practical measurable limit of accuracy. Task Group 3 has interpreted "conclusive proof" in terms of the maximum accuracy usually expected of statistical quality control as applied to electronic equipment procurement. Task Group 2 interprets "establish capability" as requiring somewhat less accuracy than "conclusive proof."

To be statistically rigorous, the confidence that can be placed in a decision or conclusion must be stated as a two-dimensional parameter. For instance, in respect to the Task Group 2 test of development equipment--and, in a hypothetical instance, requiring equipment with a mean time between failures of 100 hours--there is a 90-percent probability of making a correct decision from the specified test of equipment whose true mean time between failures is either above 100 hours (to accept) or below 50 hours (to reject). In this case, the first confidence dimension is the 90-percent probability for correct decision, and the second dimension is the interval of uncertainty, 100 hours to 50 hours, a 2:1 ratio in mean time between failures. When the same hypothetical example relating to an 100-hour equipment is applied to the tighter test prescribed by Task Group 3, the statement of confidence becomes: There is a 90-percent probability of making a correct decision on equipment whose true mean time between failures is either above 100 hours or below 67 hours. Here, the 90-percent probability of a correct decision is related to a 1½:1 ratio of mean time between failures.

In what way, if any, is the equipment user penalized by any lack of confidence in Task Group 3 reliability tests? If there is only a 90-percent probability that the test will reject equipment whose mean time between failures is below the tolerable minimum, what will be the result upon the user of an equipment that should have been rejected but may be accepted as much as 10 percent of the time? Analysis of the mechanism by which the tests operate shows that, while there may be as much as a 10-percent probability that an equipment at the specified minimum mean time between failures will be accepted rather than rejected, the chance of an incorrect decision to accept reduces very rapidly as the mean time between failures is further reduced. Specifically, for a Task Group 3 tested equipment, if the equipment's mean time between failures is exactly at the user's tolerable minimum (0.67 of the contract-specified minimum), one wrong acceptable decision in 10 will be made, whereas, if the equipment is 25 percent worse than the tolerable minimum, only one wrong decision in 50 will be made. If equipment exactly at the user's tolerable minimum will give 0.90 probability of mission success (as is typical for many Task Group 1 equipment categories), then equipment 25 percent worse than this minimum will give 0.87 probability of mission success--not a serious degradation when never applicable to more than one decision in 50. Similarly, it will be found that the effect of limited confidence in the tests of Task Group 2 on the user is minor. Furthermore, the higher the intended probability of mission success, the smaller the effect of limited test confidence.

In developing its prescribed reliability testing routine for component parts, Task Group 5 treats confidence as a unidimensional "confidence factor." Careful analysis shows that this confidence factor is a numerical coefficient which, when used as a multiplier for the failure rates obtained by simple calculation from abbreviated test data, will reduce the probability of failure-free operation of a component by a safety margin which, on the average, is sufficient to protect against the inaccuracy of abbreviated testing. Thus, in this case, the need for a second dimension of confidence has been obviated by the introduction of averaging. This approach appears to be well-justified for application to component parts, since it permits a significant reduction in the testing requirements where they are for qualification and acceptance routine. Requirements for testing component parts are introduced as a convenience to the equipment designer and manufacturer, and they in no way lessen his responsibility to demonstrate adequate equipment reliability through the tests prescribed by Task Groups 2 and 3.

Task Group 1 has converted user requirements for minimum acceptable reliability into numerical requirements for a minimum-reliability index. Task Group 4 describes how an equipment reliability index requirement can be converted into maximum tolerable failure rates for each of the component parts required in the equipment, or, conversely, how the equipment reliability index can be predicted when the failure rates for each of the parts (as applied in the circuitry) are known. Task Group 5 describes how failure rates of parts can be measured. Task Group 2 sets forth means for improving the prediction of equipment reliability index (based on the paper design, per Task Group 4 routine), once equipment models have been built and operated in the laboratory. This Group also outlines ways to ascertain that the operating laboratory model meets or exceeds the minimum specified reliability index. Task Group 3 prescribes methods for determining that the reliability index equals or exceeds the specified value through the testing of pilot-production and production equipment.

From the assignments of Task Groups 7, 8 and 9, it can be inferred that there may be some deterioration of reliability index during packing and transportation, storage and field maintenance. Through improvements in techniques of these activities, some of this deterioration can be prevented. To guard against remaining deterioration the equipment must be required to possess a sufficient surplus reliability index to ensure a residual minimum reliability index for tactical use required by the user, as determined by Task Group 1.

Task Group 3 suggested that Task Group 1 numbers be raised to allow for deterioration expected as a result of field maintenance, then further raised to allow for deterioration during storage, and raised a third time to allow for deterioration during transportation and handling. Finally, this thrice-raised figure should be increased by 50 percent to establish the contract value of reliability index for Task Group 3 pilot-production/production tests and to allow for the area of uncertainty when making test decisions to accept or reject. Extending this philosophy further, the contract figure for Task Group 2 development-model tests should be 33 percent greater than the figure for pilot-production tests, because of the greater uncertainty with the development test.

According to available data, Task Group 8 has found that reliability deterioration with storage is insignificant. Task Groups 7 and 9 were unable to identify deterioration in reliability during transportation and field maintenance in numerical terms. Any allowance for such deterioration during these phases must be based on estimates.

It appears that, at least initially, the inclusion of contract requirements for minimum reliability index will so revolutionize the equipment reliability observed by the user as to relegate to secondary importance any allowance for reliability deterioration. Consequently--and also in view of gains in contracting simplicity--it may be sufficient at first for contracting agencies to make only the single correction of an increase by 50 percent in translating the numerical values from Task Group 1 tables to contract requirements.

It is significant that several Task Groups concur in some of their findings, not only on the use of reliability index as a yardstick (Task Groups 1, 2 and 3), on reliability testing (Task Groups 2 and 3) and on reliability prediction (Task Groups 2 and 4), but in many other philosophical aspects such as test environment, test-data handling and equipment-failure analysis (T.G.2,3). The fact that no common set of definitions was employed by all the Groups is only a matter of semantics. The following terms were defined by two or more Task Groups as indicated:

Failure	1, 2, 3
Reliability	1, 3, 8
Reliability index	1, 3
Equipment	3, 4
System	3, 4
Inherent reliability	3, 4
Repair effort	1, 9

PART III

Introduction

To provide an over-all review of the nine Task Group studies from the point of view of the agencies affected by the recommendations, this summary is divided into sections as follows:

(1) Procurement agency
(2) Contractor
(3) User
(4) Department of Defense

1. Procurement Agency

1.1 Contracting for Equipment.

Task Group 6 strongly recommends that the interpretation of the Armed Services Procurement Regulations be standardized among all the procuring Services. This Group further presumes that, given the specification requirements proposed by Task Groups 1 through 5, the procurement agency can accomplish the following: (1) ensure improved reliability through the use of cost-type or redeterminable contracts during the initial production run, (2) contract for extensive pilot-run tests prior to full production, (3) carefully select highly qualified contractors, (4) restrict competition to planned suppliers, (5) provide for operational tests prior to acceptance and (6) provide for continued product improvement based on controlled testing and field experience.

Task Group 2 recommends that procurement of electronic equipment should not telescope development with prototype or production procurement; rather, that delivery dates should be established so as to provide for orderly development, followed by adequate evaluation of reliability. The procurement agency should specify to what extent he wishes to follow the recommendation of Task Group 2 that the contractor's reliability program be reviewed and supervised by an independent evaluation group. This recommendation may be made applicable only to that part of the reliability program, as specified by the Group, or it may be made applicable to the contractor's entire reliability program.

Task Group 1 recommends that the reliability figures presented in their report be adopted as a basis for specifying the minimum acceptable equipment mean life for each procurement contract, whether research, development or production.

Task Group 2 requires the procurement agency to specify, in addition to the Task Group 1 mean-life requirement, (1) the minimum performance characteristics to be monitored during the development-phase reliability test, (2) tolerance limits on the performance specification which can be used to define a failure during the test, (3) the number of development models to be simultaneously tested and (4) pertinent details of the test environment as may be dictated by equipment characteristics and, preferably, of such a nature as that suggested by Task Group 2.

In a similar fashion, Task Group 3 requires the procurement agency to specify, in addition to the mean-life requirement, (1) the minimum performance characteristics to be monitored during the pilot-production and production reliability tests, (2) tolerance limits on the performance specification which define a failure during these tests, (3) the standard environment for pilot-production and production reliability tests, chosen from the four proposed standard environments, (4) the number of pilot-production equipments to be simultaneously tested, (5) the production rates applicable to production reliability tests and (6) election of a requirement for test of longevity.

According to Task Group 9, the Military Departments should determine the minimum number of performance indexes required for each class or type of equipment or system, in order that the performance of a system or equipment may be evaluated in accordance with established standards. The Group also recommends that purchases of all supporting facilities for new production equipment be made concurrently, including, as applicable, test equipment and tools, test facilities, spare parts for both major equipment and test equipment, adequate publications for both major equipment and test equipment and provision for training material for both major equipment and test equipment. The Group considers that it is desirable to design modular units, so that, if the cost is within defined limits, they may be disposed of rather than repaired. For this reason, the cost limits should be defined by contract or specification.

Task Group 2 recommends that spare-parts procurement should use equally rigid specifications and requirements for reliability testing as are used for the parts procured by the equipment manufacturer.

1.2 Contracting for Component Parts

Task Group 5's recommendation is that the present government regulations for drafting military component specifications be amended, if these specifications are to establish the requirements for reliability based on failure-rate information.

Also, the Group recommends that present specifications for component parts be modified immediately to assure that the reliability inherent in the qualified product is maintained, and these modifications be considered as a temporary measure to maintain the level of component uniformity and to ensure the retention of whatever minimum level of quality was represented by the original qualification samples. On a more protracted basis, the Task Group recommends the development of new specifications containing (1) statistically designed experiments to produce maximum information from a minimum number of test samples and (2) the proper tests in single and multiple environments, related to the component's end use, to specify the failure rate with relation to various degrees of test severity. One possible and economical test procedure of universal applicability is described in detail.

As part of the component-part qualification approval, a sufficiently large sample should be tested, in accordance with the outlined procedure, to establish the primary failure rates required by the specification for the important parameters. If justified, a supplier should then be investigated further with respect to his in-plant quality control, operating under a new procedure. Such investigations should be periodically repeated and, at the same time, the records scrutinized, in order that the supplier may remain qualified.

The Group recommends that the Services reconcile their divergent environmental requirements and that they state a single set of coordinated environmental conditions which can serve as the basis for testing component parts to establish failure rates for these environments. MIL-STD-200 and MIL-E-1 should be revised, then, to provide tests and severities that truly measure component-parts performance for these environments. The Task Group has been advised that this work has been started by an ad hoc group of the Advisory Group on Electronic Parts.

2. Equipment and Component-Parts Contractors

2.1 Equipment Contractor.

Task Group 4 recommends that, upon completion of the study and planning phase of equipment development, the contractor shall submit a report including (1) calculations and data estimating the use reliability, (2) ease of maintenance features, (3) calculated reliability requirements for all parts and components, (4) reasons for any anticipated failure rates that are lower than those experienced with existing equipments and (5) recommendations for changes to effect simplification, improved reliability, lower weight, less space, lower cost and shorter schedule.

A detailed procedure is set forth for determining inherent equipment reliability. For the design and construction phase, the Group recommends that every effort shall be made to (1) select standard circuits and parts of proved reliability and known failure rate, (2) select parts and materials from military preferred and standard parts lists, (3) prepare and secure approval of suitable procurement information when required failure rates are not suitably described by existing military specifications, (4) adopt optimum construction for accomplishing fault location, rapid repair, future modernization and logistic support, (5) arrange for marginal testing where applicable, (6) design for optimum cooling, (7) suitably provide for expected shock and vibration, (8) protect against moisture, (9) consider the application of parts with regard for tolerance, stability, environment, interaction and end-of-life tolerance degradation, (10) [illegible] the derating of parts, (11) consider printed circuitry, automatic ass[illegible] repetitive mechanical parts, techniques for protecting parts and wiring, and [illegible] provide a complete series of evaluation tests to assure that the equipment will meet operational requirements with the desired reliability and maintainability.

Task Group 9 recommends that, wherever feasible, the required performance indexes be included in the equipment specification and designed into the equipment or system in the simplest manner. Where it is impractical to build in subchecking features, provisions should be made for easily accessible test points, so that these measurements can be easily and quickly made. Further, within the cost limits as defined by contract, disposable modular units requiring no repair should be employed.

The Group also recommends that the equipment contractor consider potential benefits versus additional cost for marginal checking provisions, and wherever it is justifiable, that he provide margins and testing frequency for all areas affected.

Task Group 2 recommends a reliability evaluation for development models consisting of (1) a review of the paper design, reliability prediction, operating conditions for all parts, parts failure rates, parts-qualification test status and design tolerances; (2) a failure-rate test; and (3) a thorough analysis of all failures encountered during test. The failure-rate test is described in detail, and, with minimum mean-life, performance criteria, tolerance limits, test environment and the number of equipments for simultaneous test are to be specified by contract. Rules for data handling are enumerated, and the Group requires that preventive maintenance during test be prohibited except as expressly allowed by contract. The supervision and approval of the reliability effort by an independent evaluation group are recommended.

Task Group 4 recommends that a report be submitted at the close of development, setting forth (1) the procedures used for selection and application of parts, (2) circuit techniques minimizing effects of parts aging, (3) calculations of predicted equipment reliability, (4) consideration given to redundancy, (5) descriptions of the assembly design technique, mechanical structures selected and manufacturing techniques, (6) analysis of evaluation tests made, (7) information on reliability weaknesses, (8) conditions expected to change reliability in operational use and (9) other comments and recommendations by the manufacturers.

Task Group 9 recommends that the equipment developer identify all parts and components obeying a wear-out law, specifying in the equipment manual the time period and procedures for preventive maintenance.

A prediction of Task Group 2 is that, as a result of the design review recommended or of failure during test, some parts may become suspect. These parts should be given special life tests or test to failure to ensure that adequate safety margins exist. Such a scrutiny of additional parts may affect the special-parts procurement specifications suggested by Task Group 4.

For pilot-production and production procurement, Task Group 3 recommends a mandatory test evaluation of minimum reliability index. The contractor follows a detailed procedure, as set forth in its final report. This Group also provides a complete procedure for a longevity evaluation, to be required at the discretion of the contracting agency.

Task Group 9 recommends that a maintainability test be performed prior to release for production, with the implication that the maintainability figure derived and its confidence limits are to be approved by the contracting agency. Details are provided to aid in planning such a test.

The Group also recommends that the "Operation Value" of production equipment be calculated from data determined by previous test and observation in accordance with a formula provided, to be used as an over-all figure of merit of the equipment with respect to field maintenance and logistic support.

This Group recommends that maintenance publications be supplemented with one or more simple, informal and well-illustrated handbooks, covering broad principles of function, maintenance and operational use. Examples and suggestions are given. (Handbooks should also be provided for test equipment that include complete calibration information based on National Bureau of Standards standards. Accuracy and precision of test equipment should be stated in two ways--standard deviation and maximum deviation over one year, measured by scientific methods.)

Task Group 8 recommends the design of simplified standard test equipment that can be (1) calibrated in the field, using available basic standards, and (2) maintained in a state of accuracy that will reduce rejection and acceptance errors as much as possible. It concludes that the design of adequate test equipment has been treated as a secondary requirement considered after--not during--the design and manufacture of the electronic equipments themselves.

With respect to the design of shipping containers, Task Group 7 recommends the maintenance of close working relations between the container designer and the equipment designer, as well as close collaboration with the procuring agency. The Group recommends continued emphasis on improving container design. The specification for the testing of packed electronic equipment that is being prepared by the Bureau of Ships and the Office of the Assistant Secretary of Defense (Supply and Logistics) should be completed and applied to electronic equipment procurement programs as rapidly as possible.

2.2 Component Parts Contractor.

Task Group 5 recommends (1) increased emphasis on the use of improved electronic components and materials and (2) a program for product improvement as a phase of the parts production plan.

3. User

3.1 Maintenance.

To provide a maximum of data necessary for reliability studies, Task Group 8 recommends that test and inspection requirements be reviewed and amended. The Group recommends a review of the apparently widespread philosophy that adequate and valid testing and reporting are not military functions of primary importance, even during peacetime. It is believed that there is a basic lack of understanding on the part of management concerning the need for the specific data required for reliability studies. Accordingly, the Group recommends that reporting procedures be revised to supply these data in a form permitting consistent reduction and analysis. All depots and similar organizations should be required immediately to start keeping a record of all equipments tested on recertification and other testing and inspection programs; details to be recorded are enumerated. Sufficient authority should be vested in quality-control organizations in all branches of the Services and in industry to assure the policing of the foregoing recommendations.

Task Group 9 recommends that the performance standard of each equipment model be used to determine whether the equipment is operating satisfactorily after any maintenance activity and that the performance standards be adequate to permit this function. Operators and maintenance technicians should be trained to recognize and use all information derived from tests against these performance standards.

This Group also recommends that preventive maintenance be limited to items that obey a wear-out law of failure and that such items be referenced in the equipment manual, with the desired maintenance frequency specified.

The Group recommends that test-equipment calibration centers be established at various locations to supplement existing facilities and that they employ standards regularly compared with those available at the National Bureau of Standards.

3.2 Storage.

Task Group 8 recommends that every attempt be made to record the life history of individual units of electronic equipment prior to their placement in storage so that more can be learned about the effect of storage on reliability.

4. Department of Defense

4.1 Directives/Instructions.

Task Group 9 recommends that the Department of Defense expand the maintainability section of Directive 3232.1[2] to require concurrent purchase of all supporting facilities for new production equipment. Supporting facilities include: test equipment and tools, test facilities, spare parts, adequate publications and provision for training material.

[2] "Approval of New Equipment and System for Service Use," 5 July 1956.

The Group recommends that preventive maintenance be redefined in DOD Directive 3232.1[3] as follows:

> Preventive maintenance is a procedure of inspecting, testing and reconditioning a product at regular intervals and according to specific instructions in order to prevent failures in service and to retard deterioration.

Task Group 9 states:

> To reduce the high turn-over rate of technicians in the Service, more effort and emphasis should be given to utilization of Service personnel for routine maintenance, with correspondingly diminished emphasis on contract technicians for this requirement; all possible steps must be taken to enhance the military career by representing to Congress the adverse effects of financial and fringe benefit limitations on the long-term efficiency of the Services.

Because of the long training time for technicians is resulting in an inefficient utilization of manpower, the Group recommends that the Military Departments establish three levels of training, according to detailed suggestions, that they limit the maximum training time to approximately one-third of the remaining enlistment and that the Department of Defense conduct conferences and symposia to stimulate and reappraise military training effectiveness.

Task Group 8 recognizes that considerable field-test and failure data are available, but this information must be laboriously converted to a standard form that lends itself to statistical and engineering analysis before it can be properly processed and analyzed. It is implied that an improved standard format is needed to ease the assessment of such data.

4.2 Special Projects.

Task Group 1 requests that the appendixes to its final report be reviewed to determine whether the underlying assumptions are consistent with the application in question. Special studies are recommended to establish reliability requirements for the major air defense data-handling systems, such as SAGE, Naval Tactical Data System and Missile Master and for missileborne electronic equipment.

The procuring Services are asked to review and comment on Task Group 3's test recommendations, with respect to a trial implementation on several selected contracts and mandatory implementation in all electronic procurement. The Group also asks that a limited group of pilot-production contracts be selected from a variety of procuring Services and contractors and that compliance with the recommended reliability test method for evaluating pilot-production equipment be made mandatory upon them. It further asks that a limited group of production contracts be similarly chosen without regard to whether pilot-production versions of that equipment have been evaluated. In addition, it urges that a portion of the production contracts be subjected to the longevity evaluation procedure. The Department of Defense is asked to review the test elections of the contracting agencies and, periodically, the progress of the contractors.

Task Group 7 recommends that a review of all rules, regulations and tariffs involving blocking and bracing of shipping containers during transit be made, with the objective of improving and enforcing those requirements.

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[3] "Department of Defense Maintenance Engineering Program," 3 December 1956.

Task Group 8 recommends that a program of analyzing the field-test and failure data now on file be initiated at an early date to capitalize on the available information so that sources of defectiveness may be discovered and corrective action taken. It further recommends that a controlled experiment involving storage and test of a statistically significant sample of typical equipments be considered.

Task Group 9 suggests that the Department of Defense establish guide lines for a study to evaluate an absolute average technician. It urges that consideration be given to mobilizing contract technical personnel in their current field assignments, in an appropriate status, immediately upon declaration of a state of emergency.

This Group recommends that present investigations in marginal checking for transistorized equipment be continued and that research of marginal checking as applied to analog devices be extended.

To alleviate the increasing shortage of engineering personnel, Task Group 9 suggests that the Department of Defense should recommend to the appropriate Federal agency and to the National Committee for the Development of Scientists and Engineers that emphasis on subjects such as mathematics, physics and chemistry be increased at the secondary-school level. An investigation should be made into the psychological reasons responsible for the antipathy of the teen-age population toward engineering sciences, and, from this, effective means for countering this feeling should be devised.

4.3 New Standing Committees.

Task Group 8 recommends that a centralized working group be established on a continuing basis within the Department of Defense to coordinate and evaluate reliability data from all sources and to report regularly on the results of these evaluations.

Task Group 9 recommends that the Department of Defense establish a group to monitor the operation of test-equipment calibration centers. The group would ascertain the number of measurements made on specified parameters, develop a program ensuring that all field calibration activities properly maintain high standards of accuracy and precision and specify the assistance required from National Bureau of Standards.

Task Group 1 recommends that, as time and effort for study are available, the numerical mean-life values tabulated be reviewed with respect to modification for test environment, state of the art, compromise with other performance features, cost, maintenance load and availability.

Task Group 5 recommends that the development of parts specifications, the testing of parts for design capability and the development of inspection methods be integrated and coordinated by a group at Department of Defense level. The group should include representatives from industry and the military, and it should include personnel from research and development, standardization, procurement and quality-assurance functions. An adequate supply of manpower and a budget to operate a coordinated system must be provided. This group should review all existing reliability programs and projects for coordination and avoidance of duplication, determination of further work and identification of needed contracts; it should establish procedures and methods for disseminating information gained and establish a basis for an application-notes publication separate from the specifications.

MINIMUM ACCEPTABILITY FIGURES

Task Group 1

7 January 1957

Acknowledgment

In submitting this report, Task Group Number One wishes to single out for mention one of its members who, prior to his untimely death, made particularly notable contributions not only in this specific study but in the entire area of reliability research. The Task Group, with its parent body -- The Advisory Group on Reliability of Electronic Equipment -- owes much to the painstaking and effective research of Dr. Richard R. Carhart. In the broad context of national defense, his work is an example of scientific endeavor at the highest level in purpose and in quality. His colleagues are indebted to "Dick" Carhart for the aid they received as a result of his many previous accomplishments as well as his untiring devotion to the task at hand. They are pleased to acknowledge their debt in this way.

Abstract

Figures are developed and presented on minimum acceptable reliability of various types of military electronic equipment. Insofar as feasible the opinions of staffs cognizant of operational needs were obtained and used as a basis for this development. The principal method of analysis (applied to aircraft weapons systems) was to allocate a maximum allowable probability of failure (in some sense) of a weapons system over various subsystems with regard to importance, complexity and time required.

Preface

In September, 1955, the Advisory Group on Reliability of Electronic Equipment (AGREE), reporting to the Assistant Secretary of Defense (Engineering), adopted a program of nine tasks. Subsequently, task groups of representatives from industry and the three services were appointed by AGREE to undertake these tasks for a period of about six months. Work began in January-February 1956, and the time allowed was subsequently extended to about a year.

The report of Task Group Number One is submitted to AGREE herewith. The assigned task (quoted in full in the Introduction) was to develop minimum acceptability figures. In prosecuting this task, the group held ten meetings, one or two days each, and made numerous visits in small groups to various commands in the field and in Washington.

Task Group Number One wishes to acknowledge the splendid cooperation received from the various commands visited during the course of this study. No direct attribution is made to these sources, and the recommendations presented here do not purport to be official positions of the services. However, it may be said that these recommendations have a good basis in unofficial expressions of operational needs.

There was very little precedent available to Task Group Number One by way of specific quantitative requirements for electronic system reliability. This is in spite of the fact that the need for the practice of reliability specification has been felt for some time.

The specific results and methods presented here are intended to be used as guidelines in the formulation of operational requirements and military characteristics and in subsequent procurement decisions. Suitably adapted, they may be directly applicable to many cases. In general, these figures should be considered as first approximations to more durable reliability standards which, it is hoped, will be evolved as a result of the actual practice of specification of reliability by the armed services.

TABLE OF CONTENTS

APPENDICES

*Appendices D and E contain classified information and are published separately in a supplement to this report.

1 INTRODUCTION

1.1 Task Assignment

Task Number One assigned by AGREE is as follows:

> "Develop minimum acceptability figures for reliability of the various types of military electronic equipment. These figures possibly may be expressed as 'time between failures' or some other truly quantitative measurement. The basis upon which the figures are determined shall include the factors of operational mission requirements, maintenance, complexity, and such other factors as may be significant."

Task Group Number One has completed its investigation into this task and submits its report herewith. The results are presented in Section 4. The general approach and various qualifications are discussed in the body of the report with further details in the appendices.

1.2 Importance of Specifying Reliability

The problem of achieving and maintaining adequate reliability in military electronic equipment is important, complex, and difficult. The solution to the problem is inextricably bound up with the healthy development of future electronics.

Significant in the AGREE program of nine tasks are (a) the quantitative approach to the problem, and (b) the recognition that reliability must be bought as are other aspects of quality. The present ominous reliability situation arises in part from the lack of quantitative specification of equipment reliability prior to development. Such specifications are fundamental to quantitative treatment of the problem--a specification is usually considered as a detailed description of a product and its performance and of the criteria which must be used to determine whether the product is in conformity with the description.

In the past, a manufacturer engaged in the design of a new system has been confronted with the necessity of meeting certain performance requirements. Theoretically, he has been equally responsible for assuring a high level of reliability in the new system. However, in contrast, the performance requirements have been embodied in specifications in quantitative terms, and the manufacturer had a <u>legal</u> obligation to meet them. Consequently, reliability has generally been treated as an afterthought, i.e., after a design has attained other performance requirements which are rigidly specified, reliability is then considered. Experience has shown that this is too late -- the design of an electronic equipment creates an irreducible failure rate which cannot be debugged from the finished machine.

Reliability requirements should originate with the groups responsible for the operational requirements and military characteristics of the various services, since it is through these groups that the services must determine how they intend to accomplish their mission. In turn, these figures should be translated into contracts let for the new developments. This should be done in a way which effectively motivates designers and provides a reasonably clear basis for subsequent decisions.

Hand in hand with the practice of specifying reliability, there is an additional definite need for parallel progress in the testing and prediction areas. These and related problems are being pursued by the other AGREE Task Groups.

2 DEFINITIONS

2.1 General Definitions

The following definitions are taken from general reliability theory:

(a) <u>Failure</u>: the inability of an equipment to perform its required function.

(b) <u>Reliability</u>: the probability of no failure throughout a prescribed operating period.

(c) <u>Mean life</u>: the arithemetical mean (average) of the operating time between failures.

(d) Up-time: the calendar time in which the system is considered in condition to perform its required function.

(e) Down-time: the calendar time in which the system is not considered in condition to perform its required function.

(f) Repair effort: the number of man-hours actually spent on repairing a failure.

2.2 Minimum Acceptable Reliability

There are at least three possible meanings of the words "minimum acceptability" which appear in the statement of Task No. 1: (a) that value which the operational commander will tolerate and below which he would take some drastic action to initiate improvements; (b) that value which agrees with the current reliability values observed for each class of equipment; and (c) that value which the current state-of-the-art and current knowledge could achieve.

All three of these possible meanings are quite general and rather vague, and all three suffer from the fact that present values and present state-of-the-art are, by and large, unknown quantities. At present, the only basis for determining these values is by rough estimates or guesses. Nevertheless, in order to accomplish the Task Group mission, it is necessary that some definite conclusions be reached in regard to the meaning of the words "minimum acceptability." The Task Group has adopted the first definition as being closest to the intent of AGREE.

2.3 Index of Reliability

Field measurements of military and commercial electronic systems have demonstrated that in general the rate of system failure is fairly constant throughout the life of the system. Therefore, the probability of non-failure over an operating-time interval decreases exponentially as a function of the length of the interval, i.e.,

$$R(t) = e^{-t/m},$$

where R(t) is the reliability (probability of no failures in operating time t hours) and m is the mean life or mean time between system failures. Additional discussion of this particular formulation is given in Appendix A.

If the reliability of electronic systems can be expressed as a simple exponential function of time, the reliability of two systems then can be compared according to their mean lives, since the mean life is the only parameter in the reliability functions. In this report, reliability will be characterized by mean life. By specifying a mean life, it is possible to develop various types of tests to assure the minimum acceptable reliability under operational usage. Under the exponential assumption, any reliability statement for an electronic system can be converted into an equivalent statement about the mean life and vice versa.

2.4 Operational Readiness

If "operational readiness" is defined as the probability that a system will perform satisfactorily at any point in calendar time, then the percentage of "up-time" is synonymous with operational readiness. For electronic systems where (a) the critical operating-time periods are of indefinite length, (b) repair is available immediately after failure and, in many cases, (c) redundancy of systems exist, a specified probability of a given number of hours of fault-free operation is not adequate for complete specification in regard to the operational needs. Although a system may fail frequently, if it can be restored to satisfactory operating condition in a short time, this system can be of tremendous value under certain operational requirements. Therefore, the readiness of the system, i.e., the percentage of up-time, is a critical factor to consider in such cases. It is clear that this operational readiness depends upon both the reliability of the system and the speed with which it can be restored after failure.

2.5 Importance Factor

It is not easy even for experienced personnel to specify a minimum acceptable reliability for a particular electronic equipment. Reliability generally is meaningful only from the standpoint of mission success. Many operational people are cognizant only of the mission success, which entails the reliability of not only the electronic system of interest but also of a combat unit, weapons system, or organizational unit. In order to determine the reliability required for the electronic system, one may determine the reliability required for the combat unit and then determine an importance factor for the electronic system of interest. The importance factor of an equipment is the relative importance of the particular electronic system to the total mission effectiveness. This is defined in this report as the ratio of the number of mission failures due to the equipment failing to the total number of failures of the equipment (see Appendix B).

2.6 Modules

A concept of module is used in this report for three purposes: (a) so that the relative complexity inherently required can be taken into account; (b) so that the minimum acceptable reliability figures will not be grossly inconsistent among the services; and (c) so that reliability requirements will be dynamic, and state-of-art changes can be incorporated as they occur.

This module concept will be the basic electronic building block. A "module" will be a group of electronic parts. This is a fictitious way of partitioning an electronic system for reliability purposes. For systems involving electron tubes, it has been found that for one tube there are approximately fifteen additional electronic parts--this we consider to be a module. Thus, the number of modules for an equipment is defined as the number of electron tubes. Account of solid state electronic components is taken in Appendix B.

3 APPROACH

3.1 Selectivity in Scope

It was desired to cover the areas where reliability is an acute problem in a fairly comprehensive manner and still be quite specific. The scope of Task Number One is unfortunately large, both from the standpoint of the number of equipments involved and for the complexity of the analysis required for a thorough study. Therefore, it was necessary to adopt short-cut methods. Typical weapons-systems, combat units or organizations were selected; and, wherever possible, equipments were categorized into functional packages, and duplications eliminated.

Missile-borne electronics were excluded by Chairman, AGREE. In the course of the task, the major air defense data-handling systems in the three services (SAGE, Naval Tactical Data System and MISSILE-MASTER) were excluded because of their complex system relationships. Needless to say, these areas are of prime importance and are recommended for separate study. Noncombatant equipments and security-sensitive equipments were also excluded.

3.2 Equipments

The equipments selected are listed in Appendices C, D, and E. These have been generalized into classes of equipments which are planned for use about 1960. These generalized equipments are classified into specific classes or types similar to those now in use: bombing-navigation, AI radars, communication sets, etc., for Army, Navy and Air Force use. They were selected according to the following criteria: (1) importance of the mission; (2) the importance of the equipment failure to the mission; (3) the importance of equipment failure to safety; (4) the length of the required operating time, (5) severity of environments; and (6) complexity of the equipments. In other words, the selection was made on the basis of the relative importance of the reliability problem.

3.3 Sources and Types of Information

To put the results on as realistic a basis as possible, considerable effort was put into contacting various staffs cognizant of operational needs. Operational commanders and other experienced personnel who were familiar with current and future tactical usage of electronic equipment were contacted. Operating personnel in general can estimate the minimum acceptable probability of success of a mission more readily than the minimum acceptable reliability for a particular electronic equipment. This mission is generally expressed in terms of an objective of a combat unit, a weapons system, or some other organizational unit. These units have a more or less clearly defined mission and length of mission time.

In the case of airborne equipments, the operational people were requested to estimate the minimum operational reliability figure for a weapons system, and also to determine the importance factors of the various electronic equipments in the system. With this information available, it is a simple matter to compute the reliability figures for the various electronic equipment. The actual method used for allocation of a system reliability to subsystems reliabilities is given in Appendix B.

In the case of surveillance equipment (shipborne and ground), the mission lengths are not well defined, and maintenance can be started immediately, so the operational commander therefore is primarily concerned with the percentage of down-time over an extended period of operation. The percentage of down-time is a function of the reliability and the maintenance time required for the system. Therefore, in a number of cases, the approach in taking the problem to the operational staff was to obtain an estimate of the percentage of down-time allowed and the length of down-time required for an average maintenance. With these two figures and the use of simple probability theory, the minimum acceptable reliability of the equipment can be determined and in each case the equipment reliability was converted to an equipment mean-time-failure. The methods of analysis used for this purpose are given in Appendices C and D.

With due regard to the above problems, questionnaires were prepared and mailed to various operational groups, in advance of the personal interviews. The purpose of the questionnaire was to supply the interviewee with background information and the questions for which answers were desired. It was hoped that the answers to the questionnaire could be formulated prior to the interview. However, the Task Group, realizing the difficulty of transmitting information by letter on such a subject as reliability where there are few common concepts, used the interview to assure that (a) those interviewee understood the problem of Task Group No. 1, and that (b) language was not a barrier to obtaining the results. The interviews were used to effect a mutual understanding of the problems of each service as well.

4 RESULTS

The minimum acceptability figures which have been developed in this investigation are presented in tables I - IV. This section is devoted to explanation of these tables, discussion of their accuracy and adaptations which should be made in their application.

4.1 Explanation of Tables I-IV

Figures for minimum acceptable mean life are given in the tables for the various equipments listed. The general approach to the development of these figures has been discussed in the preceding sections, and further details are presented in the appendices.

In the case of shipborne equipments, figures are also given for minimum acceptable percentage up-time. For the most part, these are the figures which were developed directly in this phase, since this figure of merit reflects operational needs more appropriately than mean life. The conversion to mean life figures was by means of the assumed value of average down-time per failure (obtained from VITRO data). The mean life figures should be more susceptible to test than the percentage up-time figures and, moreover, it is important that they be met (aside from the percentage up-time attained) so that maintenance facilities do not become saturated (see D 4.6 in Appendix D). It is intended that, if feasible, both the percentage up-time and mean life figures be demonstrated in acceptance testing of shipborne equipment.

It will be noted that for convenience of generalization the equipments are listed here and elsewhere in the report according to their functions, rather than according to the specific designations which were used during the course of the investigation.

In the case of airborne equipments which are duplicated in the configurations considered, the figures represent the mean life which should be demonstrated by a single equipment under the assumption that there are two on board, either of which suffices.

In the aircraft tables, there are several blank spaces where the equipments were either not on board or no figures have been developed. The omitted equipments are presumed to have their requirements determined by factors other than those which were analyzed directly for the aircraft in question (e.g., mission success, safety, aircraft defense). Some very useful equipments such as TACAN and autopilots are frequent examples of this. Their loss may represent inconvenience or discomfort which may or may not have an effect on mission success or safety--this is hard to incorporate into the analysis. Radio requirements in some cases are governed by training needs, which were not considered here.

4.2 Accuracy of the Results

It should be borne carefully in mind that the basic numbers from which these results have been derived are matters of opinion, and widely different opinions have been offered in some cases. There is very little, if any, precedent for most of this information. By the same token, it can be very valuable as a starting point, but it should be remembered that these results constitute no more than just that. They are not represented as being highly accurate nor do they purport to be official expressions of the services. However, it may be said that they have a good basis in unofficial expression of operational needs. The methodology itself should be very useful.

In Section 5 we shall discuss further qualifications and modifications that would be needed even if the present results were highly accurate in terms of the adopted definitions.

A further qualification should be cited in that it has been necessary to generalize considerably from special cases, e.g. special combat situations.

It would be most desirable that the services conduct future system studies to determine the values of the basic inputs to the analysis more accurately than has been possible in this investigation. Importance factors particularly should be susceptible to analysis.

4.3 Adaptations in Application of the results

In applying these minimum acceptability figures in the formulation of reliability requirements, one should first examine various assumptions which underly their development. It is possible that assumed conditions will fit the problem at hand fairly closely, or at least in all but a few respects. Insofar as any differences in conditions are measurable, it should not be hard to modify the numbers accordingly.

This is particularly true for the airborne equipments. Here the formula used to compute minimum acceptable mean life is essentially a proportionality formula so that the effect of changes in inputs can be computed rather simply. For example, if one considers that the minimum acceptable probability of mission success should be .80 instead of an assumed value of .90, this has the effect of halving the mean life requirements across the board for all equipments governed by mission success, i.e., one multiplies each mean life by

$$\frac{\log_e .9}{\log_e .8} \approx \frac{1 - .9}{1 - .8} = 1/2 .$$

If one considers that the importance factor of a given equipment should be doubled, then its mean life requirement is doubled. The same holds for operating time. Changes in module count required can be handled similarly.

As discussed at the end of Appendix B, it would be desirable, when allocating the requirements for a particular aircraft weapons system over its equipments, to use some basis other than module count to account for inherent relative difficulty of attainment.

4.4 Comparison between Air Force and Navy Air

The problems involved in the Air Force and Navy air phases of this investigation had much in common and the methods used were generally similar. However, in comparing these two appendices, important contrasts are apparent. As a general explanation for these differences, it is remarked that there are real differences between the problems of these two services and in addition these separate phases were studied independently.

The most striking difference is that the assumed values of minimum acceptable probability of mission success are higher for the Air Force aircraft than for the Navy aircraft. The best explanation for this difference is that these respective phases of the investigation were conducted independently. This particular parameter is more a matter of opinion than are any other numbers in the report. Independent opinions can vary widely and beyond this it appears that the Navy figures were developed amid thinking which regarded the meaning of minimum acceptability in a more severe light than was the case with the Air Force, i.e., the Navy figures seem to reflect the absolute minimum acceptability and any value lower than those stated would result in immediate drastic action to improve reliability. The difference was not derived from any feeling on the part of the Task Group as to the relative importance of aircraft types in the two services.

TABLE I

Summary of Recommended Minimum Acceptability Figures for Army Equipment

	Mean Life in Hours
Tactical Vehicular Comm. Set	160
Mobile Long Range Comm. Set	480
Radio Relay Comm. Set	2800
Mortar Locating Radar Sets	480
SAM Control Battery	46

TABLE II

Summary of Recommended Minimum Acceptability Figures for Shipborne Equipment

Communications Equipments (Assumes 6 Hrs. Down per Failure)

Transmitters	% Up-time	Mean Life in Hrs.*
HF	96.5%	165
MF/HF CW Hi Power	96.5%	165
UHF Auto Shift	98.8%	494
UHF Manual Shift	96.5%	165
VHF	97.5%	234
Receivers		
LF/MF/HF	97.5%	234
UHF Auto Shift	98.8%	494
UHF Manual Shift	96.5%	165
VHF	97.5%	234
Terminal		
Teletype/Facs.	97.5%	234

NOTE: *These figures are known to be generally below what is now being attained (see D-4.6 in Appendix D in the classified supplement). Therefore, section 5.2 is particularly applicable.

TABLE II (Cont.)

Equipments Other Than Communication (Assumes 12 Hrs. Down per failure)

Air Detection and Control	% Up-Time	Mean Life in Hrs.
Air Search Radar	95.5%	254
Height-Finder (Incl. Displ.)	94%	188
AEW Terminal	91%	120
Interrogator-Responsor	94.5%	212
ECM Intercept	95.5%	248
Standard Radar Display	94.5%	212
Off-Center Sweep Display	96%	
Carrier-Controlled Approach		
Final Approach CCA Radar	91%	120
Landing Speed Ind. Radar	85%	68
Navigation (Ship and Aircraft)		
TACAN Transmitter	94%	188
X-Band Beacon	91%	121
UHF RDF	94%	188
MF/HF RDF	91%	121
Surface Search Radar	98.8%	870
Loran Rcvr.	90%	108
Ship Identification		
Transponder	92.5%	145
Sonar		
Detection	98%	588
Tracking	95%	228
Sub Identification	94%	188
SAM Control (CLG)		
2 Target Capability	70%	
1 Target Capability	98.8%	
Tracking Radar	90%	108
Guidance Radar	95.5%	248
Computer	97.7%	88*

*Assumes 3 hours down per failure.

TABLE III

Summary of Recommended Minimum Acceptability Figures for Naval Airborne Equipment

	Mean Life in Hours for Weapon Systems Studied*	
	Lowest	Highest
Communications		
UHF Rcvr.	55**	118**
UHF Xmtr.	75**	180
MHF Tr.-Rec.	113	113
Intercom	165	2900
Data Link	17	17
Navigation		
TACAN	13	59
Compass	205	2060
Astral Compass	61	61
Flight Control		
Power Generator	316**	1250**
Autopilot	256	325
Flight Horizon	100**	2200
Radar Altimeter	500	500
Data Handling		
Air Data Unit	585	585
Interceptor Computer	11	11
Fire Control Computer	37	37
Bomb/Nav. Computer	16	16
Detection and Tracking		
Primary Radar	40	90
IR Detection	330	330
Interrogator (IFF)	133	133
Closed TV	195	195
Bomb/Nav (Radar & Computer)	25.5	25.5

*Where the same figure shows in both columns, it means that the equipment was studied in connection with only one of the Weapon Systems.

** Assumes 2 installed, each capable of carrying the entire load.

TABLE IV

Summary of Recommended Minimum Acceptability Figures for Air Force Equipment

Communications	Mean Life in Hours for Weapon Systems Studied* Lowest	Highest
UHF (Tr.-Rec.)	60	79
HF (Tr.-Rec.)	76	90
Intercom	37	640
Data Link	43	46
Navigation		
Compass (Flux Gate)	270	362
AGPI	46	145
Rendezvous Beacon	320	470
Flight Control		
Autopilot	10	76
Flight Horizon	160**	680
Fire Control		
Ranging Radar	54	54
Bomb/Nav. System	88	88
Missile Fire Control	23	23
Sight	325	325
Air Data Computer	66	66
Bombing Computer	108	108
Radar Control Rcvr. Beacon	144	144
Identification		
IFF	83	83
Aircraft Defense		
Tail Turret Control	18	18
ECM Unit (Rcvr & Jammer)	216	216

*Where the same figure shows in both columns it means that the equipment was studied in connection with only one of the Weapon Systems.

** Assumes 2 installed, each capable of carrying the entire load.

5. ADDITIONAL CONSIDERATIONS IN SPECIFYING EQUIPMENT RELIABILITY

There are important considerations in developing reliability requirements which are beyond the scope of this task. These are discussed in this section.

5.1 Environment

All considerations in this report refer to operational conditions. Therefore, if the minimum acceptability figures presented here are used as bases for acceptance testing, they should first be adjusted to allow for the change from the test environment in question to the operational environment in question.

5.2 State-of-the-Art

The next stage in determining contractual reliability requirements is to examine existing reliability and the future state-of-the-art to determine how much reliability is reasonably within reach from the technological standpoint. This consideration has entered into this report only in a gross fashion. It should result in design goals that are substantially higher than the minimums presented here. It will remain further to determine reliabilities which are optimum, in some sense, in view of the various compromises which should be struck as discussed in the remainder of this section.

5.3 Other Performance Features

In many situations, unreliability is incurred by stretching the state-of-the-art in some other aspect of performance. All performance features (including reliability) of a weapons system should be balanced in a way which maximizes over-all probability of success. An excellent example of this is the approach taken by R. P. Mettler* who considered the trade-off between accuracy of a bombing-navigation system (high accuracy required high complexity) and reliability. Optimum reliability

*R. P. Mettler, Bombing and Navigation Systems for Manned Strategic Aircraft, RDB ?571, February 1955.

was determined for an operational requirement in a way which maximized over-all probability of target destruction considered as a product of component probabilities, one of which was reliability.

Weight and size should be considered in this light also, since additional reliability can always be bought with redundancy.

5.4 Cost

Cost is so interwoven with reliability that it has been difficult for the task group to avoid cost considerations in developing minimum acceptable reliability figures. As a side issue, in order to throw some light on the problem of cost of reliability another type of optimum reliability was investigated. This optimum reliability is that reliability which minimizes total cost, considered as the sum of development cost and operational cost. Appendix F by R. R. Carhart and G. R. Herd develops a method of determining the optimum reliability based upon a simple cost model.

5.5 Maintenance Load

In some cases the determining factor for establishing minimum reliability requirements may be the saturation of maintenance facilities. This consideration has been brought to bear in this report in the shipborne phase only, but it should receive some study in the other cases also, especially in cases of equipments which are very numerous within the same type.

5.6 Availability

Of the various penalties that must be paid to improve reliability, delays in availability will probably present the most difficult decisions. The problem is pointed up by differing comments offered by two flag officers during the Naval phase of the inquiry. One considered that the most pressing problem was long lead time and urged that availability, in general, not be held up by ultra-refinement during development. The other considered that we should, in general, keep equipments in development until extremely high reliability standards have been met.

The responses in our inquiry tended to place highest reliability requirements on the equipments with highest military value. For the same priority equipments, great pressure is often present for rapid improvement in other performance features. These requirements tend to be in sharp conflict. In some cases, the wisest decision might be to accept the operational introduction of a new equipment whose reliability is less than the minimum acceptable figure presented, here, in exchange for a vitally needed early stride forward in some other performance feature. For example, a certain high priority radar function might call for a minimum acceptable reliability of 95 per cent. Suppose the existing equipment performing this function is hopelessly obsolete in terms of range. One might well accept the early introduction of a radar relieving the range shortcoming, even though its reliability is only 70 per cent, on the ground that is better than the alternative which is a useless, although presumably reliable, radar. It is recommended that a service which chooses to make such an exception should make this determination before the acceptance testing.

The reason this anomaly may arise is that the inquiry leading to the figures presented here was concerned with steady-state reliability requirements imposed by various functions in the foreseeable future, without regard for the need for improving performance features of equipments presently performing these functions. As a general rule, it should be required that the introduction of a new equipment provides a substantial stride forward in one or more performance features.

Occasions may arise wherein a new piece of equipment is brought forward which performs a function hitherto not performed by any other equipment. The fact that the reliability of such an equipment is well below generally accepted standards should not necessarily preclude its introduction for service use. Once again, the decision as to whether or not the equipment is acceptable will have to be made on an individual basis. This decision will be reached by weighing such factors as urgency of need of such an equipment to fill the operational function and reliability of the piece of equipment under consideration.

5.7 General Remarks

Many problems in specification of equipment reliability beyond the scope of this task thus remain to be studied. This is not to say that the minimum acceptability figures presented here are not immediately useful. For one thing, modifications of these figures might be made by considered opinions along the lines of the preceding paragraphs.

Even unmodified, these approximate minimum standards should be far better than none at all, which is what designers generally have for reliability guidance at present. The quickest way to arrive at durable reliability standards is to commence the practice of specifying reliability with the best figures readily available. It is in this spirit of first approximation that the use of this report is recommended.

6 RECOMMENDATIONS

As a result of the investigation reported here, Task Group Number One recommends that:

(a) The minimum acceptable reliability figures presented in Tables I-IV be adopted by AGREE on a first-approximation basis.

(b) Before application of these figures in particular instances, the appendices to this report be reviewed to determine whether the underlying assumptions are consistent with the application in question.

(c) As time and effort for additional study become available, these figures be modified with regard to test environment, state-of-the-art, compromise with other performance features, cost, maintenance load and availability.

(d) Rather than make no specifications in view of the long delays that these additional studies may require, such modifications be made by considered opinions.

(e) Special studies be made to establish reliability requirements for the major air defense data-handling systems such as SAGE, Naval Tactical Data System, and MISSILE-MASTER, and for missile-borne electronics equipment.

APPENDIX A

The Reliability Function, $R(t) = e^{-t/m}$

In this appendix a derivation is given for the exponential reliability formula. Values are tabulated in table A 1.

Suppose that a large number of electronic equipments of a given type were employed simultaneously in a single installation. It is well known that, if no repairs are made, the quantity of equipment working satisfactorily will decrease with time. Suppose the deterioration of the quantity is inversely proportional to the quantity of equipments, that is

(1) $\frac{dQ}{dt} = -kQ$

where k is the velocity constant of this deterioration. Then by separation of variables this differential equation is

(2) $\frac{dQ}{Q} = -k\,dt.$

Upon integration

(3) $\log Q = -kt + A$

where A includes the constants of integration. Then,

(4) $Q = Q_o\, e^{-kt}$

where Q_o includes the constants of integration e^A.

An interpretation of equation 4 is that Q is the quantity surviving after time t where Q_o is the quantity starting at time $t = 0$.

Dividing both sides of (4) by Q_o the fraction surviving or the probability of survival is obtained:

(5) $R(t) = \frac{Q}{Q_o} = e^{-kt}$

The reliability function (5) is a function of time with one parameter, k, the velocity constant of deterioration. It can be shown that the velocity constant is the reciprocal of the mean-time-to-failure.

This may be shown by determining the centroid of the probability distribution of the length of life since, by definition, this centroid is the mean life. The reliability function is the probability that any life time, x, is greater than some time t which may be written as

(6) $P(x > t) = \int_t^{\infty} f(x)dx = R(t)$

where f(x) is the frequency distribution of life times. Since

$$\frac{dR(t)}{dt} = \frac{d}{dt}\int_t^{\infty} f(x)dx = -f(t)$$

then

(7) $f(t) = -\frac{dR(t)}{dt}$

and from (5)

(8) $f(t) = ke^{-kt}$.

The centroid or expected life (mean-time-to-failure) is

$$m = \int_0^{\infty} t(f(t)dt = \int_0^{\infty} kte^{-kt}dt = \frac{1}{k}$$

and $k = \frac{1}{m}$.

Therefore (5) may be written as

(9) $R(t) = e^{-t/m}$.

TABLE A1

Table of Values for the Exponential Reliability Formula
Mean Life in Hours

Required Level of Reliability	Critical Time Period in Hours															
	1	2	3	4	5	6	7	8	9	10	15	20	25	30	40	50
.995	200	400	600	800	1000	1200	1400	1600	1800	2000	3000	4000	5000	6000	8000	10000
.99	100	200	300	400	500	600	700	800	900	1000	1500	2000	2500	3000	4000	5000
.98	50	100	150	200	250	300	350	400	450	500	750	1000	1250	1500	2000	2500
.97	33	66	99	132	165	198	231	264	297	330	495	660	825	990	1320	1650
.96	25	50	75	100	125	150	175	200	225	250	375	500	625	750	1000	1250
.95	20	40	60	80	100	120	140	160	180	200	300	400	500	600	800	1000
.94	16.7	33.4	50.1	66.8	83.5	100.2	116.9	133.6	150.3	167	250.5	334	417.5	501	668	835
.93	14	28	42	56	70	84	98	112	126	140	210	280	350	420	560	700
.92	12	24	36	48	60	72	84	96	108	120	180	240	300	360	480	600
91	10.5	21	31.5	42	52.5	63	73.5	84	94.5	105	157.5	210	262.5	315	420	525
.90	9.5	19	28.5	38	47.5	57	66.5	76	85.5	95	142.5	190	237.5	285	380	475
.85	6.7	13.4	20.1	26.8	33.5	40.2	46.9	53.6	60.3	67	100.5	134	167.5	201	268	335
.80	4.5	9.0	13.5	18	22.5	27	31.5	36	40.5	45	67.5	90	112.5	135	180	225
.75	3.5	7.0	10.5	14	17.5	21	24.5	28	31.5	35	52.5	70	87.5	105	140	175
.70	2.8	5.6	8.4	11.2	14	16.8	19.6	22.4	25.2	28	42	56	70	84	112	140
.65	2.3	4.6	6.9	9.2	11.5	13.8	16.1	18.4	20.7	23	34.5	46	57.5	69	92	115
.60	1.96	3.9	5.9	7.0	9.8	11.8	13.7	15.6	17.7	19.6	29.4	39.2	49.0	58.8	78.4	98
.55	1.67	3.3	5.	6.7	8.3	10.	11.7	13.4	15	16.7	24.9	33.4	41.7	50.1	66.8	83.5
.50	1.43	2.9	4.3	5.7	7.2	8.6	10	11.4	12.9	14.3	21.6	28.6	35.8	42.9	57.2	71.5

APPENDIX B

Allocation of System Failure Rates

B 1 Introduction

In this appendix we consider the problem of translating system reliability requirements into requirements imposed on subsystems. Specifically, the method developed is, in effect, an allocation of a system failure rate as a sum of failure rates of the subsystems. Later we shall apply this method to aircraft weapons systems, and therefore we proceed here in this airborne context. Actually the method applies generally to any system which can be decomposed (approximately) as a series of independent subsystems. The mission success consideration may be replaced, for example, by safety of flight or survival of enemy action.

B 2 Derivation of the Allocation Formula

Consider an aircraft with k equipments assumed to be independent and in series in their effect on mission success. Each equipment is assumed to consist of independent standard modules, one for each tube. (Allowance for duplications and solid-state substitutes for tubes will be discussed later.) Let

P = probability that the aircraft mission will not fail due to electronic failure,

and, for $i=1,\ldots,k$, let

m_i = mean life of the i^{th} equipment,

t_i = time from take-off until the i^{th} equipment is no longer needed,

w_i = probability that, given the i^{th} equipment fails, the mission will fail

$= \frac{\#\text{ mission failures due to } i^{th}\text{ equipment failure}}{\#\ i^{th}\text{ equipment failures}}$ = importance factor,

n_i = number of modules (i.e., tubes) in the i^{th} equipment,

$$N = \sum_{i=1}^{k} n_i .$$

Using these definitions, the allocation formula used in later appendices on airborne systems is as follows:

$$m_i = \frac{N\, w_i t_i}{n_i(-\log_e P)}, \text{ for } i=1,\ldots, k.$$

Here we consider the values of m_i and P to be minimum acceptable. We shall presently derive this formula under the assumed requirement that each module make an equal contribution to mission success, and later we discuss some adaptations to be made in its application. First let us examine the formula intuitively.

Note that the required mean life m_i increases with importance w_i and time t_i and decreases with relative module count n_i/N. This is clearly as it should be. That the relation should be proportionality is obvious as regards t_i, possibly not as obvious as regards w_i and n_i/N. Finally note that

$$-\log_e P \approx 1 - P,$$

so that by reciprocating the formula, it is seen that the allowed failure rate $1/m_i$ is allocated as a portion of the system failure rate. This much has intuitive appeal. It may be argued that additional factors should enter into the allocation, but those treated above are considered to be sufficiently governing for the present purposes.

To derive the formula we note first that (assuming exponential failure behavior)

$$P = \prod_{i=1}^{k} (1 - w_i(1 - \exp(-\frac{t_i}{m_i}))).$$

By using the approximation $\exp(x) \approx 1+x$ this can be simplified to

$$P \approx \exp(-\sum_{i=1}^{k} \frac{w_i t_i}{m_i}).$$

Here the approximation has been applied twice in opposite directions so that errors cancel in part. The accuracy limits of the approximation are discussed in the next section.

The requirements are carried to the module level by setting $m_i = n_i T_i$ for $i=1,\ldots,k$, so that T_i is the mean life of each module in the i^{th} equipment. We now regard the above expression for P as a product of N factors which we require to be equal, i.e.,

$$\exp(-\frac{w_i t_i}{T_i}) = P^{1/N}.$$

Thus the specific basis of allocation used is to require that each module make an equal contribution to mission success. It follows from this equation that

$$m_i = \frac{T_i}{n_i} = \frac{w_i t_i N}{n_i(-\log_e P)} ,$$

and the allocation formula is thereby derived.

The following fictitious example illustrates the application of the formula:

$$P = .9 \text{ (min. acc.)}, \quad -\log_e P = .1$$

	n	w	t	$m = 12000 \frac{w}{n}$ (min. acc.)
RCVR	20	.7	4 hrs.	420 hrs.
XMTR	30	.5	4 hrs.	200 hrs.
RADAR	200	.8	4 hrs.	48 hrs.
IFF	50	.2	4 hrs.	48 hrs.
	$300 = \sum n$			

B 3 Exceptions for Equipments of Low Importance

In equipments of low importance it may not be possible for each module to contribute to mission success equally with more important modules. This is especially true if an unimportant equipment is also complex. Including such equipments would distort the allocation. The condition to be met to avoid this is precisely:

$$w_i > 1- P^{n_i/N} \quad \text{for } i=1,\ldots, k.$$

Any equipment for which this inequality fails should be eliminated from the allocation and the module count, and should have its mean life requirement determined in some other way.

If an equipment barely meets the above inequality, it is probably better to use the allocation formula derived without the approximations used in the preceding section, viz.:

$$m_i = \frac{-t_i}{\log(1- \frac{1}{w_i}(1-P^{n_i/N}))}$$

By series expansions it may be shown that the error in $1/m_i$ incurred by using the simpler allocation formula as opposed to the exact formula is of the order of

$$\frac{1}{2t_i} \frac{n_i^2}{N_i^2} \left(\frac{1}{w_i} - 1\right)(1-P)^2 .$$

In safety of flight problems, this will be small because $1-P$ is very small. In mission success problems, it will usually be small because $n_i/(w_i N) \quad 1$.

B 4 Allowance for Solid-State Electronics

It is necessary to take account of the fact that in many present equipments functions formerly performed by vacuum tubes are now done by solid-state devices. For this purpose the following equivalences have been adopted in making up a module count:

1 transistor = 1 module

1 diode = $\frac{1}{2}$ module

1 magnetic amplifier = 1 module

This is not intended to mean that the failure rates themselves are related in this fashion. Rather it means roughly that, for example, a transistor and its associated parts perform a function equivalent to one performed by a vacuum tube and its associated parts.

In a few instances digital computers are encountered with rather high module counts. Reductions in module count are made to allow for the fact that failure rates per part in digital computers have been found to be far less than for radio-radar types.

B 5 Allowance for Duplication

In case an equipment is duplicated in parallel, it is necessary to treat the combination as a single equipment which is then allocated a mean life as such. The applicable importance factor pertains to denial of both members of the combination. There are two problems:

(a) What module count is used for the combination?

(b) How is the mean life r of each member determined from the mean life m allotted the combination?

The second is easy. We have

$$\exp(-\frac{t}{m}) = 1 - (1- \exp(- \frac{t}{r}))^2$$

$$\approx 1 - (- \frac{t}{r})^2 \quad \exp(- \frac{t^2}{r^2}),$$

which can be shown by series expansion to have an error of the order of $\frac{t^3}{r^3}(1- \frac{t}{r})$. This error is generally quite small. Thus

$r = \sqrt{mt}$, for 2 equipments in parallel

$r = \sqrt[3]{mt^2}$, for 3 equipments in parallel

The solution to problem (a) above is not as clear. Obviously the module count used as index of complexity of the parallel combination should be less than that of a single member. If the two members were in series, we would consider the combination to be precisely twice as complex as one member. Considering parallel connection to be dual to series connection, we therefore use half the tube count of a single member as the tube count for the parallel combination.

Two difference equipments with module counts $n_1 \neq n_2$ performing essentially parallel functions should be treated as a combination with tube count $1/4(n_1 n_2)$.

The formula above should then be replaced with

$$r_1 = \frac{1}{n_1} \sqrt{mtn_1 n_2}$$

$$r_2 = \frac{1}{n_2} \sqrt{mtn_1 n_2} .$$

B 6 Recommended Further Study of Allocation

The module-count method of accounting for relative difficulty of attainment leaves much to be desired. Progress here should follow progress in prediction. Adaptability to derating, air conditioning, relaxed tolerances, etc., should all be considered. The objective is to make proper allowance for relative difficulty of attainment inherent in the function of the equipments, which may be quite difference from relative reliability exhibited by past designs.

The module-count method may be unfair in that it discriminates against manufacturers developing a successor equipment to one which has already had its tube count reduced as compared to other equipments performing the same functions. For this reason it would not be wise to make a permanent practice of using module counts in the way they are used here.

APPENDIX C

Details of the Army Phase

C 1 Selection of Equipments

For the Army phase of the survey the types of equipment were selected for their intrinsic importance to Army operations. The types of generalised equipments selected were:

(a) Tactical vehicular communication sets,

(b) Mobile long range communication sets,

(c) Radio relay communication sets,

(d) Mortar locating radar sets, and

(e) SAM Control Battery.

C 2 Collection of Data

A brief discussion of the program and a copy of the questionnaire were sent to the prospective places of visits prior to actual personal contact by the members of the task group. Results for each type of equipment are presented in table C I.

C 3 Analysis

C 3.1 Tactical Vehicular Communication Sets

Two replies are presented in table C I for this equipment with the resultant mean life requirements.

In the discussion with personnel, it was clear that an 8 hour shift was the crucial period of time for which failure-free operation is required; therefore, the mean time between failures of 160 hours would be the minimum acceptable for the users of the sets.

It is interesting to note that the figure of .90 for 48 hours is not consistent with the requirement of .95 for 8 hours. The difference exhibited here in these responses indicates the difficulty in evaluating reliability requirements and the greatest variance is usually in the determination of the critical period of operation.

TABLE C I

Responses from Army Survey

Equipment Type		Mission Length	Minimum Acceptable Reliability	Mean Life
Tactical Vehicular Communication Set	(a)	8 hours	.95	160
	(b)	48 hours	.90	480
Mobile Long Range Communication Set		24 hours	.95	480
Radio Relay Communication Set		24 hours	.98	1,200
Each of 12 Equipments				14,400
Mortar Locating Radar Sets	(a)		one hour down time 23 [illegible] of every 24 hrs up	23
	(b)	24 hours	[illegible]	[illegible]40
	(c)	24 hours	[illegible]	480
	(d)	20 days		4,800
	(e)	20 days		[illegible],600
SAM Control Battery	(a)		39½ [illegible] 40 hrs	39.5
	(b)		46 hrs up, [illegible] every 48 hrs	46
	(c)	6	95	120
	(d)	24	.95	480

C 3.2 Mobile Long Range Communication Sets

A response for the requirements for this equipment is given in Table C I. An estimate of a mean time between failures for this system of 480 hours seems quite good.

In the discussion during the interview with the various groups on this equipment type, it was quite obvious that the concept of reliability, as we have defined it in this report, was not understood adequately, resulting in considerable difficulty on the part of the people interviewed to determine a probability figure. The primary reason for this was that the systems were required to operate continuously. The question - "Estimate the smallest length of time between failures that can be tolerated for 95% of the failures" was posed. The relative importance of this system, with respect to the mission accomplishment, could not be determined by the users. Again, the various alternative techniques or equipment made the important factor, as used in this report, relatively small. Basically, the user merely stated that failure of any particular equipment reduced the effectiveness of the operation (military) but it was impossible to determine what effect this might have on mission failure.

C 3.3 Radio Relay Communication Sets

The radio relay sets are continuous operating equipments used primarily for communications between Armies or among Armies. A communications network of these equipments generally consists of two terminal stations and five relay stations. Each terminal station consists of one receiver transmitter and each relay station consists of two receiver transmitters. A spare receiver transmitter is maintained at each location. The questions directed at the users of these systems apply to an entire relay system consisting of 12 receiver transmitters in use with 6 standby spare R/T's. It is known to take approximately five minutes to switch a spare unit into operating position when a failure occurs. The replies to the questions (see Table C I) have indicated that the minimum time between failures for 98% of the failures should be 24 hours for the system. Also, that 98% of the repairs should be made in less than 4 hours. This corresponds to a mean time to failure for the system is 1200 hours and the mean time of failure for a single receiver transmitter is 14,400 hours and a mean time for repair of one hour.

A response of 98% of the failures having a time between failure of 24 hours or more, means that out of a 100 day period of operation only two days would be expected to have a failure and 98 days can be expected to be failure free. This figure appears to be very high and it is the consensus of opinion that a response that 90% of the failures having a time between failure greater than 24 hours would be more reasonable. This would correspond to a mean time to failure for a single receiver-transmitter of 2800 hours.

C 3.4 Mortar Locating Radar Sets

The defensive radar sets are used primarily for locating enemy artillery or mortar installations. In response to our questionnaire, the people interviewed indicated that this equipment may be used anywhere from two days to twenty days for a single mission. The operation, during this mission, would be continuous. The users indicated that no failures should occur during this continuous period. After some discussion, it was realized that the assurance of no failures was impossible. A revised estimate (see Table C I) was obtained in which the user concluded that 90 - 95% of the 24 hour periods should be failure free. In addition, it was indicated that 30 minutes could be used for repair or preventive maintenance on each day between missions. Engineering personnel indicated that the specification requires the equipment to operate 23 out of 24 hours and the other hour was to be used for repair. The repair time of one hour could take place at any time when a failure occurs and it might be the total time to make a number of repairs.

If we utilize the 95% requirement for the 24 hour periods of failure-free operation, we would impose a requirement of 480 hours between failures. It is the consensus of opinion among the task group that the requirement of 480 hours would appear to be a reasonable requirement.

C 3.5 SAM Control Battery

Four separate groups were contacted for the requirements for the defensive missile ground system. It was clear that with the defensive mission of this system no minimum requirements could be stated without some consideration of the costs. It was suggested that it would be necessary to specify the following conditions:

(a) early warning time,

(b) level of expected attack,

(c) level of defense (deployment),

(d) enemy capabilities,

(e) types of defense, and

(f) break-through that can be tolerated.

Since these conditions could not be specified with any degree of accuracy, the official position taken by most people interviewed was that no failures of the electronic system could be tolerated. Realizing that this placed a requirement for the minimum acceptable reliability of 1.00 and that this figure is impossible, other approaches were necessary. As a result, "reasonable" requirements in light of the individual's knowledge of the existing system and his expectations by the 1960's were obtained in two cases and in another two cases the early warning period was specified.

The figures presented in table C I were in varying forms: (a) the first two instances were in the form of the number of hours of maintenance that should be required for any randomly selected period of t hours since this seemed to be the easiest method of attack by the operational people; (b) the latter two responses stated the requirement that only p percent of the time between failures could be less than t hours and specified an alert status whereby the early warning would be one-half hour.

It is clear from the data in table C I that the addition of the restriction of an early warning time created an additional consideration. Consequently a result was derived different from the others. No correct or absolute results can be determined from these responses, but it is the consensus of opinion of the group that a minimum acceptable figure of 46 hours mean time between failures would be appropriate.

APPENDICES D AND E

These appendices contain classified information and are published in a separate document as a supplement to this report.

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APPENDIX F

A Simple Cost Model for Optimizing Reliability

by R. R. Carhart and G. R. Herd

A simple cost model is utilized to describe a means of allocating expenditures between development and operating requirements by selecting that reliability which will minimize total cost. It is intended to be a quick and flexible means of establishing approximate cost allocation between requirements which are functions of reliability. The emphasis of this paper is on a methodology rather than on specific dollar values to guide the potential user on the amount of monetary emphasis that should be given to the problems of reliability.

F 1 Introduction

Although a part of a cost-analysis task is simply to determine the cost of producing and using a system, a more important aspect of the work is to establish the costs in a way that will permit judgment regarding certain significant features for budgeting. This consideration has led the authors to the method presented herein for allocating the budgetary resources between developmental and operational requirements.

The two major cost categories that are considered are: (a) developmental costs and (b) operational costs. The use of only two broad categories means that a multitude of factors are included within each category so that in the future it is essential that more refined costing should be used. However this simple breakdown does emphasize clearly the contrast of the one-time investment outlays by R & D against the investment and recurring operating expenses of the procurement and maintenance groups. This distinction will permit a better measurement of both the economic impact in terms of R & D costs against the total cost of the operation over the expected useful life of the systems. (Rand has developed a methodology for cost estimating which may be adaptable to this situation -- see Comment (h) at the end).

One way to define the optimum reliability for a piece of electronic equipment is to seek that value of the reliability which minimizes total mission cost. For bombing radar, for example, the mission might be to bomb a stated number of targets when required. The cost to maintain this capability, say for one year, will be called the total mission cost, C_m. It includes the cost of hardware development, facilities, aircraft, supplies, training, etc. - everything necessary to establish and maintain the military capability.

F 2 The Cost Model

The mission cost C_m is the sum of the operational cost and development cost

$$C_m = C_o + C_D. \qquad (1)$$

The basic cost, C_o, consists of a "basic" cost, C_B, which is independent of force size and the reliability plus a variable cost, C_s, which is dependent upon the "force" cost and reliability so that

$$C_o = C_B + C_s. \qquad (2)$$

The basic cost, C_B, since it is independent of the reliability of the electronic equipment and the number of equipments must include such costs as basic installation facilities, services, administration, etc. This basic cost includes costs of an investment nature as well as of a recurring nature. The variable cost, C_s, reflects the cost of those items, facilities, and personnel which must be increased if the reliability is low in order to maintain a certain capability. It seems reasonable to assume that there is a "force" cost, C_p, necessary if the equipment reliability for a t hours were unity and that this C_s would change inversely with the reliability, i.e.,

$$C_s = C_p/R, \qquad (3)$$

where R is the mission reliability.

For an equipment reliability of 50% (R = 1/2), twice the force size is needed because half the missions will fail; hence, cost is equipment for which cost optimization is performed over the current reliability state-of-art. If $T/T_o = 1$ the new equipment will have a reliability typical of present gear and no additional developmental cost for reliability is required beyond the nominal cost for equipment of this type, taken to be C_{R_o}. Thus C_{R_o} is the "standard" cost to develop a given type of equipment having "standard" or current reliability. If a new equipment is required to have a module mean-time-to-failure of, say 10 times that of a current equipment, then $T/T_o = 10$ and the standard development cost C_{R_o} will be increased by a factor $(T/T_o)^a = 10^a$ to achieve the required additional reliability. Here "a" is a constant which must be determined from empirical studies.

F.3 Complexity

The reliability of electronic equipment is assumed to follow the exponential law (this assumption is supported by empirical evidence*). If R is the probability of no failure in operating time t hours then by our assumption

$$R = e^{-t/m} = e^{-nt/T} \quad (7)$$

where m = equipment mean-time-to-failure, a constant (hours per equipment failure)

n = number of modules, a measure of complexity

T = module mean-time-to-failure.

The module is a concept useful in reliability work. It represents one "electronic building block" for reliability purposes. Since a typical radio or radar has one electron tube for every 15 electronic parts. By defining the module as 1/15 of the number of electron parts, the number of modules becomes approximately the number of electron tubes.

If the module mean time-to-failure is T hours, and if there are n modules in an equipment, with the modules stochastically independent, the equipment mean time-to-failure is $m = T/n$. This is shown in (7). The

*Herd, G.R., and Nedetniemi, C.J., Predicting the Reliability of Airborne Equipments. Tele-Tech. Sept. 1956
Boodman, D.M., The Reliability of Airborne Radar Equipment. Journ. Op. Res. Feb. 1953.

module concept allows the complexity factor to be removed in comparing equipments of different complexity in reliability considerations.

From (7) T can be expressed in terms of R so

$$T = -nt/\log R \qquad (8)$$

where log R is the natural logarithm of R.

Upon substitution in (6) we have

$$C_D = C_b + d(-nt/\log_e R)^a \qquad (9)$$

where $d = C_{R_o}/T_o^a$ and the mission cost given by (1) becomes

$$C_M = C_B + C_F/R + C_b + C_R \qquad (10)$$

$$= C_B + C_F/R + C_b + d\,(-nt/\log R)^a.$$

F 4 The Optimum Reliability

The mission cost (total cost per mission) is given in terms of the reliability in (10) and to minimize this cost C_M with respect to R is to make

$$\frac{dC_M}{dR} = 0\,; \qquad (11)$$

but this is equivalent to

$$-\frac{d(C_F/R)}{dR} = \frac{d}{dR}\,C_R\,; \qquad (12)$$

or from (10) with some manipulations we have

$$\frac{C_F}{R^2} = \frac{-ad(-nt)^a}{R(\log R)^{a+1}}. \qquad (13)$$

Rearrangement gives the condition for optimum reliability, say $\bar{R}$, as

$$\frac{\bar{R}(-1)^{a+1}}{(\log \bar{R})^{a+1}} = \frac{C_F}{ad(nt)^a}$$

$$\bar{R}\left(\frac{-1}{\log \bar{R}}\right)^{a+1} = \frac{C_F}{ad(nt)^a}. \qquad (14)$$

For given C_F, b, a and nt this equation can be solved for $\bar{R}$.

F 5 An Approximation for Optimum Solution

For the exponential law the unreliability is defined by

$$Q = 1-R = 1-e^{-nt/T}. \qquad (15)$$

When Q is small compared to unity the following approximation holds

$$Q = nt/T \quad (Q \ll 1) \qquad (16)$$

This approximation is quite good for R as low as .70 or $Q = .30$.

For a particular piece of equipment in which the product "nt" is fixed, the reliability cost, C_R, can be expressed in terms of the Q. The (6) may be written as

$$C_R = C_{R_o}\left(\frac{Q_o}{Q}\right)^a \qquad (17)$$

Using the approximation

$$-\log \bar{R} = -\log (1-\bar{Q}) \approx \bar{Q}; \quad (\bar{Q} \ll 1) \qquad (18)$$

in (12) we obtain the relationship

$$\frac{(\bar{Q})}{(1-\bar{Q})} \approx a(1-R_o)^a \frac{C_{R_o}}{C_P}. \qquad (19)$$

Now Q_o should be in the neighborhood of $\bar{Q}$ so

$$(\bar{Q})^{a/1} \approx a\, Q_o^a\, (1-Q_o) C_{R_o}/C_P$$

$$\bar{Q} \approx \left[\frac{a\, Q_o^a\, (1-Q_o)\, C_{R_o}}{C_P}\right]^{\frac{1}{a+1}}. \qquad (20)$$

F 6 Numerical Examples

To illustrate the remarkable savings in the force procurement program which can be effected by reliability development effort, some examples are given utilizing (20) for determining the optimum reliability. It is believed that the cost numbers used are correct within an order of magnitude. The reliability figures are assumed for illustration purposes and the approach presented assumed that the importance factor for the system under consideration is one in each case. The assumption of an importance factor different from unity will not change the analysis although the reliability, R_o, will be affected and a different optimum point, $\bar{R}$, will be obtained. The results show that the optimum reliabilities for typical airborne complex electronic equipment are extremely high according to our argument presented earlier in the paper. This means that we are falling far short of spending enough to develop reliability and far too much money is spent on buying additional forces to supplement the unreliable ones through redundancy.

In the following examples we shall assume a mission force of one hundred bombers costing about 10-million dollars a piece. (This is about equal to the present cost of B-52's with some support cost included.) In other words force cost, C_F, for the 100 bombers will be proportional to $\$10^9$, one billion dollars. The proportionality factor is to express C_F on a per mission basis. It is further assumed that the mission is to provide immediate retaliation if called upon over a one-year period of time and that the aircraft and equipment useful life are the same so that the proportionality factors cancel out in the resulting examples.

Example I.

Suppose we have a transceiver communication equipment similar to, say, the ARC-27 or ARC-34. The following information is available:

$n = 100$ $\qquad C_D = \$1,000,000$

$t = 20$ hours $\qquad T_o = 10,000$ hours

$C_{R_o} = \$250,000$ $\qquad R_o = .80 = 1 - Q_o$

(a) If reliability improvement cost is indirectly proportional to the decrease in unreliability i.e. in (17) a = 1 then from (20) we find

$$1 - \bar{R} = \bar{Q} = \sqrt{\frac{.2(.80)\ 250,000}{10^9}} = .0063$$

So the optimum reliability is given by

$$\bar{R} = .9937$$

(b) If a = 2 in (20) we have

$$\bar{Q} = \sqrt[3]{\frac{2(.2)^2(.80)\ 250,000}{10^9}} = .0252$$

So $\qquad \bar{R} = .977$

Example 2

Suppose we have a bombing - navigational equipment and the following information were available:

n	=	500	C_D	=	\$10,000,000
t	=	10 hours	R_o	=	$.9 = 1 - Q_o$
C_{R_o}	=	\$2,500,000	T_o	=	50,000 hours

(a) If a = 1 in (20) we have

$$\bar{Q} = \sqrt{\frac{(.1)(.9)\ 25 \times 10^5}{10^9}} = .0150$$

$$\bar{R} = .9850$$

(b) If a = 2 in (20) we have

$$\bar{Q} = \sqrt[3]{\frac{2(.1)^2(.9)\ 25 \times 10^5}{10^9}} = .0356$$

$$\bar{R} = .9644 .$$

7 Comments

(a) The model takes into account complexity and operating time, force cost, the state-of-art of electronic reliability.

(b) It does not include the "cost" of larger development time for higher reliability (if it is longer).

(c) The development cost function (5, 6) is an arbitrary function but it is a reasonable function to assume for empirical evaluation. At this time determining the constants a and b is difficult because of the limited amount of data available on how much it costs to increase reliability by known amounts. However, some rough estimates could be made.

(d) The reasoning employee herein is perfectly general and can be applied to several different equipments independently.

(e) The model tends to give conservative results, i.e. the optimum reliabilities should be even higher than those given by (14) and (20). One reason for this is that the whole state-of-art in reliability tends to be advanced over a broad front by improvements made in one sector (tubes, parts, installation, operational ease, etc.). Other equipments can therefore be improved in reliability at less cost. Thus, there may be a tremendous "share the profits" effect when development money is invested to improve electronic reliability on even one project. For this "share the profit" effect to be realized it is of course necessary that there be adequate technical communication about the reliability improvements in question.

(f) It is well known that a number of major electronic projects have, during recent years, produced equipment of unacceptably low reliability. In some of these projects major ad hoc "fix-it" programs have been initiated to improve the reliability of the production articles to a point where the services could use them. It is believed by the authors that attaining reliability by such ad hoc means is very much more costly than the expenditures required <u>in the development program</u> to obtain the same reliability in the end product through a well organized and well planned program. In obtaining any numerical data to project the results of this paper, therefore, only development program costs and resulting reliabilities should be considered. If the evidence from the ad hoc programs are used to furnish examples the reliability will appear to be much more costly than it in fact is and the optimum reliability will, therefore, appear to be lower than it actually is.

(g) Definition of State-of-Art. In connection with (6) it was suggested that the module mean-time-to-failure T be used as an index of the reliability State-of-Art. In applying this in practical studies, it is believed that the upper 20 percentile point, T_o, in the distribution of T should be used. That is, 20% of the equipments chosen as representative for establishing the state-of-art should have T's greater than T_o and 80% should have T's which are lower than T_o. Such a sample should, of course, be subject to some constancy in the factors which affect reliability, such as installation, maintenance, etc.*

*See "A General Guide for Technical Reporting of Electronic Systems Reliability Measurements." RETMA Systems Reliability Analysis Task Group.

Note that the complexity n and the operating time t need <u>not</u> be the same in order to compare the module mean time-to-failure for two different equipments.

(h) In analyzing force costs including support costs, it is believed that the techniques of cost allocation developed by the Rand Corporation are appropriate. A suitable reference dealing with this problem is:

David Novick, "Weapon System Cost Methodology," Rand R-287, 1 February 1956.

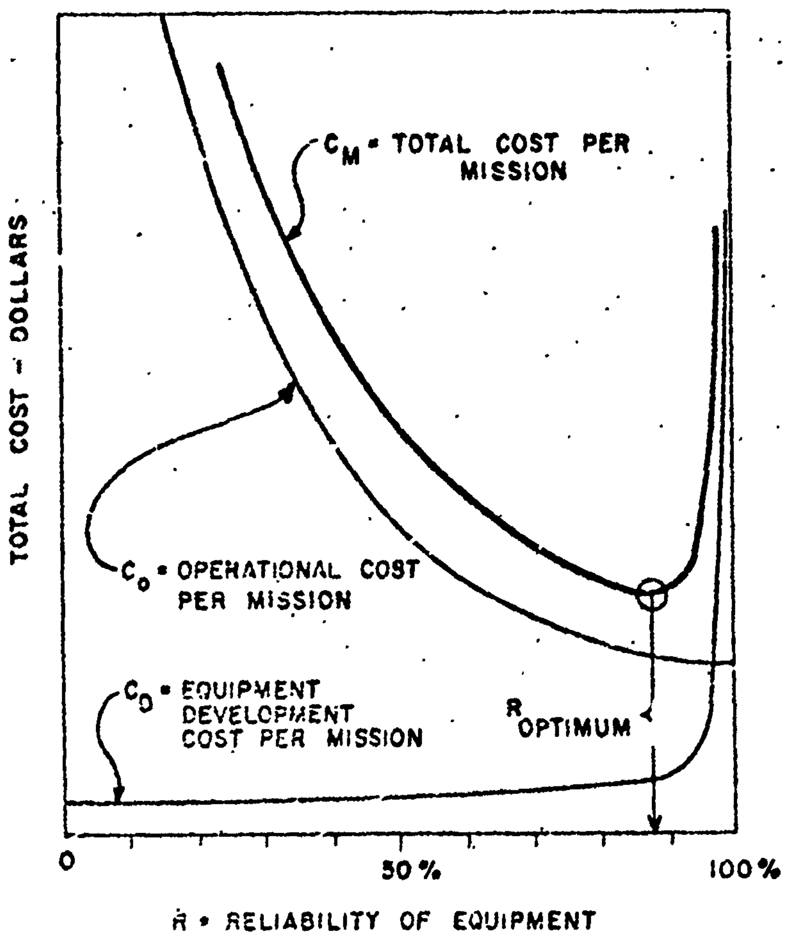

FIGURE F1. MISSION COST VS RELIABILITY

FINAL REPORT

OF

AGREE TASK GROUP TWO

REQUIREMENTS FOR RELIABILITY TESTS

DEVELOPMENT MODELS

January 1957

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TABLE OF CONTENTS

1.0 SCOPE

The mission assigned to Task Group Two by OASD is as follows: "Develop basic requirements for tests to be accomplished on development models which will prove that the design is capable of meeting the minimum acceptability figure for reliability established for the equipment type. These tests shall be designed to be performed either in addition to, or in conjunction with, whatever performance evaluations are specified for the equipment."

In establishing the scope of the Group's interests, it is useful to relate the mission as stated above to the various phases of an equipment program. These, as usually practiced by contractors for military electronic equipment, are listed below:

(1) Feasibility determination.

(2) Fabrication of one or more development models to demonstrate compliance with specified performance requirements. Assuming satisfactory results to this stage, appropriate DOD agencies determine whether or not to proceed through the following phases:

(3) Pilot production of one or more preproduction models.

(4) Production in quantity for military use.

(5) Release to the using services.

The efforts of Task Group Two are concerned with phase (2) above and with the method of arriving at the subsequent decision as to whether or not to proceed to phase (3) from the standpoint of reliability. It also is considered by the Task Group that information developed in phase (1) above, and pertinent to the assessment of reliability, is within the scope of the Group's interest.

The mission as stated above emphasizes the need for a reliability "figure". However, in arriving at the technical requirements for a reliability test, the Group discussed many other related areas and came to the conclusion that the following objectives are also legitimately within the scope of the Group:

(1) Recommendations for reliability evaluation means other than reliability tests.

(2) Recommendations to improve the validity of reliability evaluation.

(3) Recommendations for means of reliability improvement connected with reliability tests.

While not strictly within the scope of this Task Group's mission, several comments are presented in Section 6.0 with regard to present procurement practices.

2.0 RELIABILITY EVALUATION

The mission assigned to the Task Group is essentially a request to develop evaluation means to give assurance that unreliable equipment will not be released for pilot, or perhaps, production runs. Several methods have been suggested for evaluation of equipment reliability, among which are:

(1) Equipment failure rate tests.

(2) Reliability prediction based on review of paper design.

(3) Review of the contractor's component test to failure effort.

These methods will be discussed briefly prior to presenting the Task Group's recommendations.

2.1 Equipment Failure Rate Test

This test is based on observing the failures occurring on one or more sample equipments during extended life test. These life tests may be run under environmental conditions intended to approximate those encountered in service use.

It is generally assumed by those working with this type of test that the failure rate for present electronic equipment follows some such curve as shown below:

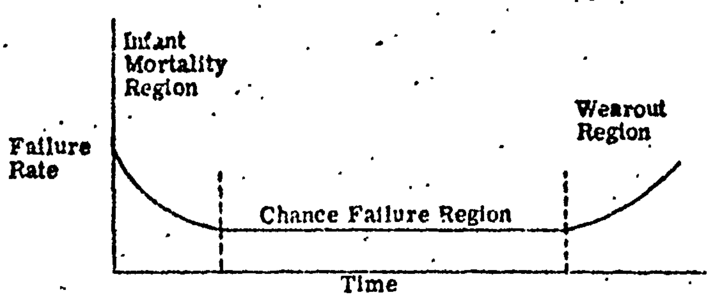

Figure 1

It is assumed that the life tests are conducted during the "chance failure" period in which the average failure rate is generally constant, with "time between failures" following an exponential distribution. Under this assumption the failure rate is calculated as the number of failures per unit time for a single equipment; the inverse of the failure rate, or mean time between failures, is also used to express a figure of merit for the equipment. Further discourse on the mathematics of this type test and accompanying assumptions will not be attempted here since this subject has been adequately covered in the literature by many workers (see Bibliography).

Retaining the above assumption with regard to failure distribution, the limits within which the failure rate of the total equipment population can be stated to lie for a given confidence level depends upon the number of failures experienced. For example, it has been calculated that if 19 failures are experienced, one may state with a confidence of 90% that the true failure rate lies within ±40% of the calculated failure rate; if 68 failures are experienced, these limits may be reduced to 20%. These failures may presumably be accumulated from lengthy tests on one or a few equipments or by shorter tests on many equipments. As a practical matter, it is fairly generally recognized that tests on larger quantities are more representative. However, since both time and quantities of development models available for tests have been limited, it follows that we cannot usually place high confidence in the results of such tests.

2.2 Reliability Prediction Based on Review of Paper Design

Workers in the field of electronic equipment design have recognized the need for detailed analysis of circuit performance to obtain a prediction of equipment reliability. It is expected therefore that any new preliminary design for electronic equipment will be accompanied by a reliability prediction. The thoroughness of this prediction will indicate the extent of the engineering effort toward reliability placed on the equipment design. A detailed discussion of a suggested technique will be found in Appendix A.

This technique is based upon having complete information on failure rates of all component parts, and assumes that a complete understanding exists on how to weight these failure rates for the particular application of each part. While information is beginning to be amassed on "catastrophic" failure rates of some parts, there does not exist at present any organized system to encourage gathering of this information or to insure its distribution to those needing it. Knowledge of proper methods of weighting these failure rates for severity of use is also somewhat meager. Even more meager is knowledge of methods which can assign failure rates due to deterioration (not catastrophic failure) of parts and their interactions, and the failure of assemblies to operate because of this deterioration.

This type reliability prediction will improve as failure rate information and experience is amassed, however, it presently is not at the stage where decision to release to production could be based on it alone.

2.3 Component Test to Failure Method

The two reliability evaluation methods discussed above result in estimates of failure rates for the equipment design. The test-to-failure method outlined below will not actually yield failure rates; rather, it is a design method for assuring adequate safety margins, which should result in long life and low failure rate.

More specifically, the proponents of this method state that every component part, even if standardized and supposedly very reliable, must be suspect until it can be proved able to withstand the equipment service conditions with the degree of reliability required. To this end, quantities of each component part must be tested under increasingly severe conditions until failure occurs. By varying the test conditions, the various critical modes of failure will become known, as will the ultimate strength of the part in these various modes. Where adequate safety margins do not exist between stresses and ultimate strengths, the part must be redesigned or a new part found with sufficient strength. By such methods, all parts are assured of having adequate safety margins, and low failure rates should then result.

The principal deterrent to the wide use of this method lies in the cost and time involved in testing to failure all the various parts of an equipment in all the various critical modes. A further factor is that extreme stresses may actually cause a change in the mode of failure and lead to erroneous conclusions; thus good engineering judgement is required in using this method.

In evaluating models at the end of a development, the test to failure method can be useful as applied to supplementary tests which may be run on suspect parts. It can also be useful in the sense that a review of the test-to-failure effort may be valuable in assessing the contractors overall reliability effort, and may aid in establishing better confidence that a reliable design exists.

2.4 Recommended Evaluation Method

The Task Group recommends that the failure rate test be accepted as the basic reliability evaluation method for development models. Based on a review of published failure data, the Group is willing to accept the exponential failure distribution for the purpose of calculating risks and developing formulae for acceptance and rejection. Whether or not this failure distribution is exactly correct is believed to be secondary to the desirability of establishing life test requirements on new equipment at the earliest possible date. The basic theory and accompanying methodology should rapidly develop once the life test requirement is firmly and widely established, and data begins to be accumulated.

The Task Group believes, however, that the failure rate test cannot stand alone as a reliability evaluation method for development models since:

(1) The time and number of models available are limited, thus placing broad confidence limits on results.

(2) The development models are not necessarily representative, as future production will undoubtedly be from different lots of parts and will be made with different process controls.

(3) The failure pattern of the development models is not necessarily representative even if all lots are considered identical, since only a small number of the multitude of the possible component variations within the tolerance limits will occur in a few equipments. These variations will lead to new failure patterns due to tolerance build-ups, different applied stresses, etc.

Therefore, the failure rate tests must be supplemented by a thorough review of the paper design, particularly with regard to investigation of operating conditions of all parts as compared to ratings, failure rates assigned to all parts, status of part qualification tests, and the tolerance structure of the design (that is, will the design accomodate expected part variations in service and still operate satisfactorily).

Failures occurring during performance evaluation tests should also be reviewed.

As a result of the design review, or of failure during test, some parts may be suspect. These parts should be given special life tests or tests-to-failure to insure that adequate safety margins exist.

The decision to release for pilot production should be made only after thorough review of all information gained as a result of the overall evaluation.

3.0 FAILURE DIAGNOSIS

An important by-product of failure rate testing should be the discovery of residual causes of unreliability and the resulting corrective action to reduce or eliminate these causes. Experience has shown that the key to corrective action is highly skilled analysis of each failure.

The need for failure analysis has been hampered by the fact that, traditionally, test specifications have assumed that the buyer's interest was limited to obtaining failure free devices that would pass all specified tests with a failure rate of zero. It has usually been stated or implied that if failures occurred, the devices ceased being of interest to the buyer and responsibility for analysis and removal of the cause of failure was the private concern of the contractor. The interest of the buyer would be resumed after an improved device had been submitted and had passed all tests.

This traditional treatment of failures occurring during test is unacceptable for military electronic equipment. The probability is high that some failures will occur during life testing. The buyer is vitally interested in the diagnosis of test-produced failures and the procedure to be followed must be an inherent part of the procurement specification. The following items are proposed as mandatory specification requirements.

(1) Competent engineering failure diagnosis is mandatory for all test failures.

(2) To the extent possible, each test failure must be assigned a cause such as test instrumentation defect, test operator error, part failure, part deterioration, circuit failure due to designer's failure to allow for normal part variations, etc.

(3) Where failure occurs in the equipment under test, the pertinent damaging stresses must be carefully measured and recorded. As an example, if a capacitor fails, the possible damaging circuit stress (voltage, or sometimes current) must be measured and recorded. Furthermore, the possible damaging external stresses (temperature, humidity, etc.) must also be measured and recorded.

(4) Where practicable, disassembly and analysis must be performed on failed or deteriorated parts. Such disassembly and analysis must be performed under the cognizance of a representative of the buyer who is not responsible for the design or production of the part (see section 4.0). A competent diagnosis must be made in terms

of specific design features and specific workmanship, production engineering and inspection procedures. Where applicable, the failure diagnosis shall include an analysis of contributing causes such as inadequate circuit design (which will not, for example, tolerate normal part variations plus expected part deteriorations).

(5) A fully descriptive report or report section must be written for each test failure. The report must assign the cause and responsibility and cover the diagnosis as outlined above. Where appropriate, recommendations for corrective action should also be included.

It should be mentioned that often the designer's knowledge is virtually indispensable to adequate diagnosis. Thus the contractor should be encouraged to maintain a nucleus of his applicable design group intact for the duration of the reliability tests, and to insure that this group is available for failure diagnosis activity. It is important that the failure diagnosis personnel be reasonably free from undue pressure by the buyer and/or other groups in the contractor's organization that may tend to restrict the investigations and produce inadequate diagnosis or even concealment of true problems. Since most of this pressure results from efforts to meet schedule and price committments by the contractor, it may be that some relief must be extended by the buyer in this regard in order to gain the desired results.

4.0 SUPERVISION BY INDEPENDENT EVALUATION GROUP

Experience has shown that those responsible for the design of a product should not be given responsibility for its evaluation. This principle is generally accepted with regard to the actual designers; however, in the experience of numerous members of the Task Group, this principle could have been profitably extended to the responsible government group as well. Thus, a government group responsible for design of a product (even though the actual design was performed by a commercial firm) should not be the primary evaluation group. Some other government group, on at least an equal organizational level with the government design group, should have this responsibility.

It is possible, and in the Group's opinion permissible, that the entire testing and evaluation program be carried out by qualified commercial or government laboratories provided that the independence cited above is maintained. In any event, no contractor should supervise the evaluation of his own product for the government even though his design and evaluation groups are presumably separate and independent; this restriction does not preclude the contractor being required to provide facilities and services as outlined below.

While the Task Group believes that the principle of independent evaluation should apply to all phases of development model evaluation, the remarks which follow apply principally to those phases directly concerned . or closely related to the Group's prime task, reliability evaluation.

It is recommended that independent evaluation of reliability tests be accomplished by requiring that these tests be "supervised" by the evaluation group. Supervision shall include but not necessarily be restricted to the items listed below:

(1) Review of contractor's reliability effort, including the reliability prediction.

(2) Approval of the proposed detailed test plan for reliability tests.

(3) Approval of the test facilities to be used for the test program.

(4) Review of data preparation and test progress.

(5) Surveillance of failure diagnosis activities.

(6) Approval of test logs and failure diagnosis reports.

(7) Approval of supplementary test programs, such as special tests-to-failure on certain components, conducted as a result of the reliability evaluation.

(8) Approval of contractor prepared report covering reliability tests.

(9) Preparation of any necessary independent report, including recommendations.

It should be emphasized that the purpose of the supervision outlined above is in no way intended to usurp any of the contractor's usual responsibilities with regard to such test programs. On the contrary, the contractor would be normally expected to supply the personnel to actually perform all required tests and to furnish necessary data. In particular, he should furnish failure diagnosis services, since the designer's knowledge is often indispensible to performing adequate failure diagnosis.

5.0 RECOMMENDED FAILURE RATE TESTS

5.1 Written Agreements

The effort to be expended by the contractor in meeting reliability requirements should be specified in the contract. Minimum contract requirements should include:

(a) Specifications for a mean time to failure.

(b) Tolerance limits on the performance specifications which can be used to define a failure during the failure rate test

(c) Requirement for a failure rate test to determine compliance with the mean time to failure specification.

Full written agreement should be reached between the contractor and buyer with regard to all aspects of the reliability tests prior to start of the failure rate tests. Later sections of this report contain recommendations for items to be included in the performance specifications, in the contract and in test procedures and associated documents. It is [illegible] particularly important that [illegible] rules for [illegible] failures be established; this need is demonstrated by a recent case where the mean time to failure of a particular piece of equipment as reported by several groups varied [illegible] eight to one range, all presumably based upon the same data

5.2 Characteristics to be Measured

These characteristics should be covered in some document such as the equipment specification or test procedure. It is recommended, however, that the number of items to be measured be kept to a minimum in order to reduce the instrumentation and manpower problems associated with the tests.

5.3 Number of Models

At least two models should be allotted for failure rate tests in order to reduce total test time and in order to have a more representative sample. This number should be considered an absolute minimum except in special cases, such as extremely complex equipment; every effort should be made to increase the number of models associated for these tests in order to gain better assurance that the design is capable of meeting requirements. More than two models will reduce the probable test time proportionately, except that the group recommends that all models be run at least three times the contract mean-time-to-failure, (refer to section 5.6 and Table I).

5.4 Environments

The Group has considered many possible environments, and combinations of environments. Several factors, however, argue for minimizing the variety of imposed environments, particularly at this time. These factors are:

(1) Environmental equipment is severely limited at many contractors' facilities.

(2) In the initial stages of reliability evaluation program, a simple test procedure will expedite acceptance of the program.

(3) Fairly simple, standard, environmental conditions would aid in developing standards of comparison for equipments and in amassing uniform part life data.

The following guides are therefore suggested for imposed environments:

(1) On-off cycling at a rate approximating service use.

(2) Usage cycling such as tuning radio equipment to various frequencies, scanning with radars, etc.

(3) Operation at nominal, maximum, and minimum line voltages (measurements at other than nominal line voltage should be kept to a minimum in order to reduce test complexity).

(4) Temperature cycling from normal room ambient to specified maximum.

(5) Mild vibration where applicable. In most cases this environment should be confined to that which can be produced by some simple means such as placing the equipment on resilient mounts and "driving" it by means of a rotating off-center weight (to minimize environmental equipment complexity).

The above environments can be obtained with a minimum of expensive equipment. The temperature cycling, for example, can be obtained by enclosing the equipment in an insulated box and controlling the external cooling air. It is recommended that full consideration be given to establishing the various cycles on a daily basis such that all or at least a majority of the necessary adjustments and measurements can be made during a normal eight hour working day.

As the reliability tests become firmly established and more experience is gained, it is expected that the environmental requirements will be adjusted accordingly.

5.5 Definition of Failure

For the purpose of failure rate test, a failure should be defined as operation outside assigned tolerances. Thus each characteristic to be measured should be assigned a tolerance in the performance specification such that a failure is counted if this tolerance is exceeded. These "failure" tolerances must be wisely assigned, with due allowance for deterioration of parts with age and in general should be wider than normal factory tolerances. Conversely, factory tolerances should be so set as to allow for known aging of parts on a statistical basis so that there is high probability of meeting the "failure" tolerances during the life of these failure rate tests.

Allowable adjustments and preventive maintenance must be carefully specified. In general the Task Group recommends that no preventive maintenance be allowed except in special cases such as complex computers or rotating machinery where regular checks are normally conducted. These special cases should be covered in the test procedures.

Details of scoring failures during tests must be precisely stated. Suggested rules are covered in Appendix B.

5.6 Acceptance Criteria

Table I is provided in order to arrive at accept or reject decisions for equipment under failure rate tests. Note that the table is presented in terms of multiples of the contract mean-time-between-failure; i.e., the actual total accumulated test time on all equipments under test is divided by the contract mean-time-between-failure (inverse of the failure rate, prior to entering in table. After entering the table, the total number of failures experienced, found in the appropriate column, will determine whether to reject, accept, or continue testing. Note also that it is stipulated that no decision can be made until each equipment test has accumulated at least three times the contract mean-time-between failure. This provision is made in order to give some assurance that equipment with unduly short life will be rejected.

Table I has been calculated on the assumption that time between failures of the equipment will be exponentially distributed. For the purpose of this test, it is also assumed that the failure rate of the equipment under test is representative of the design. This latter point, and the risks discussed below, should be clearly understood by those specifying contract values for failure rates.

It must be understood that any sampling plan has certain risks associated with it. It must also be noted that the plan recommended here is a sampling plan. The alternative (to obtain true failure rate for the sample), would require that the equipment be run on life test indefinitely to accumulate the supporting data. The risks involved may be described by an operating characteristic curve such as that shown in Figure 2, which is applicable to the Table I plan.

Thus, equipment which has a normalized failure rate of 1.0 (i.e., exactly equal to the contract failure rate) would have a 90% chance of acceptance (and 10% chance of being rejected. Equipment which has a normalized rate of 2.0 (twice the contract value) would have only a 10% chance of being accepted. Other tables may of course be devised for various other risks and failure rates. For example, the 10% probability of acceptance point may be moved from 2.0 to 1.5 or even 1.2. However, such action is the equivalent of stating that much more confidence is desired in the results and a longer test would result.

The plan presented in Table I has been chosen as representative of the shortest test believed by the Group to be practicable, since further attempts to abbreviate the test would result in undue risks to both buyer and contractor. If sufficient time and/or models are available, a test plan should be used which further reduces the risk to both parties. In order to make such decisions, a set of test plans and accompanying operating characteristic curves should be prepared and made available to those responsible for establishing failure rate tests.

5.7 Data Handling

The consequences of a reliability test are of such major importance to both buyer and contractor that rules and procedures governing conduct of the tests and interpretation of test results must be established prior to beginning the tests. Rigid adherence to this principle and to the rules once established will minimize disagreements as to interpretation of data and true test outcome.

The system of rules and procedures and data keeping should have the following objectives:

(1) Provide a continuous record of performance of test specimen and test facilities.
(2) Document all test deviations.
(3) Insure keeping of adequate data.
(4) Minimize errors.
(5) Provide for arriving at accept-reject decision in minimum time with minimum areas of disagreement. This means clear rules for interpreting data and scoring failures.
(6) Insure adequate failure diagnosis and its documentation.
(7) Provide for recommendations for corrective action.
(8) Test documents and logs, when completed, should be able to be combined together into a final report which, when approved by evaluating agency, will fully document the tests.
(9) Require approvals necessary to assure proper control by the group supervising the tests (see Section 4.0).

TABLE 1

Accept-Reject Criteria For Failure Rate Testing

1 Multiples of Contract mean-time-between-failure	2 Reject if number of failures below occur on or before time in Column 1	3 Continue Test if number of failures fall in range below at time in Column 1	4 Accept if no more than number of failures below occur by time in Column 1
3.00	8	2-7	
3.32	8	2-7	1
3.58		3-8	
4.01	9	3-8	2
4.27		4-9	
4.70	10	4-9	3
4.96		5-10	
5.39	11	5-10	4
5.65		6-11	
6.08	12	6-11	5
6.34		7-12	
6.77	13	7-12	6
7.03		8-13	
7.46	14	8-13	7
7.72		9-14	
8.15	15	9-14	8
8.41	15	10-14	
9.10	15	11-14	9
9.79	15	12-14	10
10.30	15		11
		-	14

NOTE 1: Column 1 is entered by dividing the total operating time accumulated by all equipments under test by the contract mean-time-between failure.

NOTE 2: Failures listed in Columns 2, 3 and 4 are total failures experienced by all equipments under test.

NOTE 3: Each equipment must accumulate an operating time equal to three times the contract mean-time-between-failures prior to making an accept or reject decision.

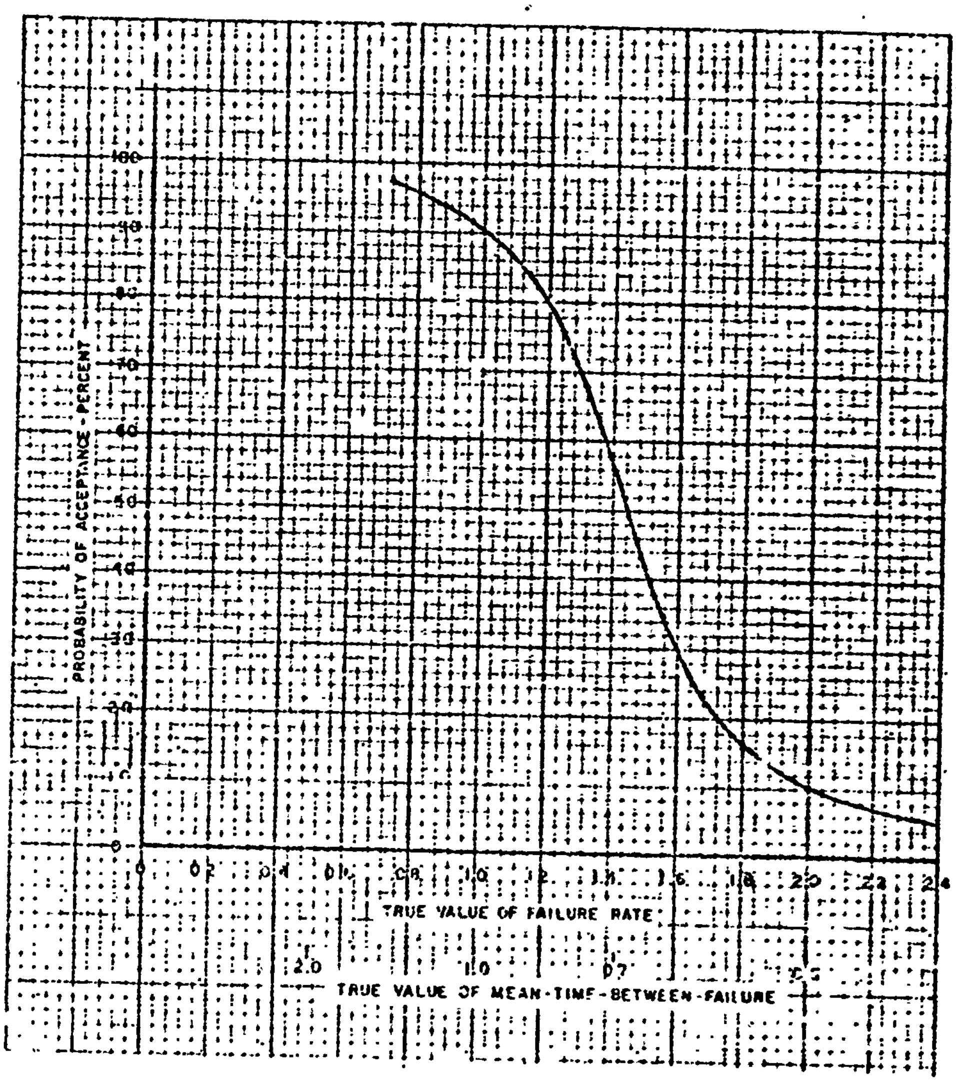

FIGURE 2

PROBABILITY OF ACCEPTING PRODUCT WITH VARIOUS VALUES OF TRUE FAILURE RATE

Appendix B describes a system which, in the opinion of the Task Group, satisfies the above requirements. This system includes elements that have been found useful in a particular test program of similar nature. These requirements may seem unduly restrictive; however, relaxation of such requirements will inevitably lead to less precise methods, less accurate records and analysis, and less assurance to the buyer that the produce is adequate.

A particular system will not be recommended here since obviously the intent of the system described in the objective above and in Appendix B could be met by different combinations or groupings of the total required information.

6.0 PROCUREMENT PRACTICES

While not within the scope of this Task Group mission, present procurement practices which aim to provide accelerated delivery of electronic equipment tend to minimize the time allowed for adequate reliability evaluation. This is considered a problem of the military services development and procurement practices charged to Task Group Six and is of primary importance in the process of achieving improved reliability of military electronic equipment. Task Group Two is especially alarmed at the trend away from the orderly development processes in the present practice of telescoping development with prototype or production procurement at the expense of a sound reliability test program during the vital development engineering phase. Additionally, it appears that present spare parts procurement procedures tend to negate improvement in reliability which might be obtained during the development of the equipment. This is brought about by the fact that adequately tested components and circuit elements should be assembled in the tested and delivered military electronic equipment. However, the procurement practices do not necessarily specify that the parts provided as spares for this equipment should be procured under the same rigid specification and reliability testing program as performed on the original components. Thus, unreliability and non-predictable reliability can very well be built into a reliable equipment by the inclusion of questionable or non-reliable spare parts.

7.0 CONCLUSIONS

7.1 Requirements for reliability evaluation by means of failure rate tests of development models have been presented. These tests are intended to give assurance that the design is capable of meeting a required failure rate (or mean-time-between-failure).

7.2 Since the number of samples and time available for failure rate testing is usually severely limited, the failure rate established by the tests will have broad confidence limits. Therefore, before deciding whether or not to release for pilot production, the test program must be supplemented by:

(1) A thorough review of the contractor's reliability effort, particularly his paper design and part qualification and selection effort.

(2) Supplemental tests on parts found suspect as a result of the tests or the reliability review.

7.3 Observation of the principle that no design or manufacturing group should evaluate its own product is vital to reliability. Therefore, independent evaluation groups should supervise reliability test programs.

7.4 An important by-product of reliability testing should be the discovery of residual causes of unreliability. Competent engineering failure analysis should be mandatory for all test failures in order to initiate adequate corrective action.

7.5 The Department of Defense must review and revise as necessary its regulations pertaining to research and development and the procurement of equipment and spare parts. In some cases, conflicting regulations exist which tend to negate good procedures and practices outlined in other regulations. While this task is explicitly assigned to Task Group Six, it is also emphasized here, since it is felt that improvement of the development article cannot be assured without some changes in procurement practices aimed specifically at installing the controls recommended herein. Furthermore, improvement of the produce is futile unless spare parts procurement practices, and similar regulations will allow high quality to be maintained during the service life of the equipment.

APPENDIX A

PREDICTION OF EQUIPMENT RELIABILITY BASED ON REVIEW OF PAPER DESIGN

The design of complex electronic equipment has been concerned mostly with the achievement of performance requirements at the time of initial testing. Reliability estimates, if made at all, have been computed by the simple formula equating the overall reliability to the product of its component parts reliability. (Product rule)

Such a formula, is the ultimate in simplification because it does not consider the effect of the stresses applied to the parts as a consequence of the assemblage of them into the equipment. It also neglects the many interactions that arise from the combination of various components and the many conditions of operation peculiar to the particular equipment. An evaluation of overall equipment reliability must consider the effect of environment and operating conditions upon parts life and must determine the actual dependence of the equipment failure to parts failure in a detailed analysis of the equipment components.

An analysis of this nature has been compared to a stress analysis in mechanical engineering but it involves many more variables than simple stresses and strains. It may become extremely complex if carried to its ultimate conclusion.

Many attempts at reliability analysis at various levels of approximation have been made by the major electronic companies, and several papers have been published on the subject. It is expected, therefore, that any new preliminary design for electronic equipment submitted for approval to the Armed Forces will be accompanied by a reliability analysis to predict at least what order of magnitude to expect for the reliability of the completed equipment. In future years the extent of this analysis will certainly indicate the extent of the engineering effort placed on the design and preliminary development of the equipment.

As indicated by the widely different approaches to the problem published in the literature, it would be unreasonable to establish a detailed set of rules on how to perform a reliability analysis. They would become obsolete almost before publication and they could not cover all the requirements of the great variety of electronic equipments now in use. In this section only a few general ideas will be given to indicate the broad scope an analysis of failures should involve, and the few essential assumptions and ground rules will be mentioned that must be considered to obtain valid results.

Parts failure has been divided by other workers in this field into two general classes. In the first are failures produced by random catastrophic changes in the parts forming the equipment, changes that are not particularly affected by stresses applied by the equipment but are produced by inherent malfunctioning of the part itself. The second class includes failures that are produced by the combination of deterioration of the part and the failure of the subassembly or component to operate because of the deteriorated characteristic of the part.

One could explain these two categories as being produced -- the first by the state of the art of the parts manufacturing industry, and the second by the engineering level of the designing agency.

The first is practically independent of the way the parts are assembled in the equipment, and therefore it is easy to appraise its effect on the overall failure rate of the equipment by taking the product rule. However, since quality control should be continuously improving the quality level of parts production, this category of defects should decrease to a low value although it must still be considered in the overall evaluation.

The second class, or deterioration failures, is the most difficult to appraise but appears to be the dominant one even in relatively obsolete equipments; this is shown by ARINC field investigations. It determines whether the design of the equipment has taken into consideration the time variation of parts characteristics with large enough margin to reduce the probability of failure of the equipment within the required limits.

A failure analysis for deterioration effects may consist of a detailed study of each component circuit and its component parts through the use of multi-variate analysis, or may determine only the dominant causes of failure. In any case, it should determine how great a margin of performance the component circuit possesses for the expected variation of the characteristics of each component part during life or at least for those characteristics that are dominant in the mechanism of deterioration. (Failure due to poor quality in components assembly cannot be detected by paper design analysis.)

This approach implies that the part fails only when the component of which it is a member is failing, and therefore puts a new and variable meaning to the concept "parts failure". In other words, the dependence between parts failure and component failure is not invariant but is a function of design. In this case the product rule does not apply unless corrections are introduced. For example, if the product rule is used for an amplifier stage which fails to deliver the required output when the tube has reached 50% of its original mutual conductance value, this point will be considered the limiting value to assign failure rate for the tube in that component. If another component with that same tube type fails when the mutual conductance has reached only 90% of its original value, that tube type should be assigned a much higher failure rate when the second component is considered.

Failure analysis requires knowledge of performance of all parts under the various conditions of operation and periods of time. The interaction that characteristics of the various parts may have upon each other and on the overall performance must also be known. This knowledge is now extremely meager. Some of the few available data are found in the references, but many more are being accumulated by various activities in the many recently organized Reliability Departments of equipment manufacturers.

We can say that at the present time we are at the stage of making the very first rough approximation on these methods but every future evaluation based upon this first experience will be a more accurate approximation. By collecting and using all data obtained in successive approximations, "reliability analysis" will become a valuable engineering tool in the very near future.

In order to obtain a valid computation of reliability for an equipment, it is important to observe several general rules. The most important ones are listed here.

Whenever the product rule is used, the parts composing the unit must be independent and in series, that is, failure of any part produces failure of the component or unit. (Unit being equal to, or smaller than, a component.)

Whenever a simple condition of independence is not apparent, the interaction of the various parts must be considered and a failure probability assigned to the unit rather than the parts.

Whenever redundancy in any form is present, it is necessary to subdivide the equipment into components in such a way that the effect of redundancy and duplication can be fully estimated.

Whenever special environmental or operating conditions are affecting more than one part in the equipment, their effects should be assigned to the largest unit affected rather than the individual parts or components.

If more than one mode of operation is possible, the components involved in the various modes must be clearly separated and a reliability figure must be computed for each of the modes considered.

In order to avoid difficulty in computation arising from the various distributions of failures as functions of time, it is better to compute the failure rate for a given period of time for the various components and then combine them to obtain the failure rate of the equipment. If hours are used as units of time, then the failure rate will be the probability of failure in an hour. For parts showing normal distribution of failures or generally, a failure rate increasing with time, the period of time considered should be specified. Since for complex equipments it is safe to assume an exponential distribution of time between failures, that is a constant failure rate, it is easy to convert the failure rate into mean time between failures or into the reliability function for the equipment.
As an example, a procedure for a design stage prediction of reliability of a new equipment could be made by following the 12 steps listed below.

STEP 1: Define the equipment explicitly and uniquely in terms of its functions and boundary points. Once the equipment is defined, and the operating conditions as well as the performance characteristics with extreme allowance variations are known, then the failure of the equipment is automatically defined as being the conditions in which the equipment operates outside the above mentioned allowable variations.

STEP 2: Specify the components within the system. Components must be uniquely identifiable without duplication and must be selected in such a way as to take into account any redundancy and independence of operation. A wise subdivision into components will make the computation of overall reliability more straightforward and accurate.

STEP 3: Select the parts which affect system unreliability. Within each component some parts have a very small effect on reliability and can be disregarded for a first approximation. Other parts, instead, have a dominant effect on the reliability of components, either because of their large number or because of their large failure rate.

STEP 4: Determine a failure rate for each part or class of parts used in each component of the system. If parts are grouped and not analyzed singly, then classification of parts could be made in terms of homogeneity of failure rate, such as: tubes with high temperature of operation, tubes with low temperature, tubes that can deteriorate to the life test end point, tubes that can deteriorate well below life test end point, condensers with high voltage applied, resistors with high power rating, etc. From data obtained in the references mentioned, or other available sources, the failure rate as related to the various stresses applied to the parts will be estimated. In the case of new parts or applications, it may be necessary to obtain new data through special investigations.

STEP 5: Determine a preliminary figure for the failure rate of each component within the equipment. Add the failure rate for all parts in each component of the equipment as determined in Step 4 to obtain the preliminary figures for component failure rates.

STEP 6: Determine the correction factors to be used to modify the preliminary figures for the failure rate of each component. Some effects of dependence between part and component can be accounted for by a single correction factor in the component failure rate if it has not been considered when the parts failure rate was computed. As was mentioned previously, in many cases when stresses are applied to the whole component, it is more practical to apply a single correction to the component rather than to correct the failure rate of each individual part.

STEP 7: Determine the failure rate for each component. Once the correction factor has been determined, the preliminary figure for failure rate of the component can be multiplied by such correction factor to obtain the component failure rate.

Steps 3 to 7 can be considered as the most elementary way of obtaining a failure rate estimate for each component since the product rule has been used with only partial corrections considered. For a better approximation of the true overall failure rate, the interaction between components and operating conditions must be fully evaluated by means of multivariate analysis in which the various performance parameters of each component are expressed as functions of the characteristics of the individual parts and of time. Since these characteristics deteriorate with time and if this variation with time is known it is possible to determine the time variation of the performance parameters of the components and therefore also their probability of failure.

STEP 8. <u>Determine a preliminary figure for the failure rate of the equipment.</u> Add the failure rates for all independent components within the equipment to obtain the preliminary figure for the equipment failure rate.

STEP 9. <u>Determine the correction factors to be used to modify the preliminary figure for the failure rate of the equipment.</u> As in Step 6, the equipment may be subject to special stresses that have not been considered in the computation of parts and components and that may produce a change in the failure rate that must be considered at this stage.

STEP 10. <u>Determine the failure rate of the equipment.</u> Multiply the preliminary figure for the equipment failure rate by each of the correction factors applicable to the equipment to obtain the equipment failure rate.

STEP 11. <u>Determine the predicted reliability function for the equipment.</u> The reliability function for the equipment is given by:

$$R(t) = e^{-t\,(\text{equipment failure rate})}$$

STEP 12: <u>Determine the predicted mean number of hours between equipment malfunctions.</u> The predicted mean number of hours between malfunctions, ξ, is given by:

$$\xi = \frac{1}{\text{equipment failure rate}}$$

APPENDIX B

A SUGGESTED SYSTEM OF RULES AND PROCEDURES FOR RELIABILITY TESTS

1. FORMS

Prior to the start of a reliability test, all data forms deemed necessary for the maintenance of accurate records shall be agreed upon by the contractor and the procuring agency or the evaluation group delegated to supervise and/or perform the test. These forms shall be laid out in an orderly fashion with the objective of maintaining accurate, sequential recordings that will permit rapid evaluation of results on completion of the test. If data is kept in this manner, it will automatically be in such form as to enable the contractor to evaluate the test results for conditions requiring corrective action.

It is not practicable to establish standard data forms which would be applicable to the wide variety of electronic equipment presently in development or to be developed in the future. However, the similar conditions attendant with all reliability tests do permit the establishment of certain general forms considered to be necessary in order to maintain adequate test documentation and insure proper test conduct.

The following forms shall be used:

(1) Test Data Log
(2) Operators Log
(3) Equipment Failure Log
(4) Failure Diagnosis Report

A general description of each of these forms follow. It is recommended that they be prepared on a form suitable for reproduction such that original data entries will not have to be re-copies. The exact format may be arranged to suit individual requirements.

2. TEST DATA LOG

The Test Data Log should be designed to permit data entry in chronological order such as to provide a continuous record of the test specimen and test facility performance including time required for test specimen maintenance. It provides means to cross check for the existence of any failure inadvertently omitted from the Failure Log. Further, it provides means for arbitrating any contention that observed equipment failure was in truth the fault of the test facility rather than the test specimen. It also establishes the presence of operating personnel on the desired routine basis throughout the duration of the test.

The heading of the Test Data Log should contain the identification of the test, identification of the equipments under test, and identification of the various pieces of test equipment used in the test facility.

All test facility and test specimen parameters that are monitored on a periodic basis should be entered chronologically in the body of the log. It is recommended that the body of the log be ruled into lines and columns so that all parameters measured at any given time will occupy one line, with each parameter being entered in its respective column. All columns should be appropriately titled to identify the parameter entered thereunder. Columns should also be provided for entering the date, time and initials of the recorder for each entry. If the number of parameters to be monitored is excessive, it may be advisable to have two separate logs, one for recording test facility parameters and one for equipment under test.

It is recommended that log entries be made on a periodic basis rather than continuously monitoring the facility and recording only on occasion of irregularity. Periodic entry will provide a permanent record of drift tendencies. In this respect, it is also recommended that numerical data be entered rather than a check-mark notation indicating in-tolerance operation.

3. <u>OPERATORS LOG</u>

The Operator's Log should be designed to permit recording by the test operator of any information relevant to the test, such as replacement of test equipment, deviations from normal test procedure or conditions, visual evidence of test facility or test specimen abnormality that would not be covered in the Test Data Log, reasons for test interruptions, etc. Each entry pertaining to a test deviation should be signed by the properly authorized delegate of the evaluation group as indication of agreement with the deviation. In this manner, the completed Operators Log will serve as official agreement as to proper conduct of the test as well as providing an official record of all significant events.

The heading of the Operators Log should contain the same information as the Test Data Log heading. The body of the log should be ruled with horizontal lines such that the operator can make neat longhand entry. All entries shall be made in chronological order with date and recorders initials affixed to each entry.

Consideration may be given to combining the Test Data Log and the Operators Log. A combined log of this nature could be of the general form herein described for the Test Data Log with an additional column on the right of the sheet provided for entering remarks. However, experience on a similar testing program has indicated that explanatory remarks are frequently required and tend to be rather lengthy, requiring more space than would be conveniently available in the combined log. For this reason, the use of two logs is recommended.

4. EQUIPMENT FAILURE LOG

The Equipment Failure Log is a form inte. ed to contain all of the information needed to reach a decision as to whether or not the tested equipment passes or fails the test.

The heading of the Failure Log should contain identification of the test, identification of the equipment under test, and name of the data recorder.

The body of the Equipment Failure Log should be ruled into the necessary number of columns, seven (7) columns being required for the simultaneous tests of two equipments. Each addition or reduction of equipment will require the addition or deletion respectively, of one column. The columns should be headed in accordance with the following list:

(1) Line Number
(2) Consecutive number of failure observed.
(3) Date and time of failure observation.
(4) Accumulated operating time on equipment #1 at time failure in column two (2) was observed.
(5) Same as (4) for equipment #2.
(6) Total of columns 4 and 5.
(7) Column 6 divided by contract specified MTBF (This figure will be "normalized time" as used in Table I, Column 1.)

Under the column headings the form should be ruled with a number of equally spaced horizontal lines, with sufficient spacing to permit each line to be used . [illegible] separate equipment failure. An entry shall be made at the occu[illegible] of each apparent equipment failure. If failure diagnosis reveals [illegible] the test specimen was not at fault, the entry may be struck out and initialed by the operator. Appropriate explanation shall be entered in the Operator's Log.

5. FAILURE DIAGNOSIS REPORT

A Failure Diagnosis Report shall contain all pertinent information bearing on an apparent test specimen failure as necessary to isolate the discrepancy. If the discrepancy is found to be in the test specimen, additional information shall be included explaining the cause of the discrepancy and, where appropriate, proposing corrective action to prevent its recurrence. It is intended that a separate Failure Diagnosis Report be filled out for each apparent test specimen failure except those, such as operator errors, that are readily demonstrated to be not associated with the equipment under test. The Failure Diagnosis Report, when filled out and signed by the properly authorized delegates of the contractor and the evaluation group, shall constitute official agreement as to the assignment of an apparent test specimen failure into its proper category, either test specimen failure or otherwise, as the case may be.

The Failure Diagnosis Report shall contain two major sections. The first section shall pertain to the failure symptoms, diagnosis action taken, identification of the discrepancy and repair of the specimen (providing a discrepant condition is found to exist in the test specimen). This section of the Failure Diagnosis Report will be required for all apparent test specimen failures and its format should be established prior to beginning the test. The second section of the report will be required only in the case of verified test specimen failures. It shall pertain to analysis of failed components, analysis of cause of failure, and proposals for corrective action. The amount of information contained in this section of the report will vary widely depending on the complexity of the specimen failure. It is recommended that no formal format be established for this section; rather, the section should be composed of separate reports covering failed component analysis, equipment design investigations, and corrective action proposals. Details of the information to be contained in both sections of the Failure Diagnosis Report are as follows:

5.1 Section One

This prepared form shall contain printed spaces at the top with suitable instructions for inserting the following information:

(a) Failure Diagnosis Report Number

(b) Test Identification

(c) Test Specimen Identification

(d) Date of Apparent Failure

(e) Total Test Time on Test Specimen When Apparent Failure Was Detected.

(f) Sequential Test Failure Number (if the apparent failure proves to be a test specimen failure).

Below this heading information shall be four separate sub-sections as follows:

5.1.1 Symptoms

This section shall be filled out by the test operator, fully describing the symptoms of the discrepancy including both normal and abnormal performance parameters, and referencing the test sequence in effect at the time the discrepancy was detected.

5.1.2 Diagnosis Action Taken

This section shall be filled out by the person performing failure diagnosis and shall include verification of the originally observed symptoms, a description of the test methods used in performing failure diagnosis, and numerical data on all performance parameters checked during diagnosis.

5.1.3 Identification of Discrepancy

This section shall be filled out by the person performing diagnosis and shall list the defective item or items causing the discrepancy. If the discrepancy is found to be in the test specimen, a description of the discrepant condition of each defective item shall be included. This shall include both visually detectable attributes and measured parameters, (i.e., resistor cracked and measures open). In the case of test specimen failures, each discrepant item shall be classified as either a primary or secondary failure (see "Rules for Data Interpretation" for definitions of primary and secondary failure). Each primary failure shall be assigned a sequential number and the number shall be inserted in the prescribed block at the top of the report.

5.1.4 Repair of Specimen

This section shall be filled out by personnel in the repair activity, listing the items replaced and/or the conditions repaired in the test specimen. A description of the past history of any replacement parts (new, burned in, temperature cycled, etc.) together with the identifying nomenclature (circuit symbol) and the serial number, date code, etc. of the part it replaces shall be included.

Spaces should also be provided at the foot of the form for signature of contractor and evaluation group representatives, signifying agreement with the diagnosis and classification of primary and secondary failures. (It is strongly recommended that the evaluation group have a technically competent representative in attendance during all failure diagnosis activity. This is the best way to insure agreement on diagnosis. If this is not done it may be necessary to provide considerably more documentation of the diagnosis activity.)

5.2 Section Two

This section shall be composed of the reports on those supplementary investigations and analysis as may be required to determine the type of corrective action needed to prevent recurrence of observed test specimen failures. In general, a minimum of three reports will be required, as follows:

5.2.1 Analysis of Failed Component Report

This report may be prepared on any appropriate format, i.e., formal test report, company internal correspondence, company memorandum, etc., but should be readily reproducible. It shall be prepared by the person performing the component analysis and shall contain the following information:

(1) Appropriate heading, referencing the applicable test specimen failure.

(2) Verification of failure diagnosis findings as to discrepant conditions.

(3) Results of tests performed on the component, i.e., resistor temperature cycled and found to be open only above 80° C, etc.

(4) Results of dissection, if such is possible, and microscopic analysis.

(5) Statement as to possible causative factors, relating the normal equipment operating conditions either significant or insignificant.

(6) Results of any tests performed on additional new components to determine the susceptibility of the component to the type of failure under investigation.

(7) Conclusions drawn as to the overall quality of the component and its suitability for use in its intended application.

5.2.2 Design Analysis Report

This report may be prepared on any suitable, reproducible format. It shall be required in the event that failed component analysis cannot reveal the true cause of component failure or when the equipment failure is caused by design deficiency. It shall include at least the following information, wherever applicable:

(1) Appropriate heading, referencing the applicable test specimen failure.

(2) Results of design tolerance studies, if this appears to be related to the equipment failure.

(3) Results of electrical and/or mechanical design studies of mounting techniques, parts layout, materials used, etc., as may be applicable to the failure.

(4) Conclusions drawn as to the suitability of the equipment design to perform its intended function in view of the observed failure.

5.2.3 Corrective Action Proposal

This proposal may be prepared on any suitable, reproducible format. It shall be prepared based on the failure diagnosis findings, failed component analysis, and design investigations, and shall contain proposals of methods to prevent the recurrence of the observed failure. The proposal shall contain heading information referencing the applicable equipment failure and shall contain one or more proposals of corrective action, representative examples of which are as follows:

(1) Component specification to be changed to reflect new tolerance limits.

(2) Additional tests to be added to component specification which will effectively sort out defectives.

(3) Specify different materials to be used in construction of component.

(4) Change part vendor.

(5) Alter circuit design.

(6) Relax equipment specifications toward more realistic requirements.

Each corrective action proposal shall be substantiated with sufficient background information and/or data to adequately verify the effectiveness of the proposal.

On completion of the reports required in section two, they shall be compiled and attached to the form of section one. This shall then comprise the completed Failure Diagnosis Report as required for test specimen failures.

6. RULES FOR PROCEDURES

6.1 Prior to beginning the test, the periodicity for monitoring test facility and test specimen parameters shall be established. After the test has been in progress for a reasonable length of time, test results should be reviewed and consideration given to either shortening or lengthening the period, as test conditions indicate.

6.2 Prior to beginning the test, allowable breaks in testing should be established. This should include decisions as to permissability of one shift operation, shut down due to week ends and holidays, etc.

6.3 Periodic intervals for test station calibration should be established prior to the start of the test. However, no test specimen should be penalized for test equipment out-of-tolerances occuring between scheduled calibration periods.

6.4 The contractor is allowed to perform any necessary debugging and testing on the test specimen prior to the start of the test. Operating time so accrued shall not be counted as test time.

6.5 In initiating the test, the test specimen may be operated in the test facility for a sufficient length of time to insure proper operation and calibration. Operating time so accrued shall not be counted as test time. Any specimen failures occurring during this period shall not be counted as test failures.

6.6 If the test facility fails during the course of the test, it is recommended that the test specimen be replaced with similar equipment not under test if such is needed for proper diagnosis of the test facility failure. If no other equipment is available, the test specimen may be used but time so accrued shall not be counted as test time unless the representative supervising the tests agrees that test conditions are reasonably representative of normal requirements. However, any test specimen failures that occur during this period must be counted as test failures unless it can be adequately verified that the failure was due to abnormal conditions existing in the test facility.

6.7 Preventative maintenance on the test specimen shall not be allowed unless specifically called for in the contract with respect to this test. Adjustment of operator controls is not considered preventive maintenance. Anticipation of failure shall not be justification for preventive maintenance.

6.8 It is permissable for the repair activity to operate a repaired test specimen for any length of time necessary to verify the correctness of diagnosis and repair.

Any operating time so accrued on the test specimen shall not be counted as test time under the representative supervising the tests agrees that test conditions are reasonably representative of normal requirements. However, failures occuring during this time shall be counted as test failures.

6.9 Before replacing any parts in a test specimen, authorization must be obtained from the cognizant representative of the evaluation agency.

7. <u>RULES FOR CLASSIFYING FAILURES</u>

7.1 An apparent test specimen failure that is reported by the operator but cannot be verified by the failure diagnosis activity, or that disappears during the course of failure diagnosis, shall be counted as a test failure.

7.2 The following rules shall govern the assessment of discrepant parts detected during failure diagnosis: (Parts are considered to be such items as resistors, capacitors, tubes, etc.).

(1) Any part which is outside its specification tolerance but does not cause equipment malfunction shall not be counted as a test failure and shall not be replaced.

(2) If an equipment malfunction is found to be caused by a part which is within its specification tolerance, it shall be counted as a test failure and shall be replaced. The condition must be covered by a corrective action proposal.

(3) In the event failure diagnosis reveals that more than one part in a failed specimen is both outside specification limits and will independently cause unsatisfactory equipment operation, each such part shall be counted as a separate test failure unless it can be adequately demonstrated that the failure of one part in turn caused the immediate or subsequent failure of one or more of the other parts. In this event, the initial failure, hereafter called a primary failure shall be counted as a test failure; the dependent failures may be classified as secondary failures and need not be counted as test failures.

(4) If two or more parts are found, either within specification or not, that jointly contribute to an equipment malfunction, no single part being independently capable of producing equipment out-of-tolerance, all such parts shall be removed and only one test failure counted for the combination. Details of the circumstances shall be presented to the design activity for close study and the condition must be covered by a corrective action proposal.

(5) In the case of mis-diagnosis in which a part is replaced and equipment out-of-tolerance is not corrected the original part shall be replaced. If the part is damaged during removal and cannot be replaced, it shall be counted as a test failure unless the representative supervising the tests can be completely satisfied that no attempt is being made to replace incipient failures.

8. TEST PROCEDURE AND USE OF FORMS

Prior to beginning the test, the contractor shall prepare a detailed test plan and the necessary official data forms. These shall be approved by the evaluation group. The contractor shall also obtain approval from the evaluation group of the test facilities to be used.

When the approval of the above has been obtained, the test may begin. Heading information is to be inserted on the Test Data Log, Operators Log and Equipment Failure Log. The equipment under test is then installed in the test facility and necessary proof runs are made to insure proper operation of the facility. When satisfactory operation has been obtained, the test operator shall make the first entry in the Test Data Log and the test shall officially begin. This entry and all subsequent entries in the Test Data Log, Operators Log, and Equipment Failure Log, shall be initialed by the operator making the entry. Entries shall be made thereafter in the Test Data Log at the prescribed intervals. Appropriate entry shall be made in the Operators Log at intervals of test facility calibration. When the first apparent test specimen failure is observed, the test operator shall make an entry in the Equipment Failure Log, suitable entry in the Test Data Log and initiate section one of the Failure Diagnosis Report. The failure diagnosis activity shall be immediately notified and shall verify the existence of the discrepancy without removing the test specimen from the test facility. If the discrepancy is verified, the specimen shall be removed from test without disturbing the remaining equipments under test. The failure diagnosis activity shall then proceed with failure diagnosis, filling out applicable portions of the Failure Diagnosis Report. The repair activity shall perform required rework on the specimen and fill out the applicable portion of the Failure Diagnosis Report. After appropriate signatures have been affixed to the completed first section of the Failure Diagnosis Report, the repaired specimen shall be returned to test and entries made in the Test Data and Operators Logs to indicate satisfactory operation. Failed parts removed from test specimen shall be analyzed and the design group shall be informed of the failure. Section two of the Failure Diagnosis Report shall be prepared by the responsible personnel. If failure diagnosis reveals that the observed discrepancy was not caused by the test specimen, the entry in the Equipment Failure Log shall be struck out and initialed and appropriate explanatory entry, referencing the Failure Diagnosis Report number, shall be made in the Operators Log. All additional apparent test failures shall be handled in a similar manner. At the time of each entry by the test operator in the Equipment Failure Log, he should check the test chart to determine if a decision to pass or fail the test specimen can be made, or if the test must continue.

As soon as the decision is made, either pass or fail, all Test Logs and Failure Diagnosis Reports shall be compiled into a final Test Report. The contractor shall include in the Test Report a test summary, including evaluation of the test results and recommendations as to which corrective action proposals should be incorporated into the equipment. The final Test Report shall be submitted to the evaluation group for approval.

APPENDIX C

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Task Group No. 3

PILOT PRODUCTION AND

PRODUCTION MODEL TESTS

15 January 1957

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The Task Group further expresses its appreciation to the Vitro Laboratories Division of the Vitro Corporation of America for providing the typing and reproduction of the Group's Minutes and of this Report.

TABLE OF CONTENTS

ABSTRACT

Practical means for performing quantitative evaluation of the reliability of pilot production and production models of electronic equipment are available. These can determine conclusively whether or not the equipment meets a specified minimum acceptability requirement.

The testing methods which provide specific routines for (a) reliability index evaluation of pilot production equipment, (b) reliability index evaluation of production equipment, and (c) longevity evaluation of pilot production and/or production equipment are presented. These test routines permit, respectively, (a) establishment of capability for meeting minimum reliability requirement, based upon the greatest testing economy with respect to number of equipments tested and testing time required; (b) statistically conclusive proof that an acceptable percentage of quantity-produced equipments meet a minimum reliability requirement, with maximum economy of test cost and time; and (c) conclusive proof that equipment reliability does not degrade during the desired equipment life below a prescribed minimum level.

The procedures are developed in such a manner that they are reasonably immune to tampering by the contractor or by prejudiced testing personnel. In addition, selected redundancies in data handling render the testing methods reasonably self-checking and immune to errors in data recording. Specific means for accomplishing the evaluations are described. These are in the form of detailed testing methods, circumscribed by complete rules for administration and procedure. Elective parameters left to the procuring agency are only those which must relate (1) conditions of equipment end-use to the testing procedure, and (2) conditions of procurement volume and scheduling to the testing sequence. Factors which cannot affect evaluation conclusions but can affect testing convenience are left for election by the procuring agency or the contractor.

Recommendations for a program of implementation are offered.

I. INTRODUCTION

A. Statement of Mission

1. General

AGREE Task Group No. 3 was directed to develop basic requirements for a quantitative evaluation to be accomplished on pilot production and production models of electronic equipment which will prove conclusively that the equipment will meet the minimum acceptability figure for reliability established for the equipment type. The directive provided that this evaluation should be designed to be performed either in addition to or in conjunction with (but not in lieu thereof) whatever performance evaluations and operational suitability evaluations are specified for the equipment.

One of the first functions of the Task Group was to interpret this directive in terms of a definitive statement of its mission. This was originally stipulated in the minutes of the Third Meeting in April, 1956. This mission in final form follows:

> It is the mission of the Task Group to formulate a body of rules which should govern the materiel services of the military in the technical aspects of specifying reliability evaluation requirements for military electronic equipment procurement; particularly, this Task Group is concerned with the evaluation of equipment reliability in pilot production and production.

A number of more detailed criteria governing the nature of the rules were agreed upon. These include importantly the following:

(a) They shall be submitted in a form suitable for immediate application by the procuring service.

(b) Their applicability shall be suitable for extension to all military electronic systems and equipment procured in pilot production and production quantities by any of the services.

(c) The principles reflected therein shall be sufficiently basic so that their applicability shall extend equally among variations in type, application, construction, and production methods and so that it shall insofar as possible ensure independently of the state-of-the-art in electronic equipment. The advent of improved techniques and procedures appropriate to the determination of reliability in pilot production and production equipment may, of course, lead to refinement or change.

(d) While the evaluation techniques and procedures are to be explicitly specified, and background material shall be included to permit alteration of the data evaluation method and the acceptance criteria recommended, sufficient basis shall be provided to govern the selection of procedure and conditions by the procuring agency to aptly suit the type of equipment (and its application) to be evaluated.

2. Definitions and Related Philosophy

To provide unanimity of purpose and sound understanding within Task Group No. 3 it was found essential to redefine certain applicable terms with respect to the task mission. Most basically it was necessary to specify definitions for equipment reliability and its antithesis, equipment failure probability, which would be suitable to all requirements of the assigned mission. Table 1 provides a list of definitions adopted by this Task Group.

Since equipment reliability can be conveniently expressed as a probability of desired operation without failure, prediction of the pattern of equipment failure occurrences during the useful life span becomes essential to reliability determination. The observation of newly produced equipment submitted to synthesized conditions of ultimate use permits notation of the times of occurrence of failures. These data can provide sufficiently accurate measure of the intrinsic failure/time pattern to permit useful determination of reliability index. To establish proper basic references equipment failure is herein defined as follows:

> An equipment failure, during pilot production or production reliability evaluation, is the cessation of the equipment's ability to meet minimum performance specification imposed by contract. Adjustment of operator controls is allowed to any extent necessary to maintain specified performances, and such adjustment shall not in itself constitute a failure.

If the minimum performance specification imposed by contract, and applicable to the above definition of equipment failure, differs appreciably from that minimum performance essential to any particular field condition of operational use, the operational reliability of the equipment observed during field use may be significantly different from the reliability predicated on pilot production or production tests. While it is desirable that the latter prediction yield a reliability index suitable for computation of inherent equipment reliability, and thus useful to essentially all varieties of operational use, it is imperative that the minimum performance specification imposed by contract for use in the reliability testing described herein be realistically limited to a minimum

TABLE 1

DEFINITIONS

EQUIPMENT An equipment is a fixed number of items which are required for the performance of a complete, specific, operational function.

SYSTEM A system is a group of equipments, including any required operator functions, which are integrated to perform a related operation.

PILOT PRODUCTION Pilot production is the initial post-tooling production, the primary purpose of which is to prove the capability of the tooling and production line.

EQUIPMENT FAILURE An equipment failure during pilot production and production is the cessation of ability to meet that minimum performance specification essential to satisfactory application. Further, equipment failure shall imply that the minimum acceptable performance specified for the application is not reobtainable through permissible readjustment of operator controls.

EARLY FAILURE PERIOD The early failure period of an equipment is that period of equipment life starting just after final assembly where equipment failures occur initially at a higher than normal rate due to the presence of defective parts and abnormal operating procedures. Also called the "de-bugging" or "burn-in" period.

NORMAL OPERATING PERIOD The normal operating period of an equipment is that period of equipment life during which the equipment failure rate remains essentially constant.

WEAROUT PERIOD The wearout period of an equipment is that period of equipment life, following the normal operating period, during which the equipment failure rate increases above the normal rate.

EQUIPMENT LONGEVITY Equipment longevity is the length of the normal operating period of equipment life. The beginning of equipment longevity usually occurs when the equipment failure rate during the early failure period drops sufficiently low to be within and remain within specified limits and usually ends when the equipment failure rate rises above the specified limit, marking the beginning of the wearout period. Longevity can be specified either in terms of equipment hours of operation or calendar time of equipment life. In the case of the latter, the number of equipment operating hours to be expected per unit of calendar time is an important consideration.

TABLE 1 (continued)

RELIABILITY Reliability is the probability of performing without failure a specified function under given conditions for a specified period of time.

INHERENT RELIABILITY Inherent reliability is the probability of performing without failure a specified function under specified test conditions for a required period of time.

EQUIPMENT RELIABILITY Equipment reliability is the probability of performing a specified function, under given conditions, at a measured reliability index (average failure rate in terms of its reciprocal mean-time-between-failures) and for a measured equipment longevity (the total period of time during which this quality is maintained).

RELIABILITY INDEX Reliability index is that average measure of the equipment failure rate (usually obtained during the normal operating period of equipment life) expressed in terms of "mean-time-between-failures" (MTBF or $\bar{T}$). Unless otherwise stated, the convention is that the mean equipment operating time between failures is meant by "mean-time-between-failures."

number of performance characteristics readily assessable by operating personnel such that evaluation techniques are not cumbersome. The reliability index derived must permit calculation of inherent equipment reliability that is neither much higher nor much lower because of differences in performance criteria than typical or average operational reliability observed during field use. Compliance with this philosophy will permit ready and valid comparison between test indices on unlike equipments as well as comparisons between test indices and field observations.

The basic motive of the task mission is to provide means generally effective in preventing equipment below selected minimum reliability requirements from reaching the field. Accordingly, the evaluation methods proposed permit evaluation of the failure rate (and, conversely, its reciprocal, mean-time-between-failures) versus equipment age. Since the basic desire is to recognize equipments whose failure rate is too high, either initially or prior to the end of a selected and prescribed life duration, it is convenient to illustrate this type of failure rate versus life characteristic which must be recognized through the evaluation procedure described and recommended herein.

Figure 1 is idealized to emphasize that the general life characteristic should be considered with respect to 3 phases, which are identified as the early failure, normal operating, and wear-out periods. Perhaps the most important liberty taken in using a smooth curve such as that of Figure 1 for illustrating the failure rate life characteristic, is that the smooth failure rate curve implies that failures occur at uniform time intervals of either constant value or of uniformly charging value, whereas in actuality the failures (of interest to this discussion) occur randomly in time, and it is the value of their average occurrence interval that has been used to compute the failure rate illustrated. Since averaging requires group consideration of a number of failures (rather than one or two), one must collect such failure groups over a period of time (which may become significant with respect to the time scale used in Figure 1), or one must collectively use data from a number of the same type of equipments under like conditions and exhibiting like characteristics (though not necessarily exhibiting simultaneous failure occurrences.

Operating time accumulated prior to delivery by the manufacturer, combined with the inherently lower-slope portion of the initial portion of the failure rate time curve may prevent the equipment user from recognizing the existence of the early failure phase. Equipment obsolescence, or perhaps unrepairable major failure may prevent service use into the actual wear-out period. The basic interest of the task mission with respect to failure rate during a prescribed interval of equipment operation (desired useful life) is in the development of means for determining that no recognizable circumstances can or will exist to permit significant increase of failure rate before the elapse of the life period. Accordingly, the life characteristic as illustrated by Figure 1

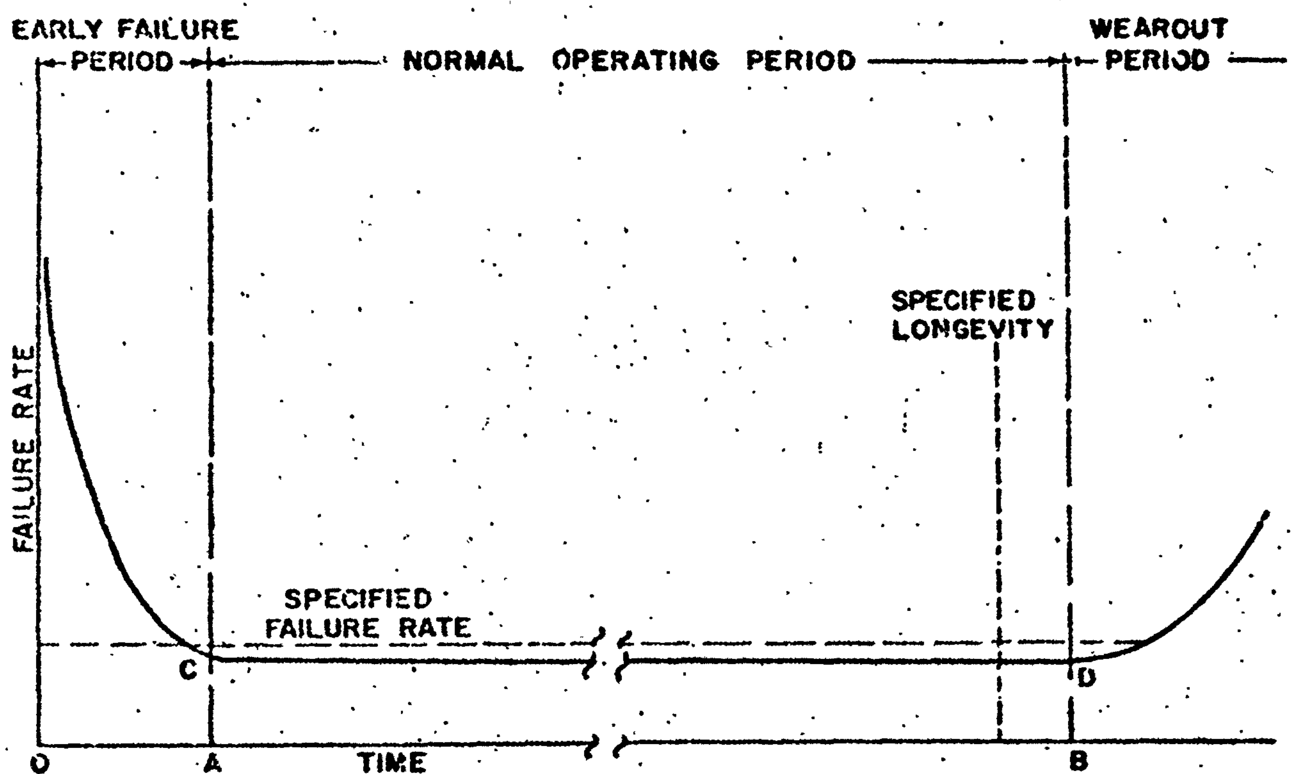

Figure 1. Equipment Life Characteristics—The Reliability Function Under Constant Environmental Operating Conditions

is most suitable for illustrating the consideration which has been given to the evaluation procedures recommended herein. Figure 1 shows that the failure rate (λ) with respect to time decreases during the time 0 to A, remains essentially constant during A to B, and increases beginning at time B. These three phases or periods of time are correspondingly called the "early failure", "normal operating", and "wear-out" periods.

The early failure period (0 to A) is that period which (when its existence can be detected) begins at the first point during manufacture that total equipment operation is possible and continues for such a period of time as permits (through maintenance and repair) the elimination of marginal parts, initially defective though not inoperative, and unrecognizable as such until premature failure. Upon replacement of all such prematurely failing items, the failure rate will have reached a lower value (point C) which will remain fairly constant and which defines the beginning of the normal operating period. Because customary curve smoothing techniques, necessary to develop an average from ra⋯m data points, markedly reduce the accuracy with which a ⋯int of inflection can be located, it is probable that som⋯ difficulty may generally be encountered in determining the abcissa (time) location of point C. However, once the failure rate falls below the allowable maximum specified, a precise determination of the time location of point C is of secondary interest, as the failure rate will not be expected to again increase until the end of the normal operating period of the equipment life, point D.

The normal operating period (A to B) is that period in terms of equipment operating time in which the average failure rate is and remains essentially constant. Here, in measuring reliability, the average height of the curve (A to C or B to D) is essentially constant. Also, the useful operating life, in the sense of longevity prior to the old-a⋯e or wear-out period can be identified as A-B if the failu⋯ rate during the early failure period is intolerable, or som⋯thing closer to 0-B and measured from the time of equipment delivery, if the higher early-failure rate is within the limit of acceptability. It should be noted that sometimes the onset of the wear-out period (point D) is a basic function of total equipment age (distance 0-D) and sometimes it is a basic function of the user's environment and maintenance technique and thus not affected by an interval (such as 0-A) which elapses prior to delivery to the user. Reliability evaluation techniques as set forth herein rely on synthesized rather than actual user environment, and equipment repairs are perforce performed by personnel with considerably different skill than expected in the field. Accordingly, in such instances where the onset of equipment wearout is more a function of user environment and maintenance than of total accumulated equipment operating time, the estimate of the time of wearout made during reliability evaluation may differ somewhat from the time of the wearout later observed in the field.

For purposes of reliability evaluation the convention of expressing the reliability index of the equipment ($\bar{T}$) in terms of the reciprocal of failure rate ($1/\lambda$) or mean-time-between-failures (MTBF) has been adopted. The specified acceptance level for failure rate shown in Figure 1 would therefore have been equal the reciprocal of the specified MTBF. Convention also dictates that MTBF be taken as operating hours. Longevity specified, however, is intended to be calendar time including, therefore, the total life of the equipment. Longevity is specified as indicated in Figure 1 and may be expressed in hours or years or other time units as appropriate to the application.

Thus equipment reliability and longevity during pilot production and production may be defined as follows:

> The reliability index ($\bar{T}$) is the constant coefficient in the formula $P_o = e^{-t/\bar{T}}$ expressing the probability of performing a specified function, under specified test conditions, as a function of accumulated operating time (t), and is measurable and expressible as hours mean-time-between-failures (MTBF).
>
> Equipment longevity is the operating life span during which at all times the specified equipment reliability index is equaled or exceeded.

It is worthy of note, with respect to the possibility or likely existence of an early failure period during which the reliability index is inferior to that exhibited later, that there may be some temptation to prescribe a standard operating period (frequently identified as a burn-in or debugging period) prior to reliability evaluation. However, it must be kept in mind that the existence of such an early failure period is a function of manufacturing techniques, parts control, inspection, and quality control, rather than equipment design, and is thus subject to change with production evolution. It would seem prejudicial to arbitrarily expend any part of the useful equipment life in preference to improvement of production techniques, except as an interim measure to provide time for study and preferred remedy. In any case reasonable assurance should exist that all delivered equipments meet reliability requirements at the time of delivery and do not require any burn-in by the user in order to demonstrate acceptable reliability.

3. Evaluation Characteristics

The specified tests when performed on the prescribed production samples establish with a selected confidence that a statistically known major fraction of the entire production lot of equipments possess a reliability index and a longevity equal to or greater than those minimum values required by contract. In addition, and as a result of performing the specified tests, it will be possible to make the following observations:

(1) While test results from the test of pilot-production equipment will in general only be representative of production capability for achieving reliability, the same tests when applied to controlled-process production will yield results indicative of the actual characteristics of the produced equipment.

(2) The data collected during performance of test will be in a form suitable to give strong indication of the nature of remedy to obtain reliability improvements.

(3) Conclusions relative to the mean-time-between-failure as determined by manufacturer's evaluation will be as applicable to mean-time-between-failure performance in tactical application as present state-of-the-art, desirable standardization, and practical economy permit, when adjusted for the relative field maintenance capability, and it will be reasonably convenient to adjust the method of selection of test conditions by the procuring agency to effect closer correspondence with the field as rapidly as field experience on tested equipment is acquired and correlation becomes possible.

(4) From viewpoint of program economy, both with respect to the number of tested equipments withheld or delayed from delivery schedule, and with respect to duration of test beyond desirable schedules before conclusions can be reached, the confidence level associated with test conclusions may purposely be reduced below an otherwise desirable level in order to suffice with less extensive and protracted tests. This particularly applies with respect to tests for longevity. However, it must be borne in mind that lowered confidence in primary determinations does not invalidate or prevent several important secondary yields from abridged testing, such as: (a) insight to logistic maintenance requirements, (b) added data for correlation with field experience, and (c) engineering information of great benefit to future design changes, new models, and later development.

B. Approach to Achievement

The Committee members undertook as their first objective the establishment of background familiarization in the electronic reliability problem. To this end, a bibliography of reports dealing with electronic reliability in its various aspects was prepared. This was augmented from time to time as additional titles came to the attention of the Committee. The final bibliography is included herewith. The reports were obtained by OASD (AE) and distributed to the Committee members for review.

A total of 15 meetings were held by the Committee between 17 February and 18 December 1956, the dates of the first and last meetings. During the course of these meetings, various aspects of the problem were considered and at any meeting where an immediate basis for formulating procedure was not available, members were assigned the task of organizing the material for the next meeting. Several visitors qualified in various phases of the problem attended the meetings from time to time and the Chairman obtained consultations on certain statistical aspects from others. The Chairman also made a field trip to the Naval Air Development Center at Johnsville to witness and discuss reliability tests on the AN/ARN-21, TACAN.

It has been the expectation of the Committee by these means to fulfill the objective of its mission by providing specific recommendations in as readily useable form as possible. Particularly, it is intended that these be of a sort which are suitable for defining practical procedures from the standpoint of technical considerations as well as considerations of time and cost in their employment.

C. Summary of Results

The Committee feels that it has fulfilled the essential elements of its objective. A framework of methodology has been formulated and is presented in Section II. of this report. Review and evaluation of statistical test techniques have led to the development of a unique sequential sampling method for the reliability testing of pilot production and production models in order that the evaluations will not necessitate intolerable production delay and will permit sound decisions at adequately low risk. The material presented in Section II of this report describes the complete test method and procedure. It is in a form which can be readily adapted for use in standards or specifications. Recommended methods for data collection, handling, and interpretation are included as part of the overall procedure.

It is only recently that reported reliability programs have begun to look for correlation between the results obtained from tests of the nature described in this report and the frequency of equipment failure found in field use. Although favorable correlation is as yet meager, this can more than likely be attributed to the usual lack of discipline during tests and to the major differences between the conditions of tests and the conditions of field use. However, there is beginning to appear encouraging evidence which indicates that reasonably good correlation should be obtained when testing is controlled to the extent recommended in this report. There is unquestionable evidence that superior equipment performance during such tests will always be associated with markedly improved reliability in the field. The techniques for testing as recommended herein have been designed to permit certain election and choice by procuring agencies such that improvement in correlation will be rapid, automatic, and in proportion to field experience gained on previously tested equipment categories.

Section II of this report is intended to provide the basic material or end-product resulting from the work of this Task Group. Section III of the report offers a general discussion of this material. Conclusions and recommendations are included in the remaining sections.

II. Methods for Reliability Testing of Pilot Production and Production Equipments

A. Philosophy of Test Procedures and Methods

Reliability evaluation is intended to augment all normally required performance tests. It should not be construed that the environmental requirements associated with the reliability evaluation recommended herein in any way supplant or obviate contract requirements for type testing. While it is not necessary to establish compliance with type test requirements prior to conducting reliability tests, there should be reasonable assurance that the equipment is capable of expected performance under the environmental conditions chosen for the reliability evaluation before it is begun. The performance of the equipment under the conditions of the reliability evaluation must be specified.

By reference to Figure 1 and the definitions given in the introduction, it is readily seen that the two basic characteristic measures of equipment reliability in pilot production and production are MTBF and longevity. It is readily apparent, from a measurement or test viewpoint, that the former characteristic is the more important. This is particularly so since continuation of the equipment reliability quality test in time may yield all data necessary for the evaluation of equipment reliability longevity. Hence, let us first consider the pertinent aspects of equipment reliability quality testing.

1. **Reliability Evaluation**

The MTBF characteristic for the equipment (and in fact for a particular lot of equipment) is chosen as the measure of equipment reliability index. Since the reliability index of an equipment in tactical operations can be established in terms of a single limiting value of its MTBF, such that equipments whose characteristic exceeds this value are judged satisfactory, and those which fall short of this value are judged unsatisfactory, it is possible to design a corresponding testing methodology statistically sound and requiring minimum test data.

Accordingly, the statistical design of the sequential test methodology recommended herein embraces the evaluation of a single variable against a single (lower) limit. This statistical evaluation in effect tests a basic equipment parameter; viz., MTBF. This parameter in its relationship to the lower limit is the measure of acceptability, rather than the often used measure, lot fraction defective. In the realm of testing economy, it may be noted that variables tests require fewer data observations than attributes tests. The required number of observations is further reduced by the employment of a sequential test technique. The net result of this test selection is to reduce testing time (or conversely the number of equipments for tests) to about 30% of that normally required by more conventional techniques. The two kinds of conventional risks, found in all statistical testing methods, have in no way been compromised in effecting the aforementioned economy. The first risk is that of judging the equipment unacceptable when in reality it meets the required minimum, and this risk has been arbitrarily set at 10%. The second risk is that of accepting equipment which in reality does not meet the minimum requirement, and this risk has been arbitrarily selected to permit 10% probability of acceptance of equipment whose MTBF is 67% of the minimum required. The minimum MTBF required by contract has been chosen so that 67% of its value is sufficient for tactical requirements. Information is contained in Section III to permit the procedures of this section to be corrected for any other values of risk judged more suitable, but it should be noted that lessening of risk is always associated with increase of test cost.

Any test to determine the MTBF necessitates operation of equipment tested for sufficient length of time to observe several failures. Although such operating requirements may consume no more than a negligible portion of the equipment's normal useful life, it is difficult to make a general statement that such tests can regularly be considered nondestructive. Accordingly, the proposed reliability tests have been designed to reduce to an absolute minimum the cost and duration of the test program even if the tests should be considered destructive and the tested equipments unsuitable for consumer use.

Determination of MTBF necessitates the observation of the time of occurrence of a number of failures, which can be and are treated as a sample of all the future failures expected to occur during useful equipment life. Thus, since sampling techniques are inherently required for determination of the reliability characteristic, it is both convenient and consistent as well as economical from the destructive view to judge the production product by testing samples randomly drawn from production lots. Although the validity of general conclusions based on data from a sample usually presume and rely on characteristics behavior explicitly in accordence with a known type of distribution (viz., exponential, random, gaussian, etc.) the statistical method employed herein for production permits certain general conclusions which are totally independent of distribution. More specific conclusions, available when the production quantity and production cycle justifies a larger sampling, do have dependence upon the assumption that the MTBF of individual equipments in a production lot will be distributed (vary) in a normal manner (following a Gaussian distribution). The most significant argument in favor of this conclusion is that regardless of the heterogeneity (rather than homogeneity) of minor details in a production lot of otherwise identical equipment the manufacturer, in face of requirements for minimum acceptable MTBF obtainment, will do everything within reason that he can to maximize the MTBF, and such concentrated effort regularly leads to a normal distribution of the result.

The sampling tests for production equipment herein proposed are based on a continuous sampling plan for a single attribute, the MTBF either above or below the acceptable value as determined by the sequential test technique as prescribed for pilot-production equipments. The types of risks are the same (as in pilot-production sequential tests) and their numerical values are selected to permit the magnitude of test endeavor to be consistent with production quantity and scheduling.

The reliability index evaluation method for application to pilot production, since it involves determination of capability alone, embraces only the method for determination that the MTBF exceeds the expected value with adequately limited risks. The test procedure for production equipment involves a combined test wherein the test method for pilot production is expanded to relate findings from the production sample to the entire production output.

2. Equipment Longevity Evaluation

As previously indicated, longevity may be measured using the identical procedures, environmental conditions and methods of test herein applied to reliability evaluation. The statistical methods of selection, the quantities tested and the acceptance or rejection of equipment by means of a sequential test, as above, are similar to those for production reliability evaluation except that the confidence level is lowered to permit the frequency of this protracted test to be consistent with production quantities and schedules.

This latter characteristic of longevity testing makes the establishment of longevity test criteria difficult. For example, the test period required to measure time to ultimate wearout of a single relatively small and uncomplex equipment (inter-com) may extend over several years when testing is done under normal environmental conditions. Also, and in contrast, a large and complex computer may never reach a recognizable wearout period because of the continual maintenance program associated with and presently required by its operation prior to obsolescence.

B. Pilot Production Test

Perhaps the most usual reason for a requirement for pilot production is to establish to the customer's satisfaction his acceptance of a sample of what might be available from regular production. From the manufacturer's viewpoint, pilot production permits him to prove out tooling, manufacturing processes, evaluate needed skills, and generally pin down final details involved in designing a suitable production process. Accordingly, it is generally assumed that a pilot production run will yield equipments only generally indicative of those to be expected from production, inasmuch as higher level personnel are generally employed at the pilot production line than will later be assigned to man the regular production line, and the process control during pilot production is kept in a very flexible condition to permit process adjustment to maximize economy and adjust for performance requirements. Usually, many changes take place between the beginning and the end of pilot production even though but few equipments are produced during this run. All of these factors contribute to the conclusion that any tests of pilot produced equipments can at best measure capability only, and pilot produced equipments certainly do not belong to the same population as regular production equipments processed under tight production control. With capability as the single yield from pilot production reliability testing it is possible to grant the manufacturer complete freedom to choose any equipments he may desire from the pilot production run for the reliability test. If he chooses especially reliable equipments he risks generating false confidence in the extent of reliability attainment which will handicap his chances for satisfactory reliability in production equipments, as well as tempt the procuring agencies to raise the reliability requirement. If he chooses especially unreliable equipments he risks finding that they will fail to pass the reliability test. In order to minimize the possibility that the pilot-run equipment tested is not typical, the minimum quantity of equipments tested should not be less than two

The methods and procedures for sampling, selecting standard environmental conditions, performing the reliability test and recording its data, as well as for data handling and interpretation are set forth in the subsections below.

1. Reliability Index Evaluation Methods and Procedures

(a) Sample Selection

Possibilities for sample selection for pilot models are limited by the usually small number of equipments available. Equipments may be selected in any sequence desired. Each should already have demonstrated its ability to perform properly.

The contracting agency shall make an election as to the number of equipments to be assigned to reliability test. It is to be noted that the probable length of test will vary inversely with the number of equipments on test (for a fixed confidence level in the test outcome). As limits, the minimum number of equipments assigned to test should not be less than two, and the minimum length of test even for large numbers of equipment under test should not be less than three times the contract specified mean-time-between-failures. Table 2 illustrates possible testing duration versus number of equipments assigned to test:

Table 2 - Reliability Test Time

No. of Equipments for Test	Length of Test* (in multiples of MTBF)		
	Shortest Possible	Most Likely	Longest Possible
2	3 (2.29)	10.0	16.5
3	3 (1.53)	6.7	11.0
4	3 (1.15)	5.0	8.3
5	3 (0.92)	4.0	6.6
6	3 (0.76)	3.3	5.5
7	3 (0.66)	3 (2.9)	4.7
8	3 (0.57)	3 (2.5)	4.1
9	3 (0.51)	3 (2.2)	3.7
10	3 (0.46)	3 (2.0)	3.3

*Length of test is shown for acceptable equipment. Unacceptable equipment will fail the test in an equal or shorter period of time than that shown. The values shown are multiples of the specified MTBF ($\bar{T}$). Numbers in parentheses are the times expected were it not for the arbitrary requirement that the length of tests be not less than three times the contract's specified mean-time-between-failure. The convention of extending the tests to at least three times the specified MTBF is accepted to (a) provide additional data in case of a dispute and (b) provide information for corrective action in case the equipment is rejected.

(b) Environmental Specification and Test Conditions

The following section specifies standardized test conditions for the reliability test which will permit reliability comparison between the many procurement programs without significant compromise to field correlation. The figure of merit or reliability index (mean-time-between-failures) obtained for the equipment under test will be a useful measure of the field reliability even though the test conditions only approximately simulate the combined environmental effects which may be obtained in field use. Thus, while the measured MTBF may differ somewhat from that prevailing during operational use, this discrepancy will be small in contrast to that due to errors of measuring technique, differences in application, field maintenance, etc., and is a small price to pay for the many benefits of standardization, especially the opportunity to compare unlike equipments under standardized conditions.

A series of especially chosen environmental test conditions in four levels of stress severity are presented. The four levels chosen are a practical compromise to cover a wide range of actual environmental conditions. Field correlation with test results as well as a general increase in the state-of-the-art may justify more stringent tests which can then be devised. The four conditions given are believed adequate for use on pilot-production and production equipments in proving the approximate inherent reliability of most present-day and near future electronic equipments.

The appropriate level for use on any specific project is to be selected by the contracting agency. The level which most closely duplicates the extreme conditions of end use is preferable. The level thus selected will then apply to all subsequent production of the same item so that uniform reliability comparison is possible. In the interest of standardization of tests and correlation of results no deviations from the prescribed tests should be considered. It is assumed, however, that all use parameters critical for specific equipments, such as cooling air flow and extreme humidity will be specified for test simulation in addition to the specifications herein. It is emphasized that these tests are intended to be applied in addition to all normal type-approval and acceptance tests.

Scope of Environmental Tests

The environmental conditions chosen are restricted to vibration, temperature, on-off cycling, and input voltage for reasons of practicality and correlation of results through simple standardization. Tests involving other environmental conditions such as altitude, humidity, and shock are omitted. It is felt that the standard type-tests will reveal basic faults in these areas and that little is to be gained by including them here.

The reasoning behind the selection of each of the environmental tests is as follows and should be used as a guide in establishing tests for future equipments as well as establishing additional tests which may be appropriate.

<u>Temperature</u>

The temperature is intended to approximate the service conditions under which the equipment will be required to operate.

<u>Vibration</u>

This is not intended to be the most severe condition encountered, but is felt adequate to show up workmanship items such as loose solder joints, loose parts such as screws, bits of wire, etc. This test is to be performed with the equipment mounted solidly on the vibration table without shock mounts.

<u>Off-On Cycling</u>

This test is primarily to give the equipment a temperature cycle, causing the entire equipment to "breathe", expand and contract, be exposed to the surges of starting electrical power, plus checking actual operation.

<u>Input Voltage</u>

Varying the input voltage both above and below the normal rated voltage places strain on the various circuits and, since this is a normal condition in service, will reveal many weak conditions.

<u>Test Levels</u>

The four levels of stress severity are L, M, H, and X, standing for Light, Medium, High, and Extreme, respectively. Since there is always a possibility that any prolonged stress can cause part depreciation, it is recommended that the lowest adequate level of test be used. The adequacy of a test can be established by correlation between test results and field results. The adequacy of an equipment to meet specified test levels will be revealed in the failure rate obtained during the test interval.

The factors of length of test, quantity of equipments tested, and failure analysis techniques are discussed elsewhere.

<u>Test L (Light)</u>

Temperature	=	25° ± 5°C (68°F - 86°F)
Vibration	=	None
On-Off Cycling	=	Three hours "on" plus long enough to stabilize at both high and low temperature by actual measurement. See below.
Input Voltage	=	Nominal so long as within equipment specified voltage range.

The Test L is intended to be a simple bench test run under normal factory conditions for use with equipments which will operate under similar mild conditions. A typical equipment for which test L might be used is a ground based radio-relay set. A set which must be used in the tropics or in a poorly ventilated area may require the use of more severe tests. The application will indicate the appropriate test.

The "off" cycling time may be more or less than one hour depending on the size and complexity of the equipment. The criteria is to determine by actual measurement that the hottest internal area cools down to approximately room temperature during the "off" cycle. The rate of cool down can be used as an indicator. As the hot spot temperature approaches its local ambient the cooling rate will level off. At this point the "on" cycle can begin.

The "on" cycling time may be more or less than 3 hours depending on the conditions and type of equipment. For example, some equipment may have several states of "on" such as transmit and receive, etc. The duty cycle of the transient operating conditions for the "on" period must be established by the contracting agency. This is similarly true for all the levels of test to be described in the following paragraph.

Test M (Medium)

Temperature	= $40^\circ \pm 5^\circ C$ ($95^\circ F$ to $113^\circ F$)
Vibration	= 25 ± 5 cps at $\pm 1/32$" max. Amplitude
On-Off Cycling	= Same as Test L
Input Voltage	= Maximum specified permissible Voltage +0 -2%

This medium test M is similar to test L, but requires a mild vibration test and a heat room which can be elevated in temperature and maintained at $40^\circ \pm 5^\circ C$. This will simulate conditions for mobile and shipborne equipment. Equipment with marginal cooling provision will develop serious hot spots in this test to reveal inadequate design. The "on" time should be three hours plus time to stabilize the internal average temperature to the external ambient. The "off" time should be adequate to cool the interior to external ambient.

The vibration provision can be met by mounting the equipment solidly to a strong flat plate which is supported by vibration mounts and to which a synchronous motor with an asymmetric weight is attached. Adjusting the asymmetry of the weight can control the maximum amplitude of vibration to ±1/32 of an inch. The direction of vibration is not critical. The purpose of this shake test is to dislodge faulty connections such as no-solder joints, and to reveal other workmanship defects in tubes and equipment. Tests, conducted on equipment under vibration, can detect malfunctions not apparent when the equipment is operated under static conditions. Examples of discrepancies which can be located in this manner are: microphonics, intermittents, and instabilities. It may also reveal tubes which are sensitive to mica wear. The duration of vibration should be at least 10 minutes out of every hour of "on" time and continuous vibration is permissible.

Test H (High)

Chamber Temperature	= -54°C to +55°C (-65°F to 130°F)
Vibration	= Same as Test M
On-Off Cycling	= " " " L
Input Voltage	= Maximum Specified permissible Voltage +0-2%

This High test H is intended for use with such equipments as must operate within this temperature range. It requires the use of an environmental test chamber which can change rapidly from -54°C to +55°C or two chambers and a means for rapidly moving the equipment in a water-tight plastic bag or dry air lock. The test sequence is shown in Figure 2. If the equipment is hermetically sealed or is intended to operate when dripping wet, no precautions need be taken during the chamber transfer. There is no intention here to penalize the equipment with high humidity or condensation. This test combines severe thermal shock with vibration and with starting from a very cold condition. (The equipment is turned on in cold condition before warming up.)

Test X (Extreme)

Temperature*	= -65°C to +71°C (-85°F to 160°F)
Vibration	= The same as Test M
On-Off Cycling	= " " " " L
Input Voltage	= " " " " H

The Extreme Test X is the same as Test H, but is intended for use with equipment which will be subjected to a more extreme temperature range. It is important in both Tests H and X that the equipment be turned "on" as soon as it is placed cold in the hot chamber or as soon as the heat is turned on. The length of time required to stabilize the equipment at both extremes can be measured once for a given equipment and thereafter automatically timed.

c. Test Procedure

This is a testing procedure based on sequential analysis to determine if, under specified test conditions, a given sample of equipments exhibits a mean-time-between-failures which is equal to or greater than a specified minimum value.

(1) The sample of equipments for reliability test may be selected in any manner at the contractor's discretion.

(2) The selected equipments shall be fitted with elapsed operating time meters which will indicate the total hours of test time accumulated by the equipment to which attached.

(3) A log shall be set up for use during the test which has columns assigned to the following:

*The extremes of temperature will be governed by the latest applicable specifications.

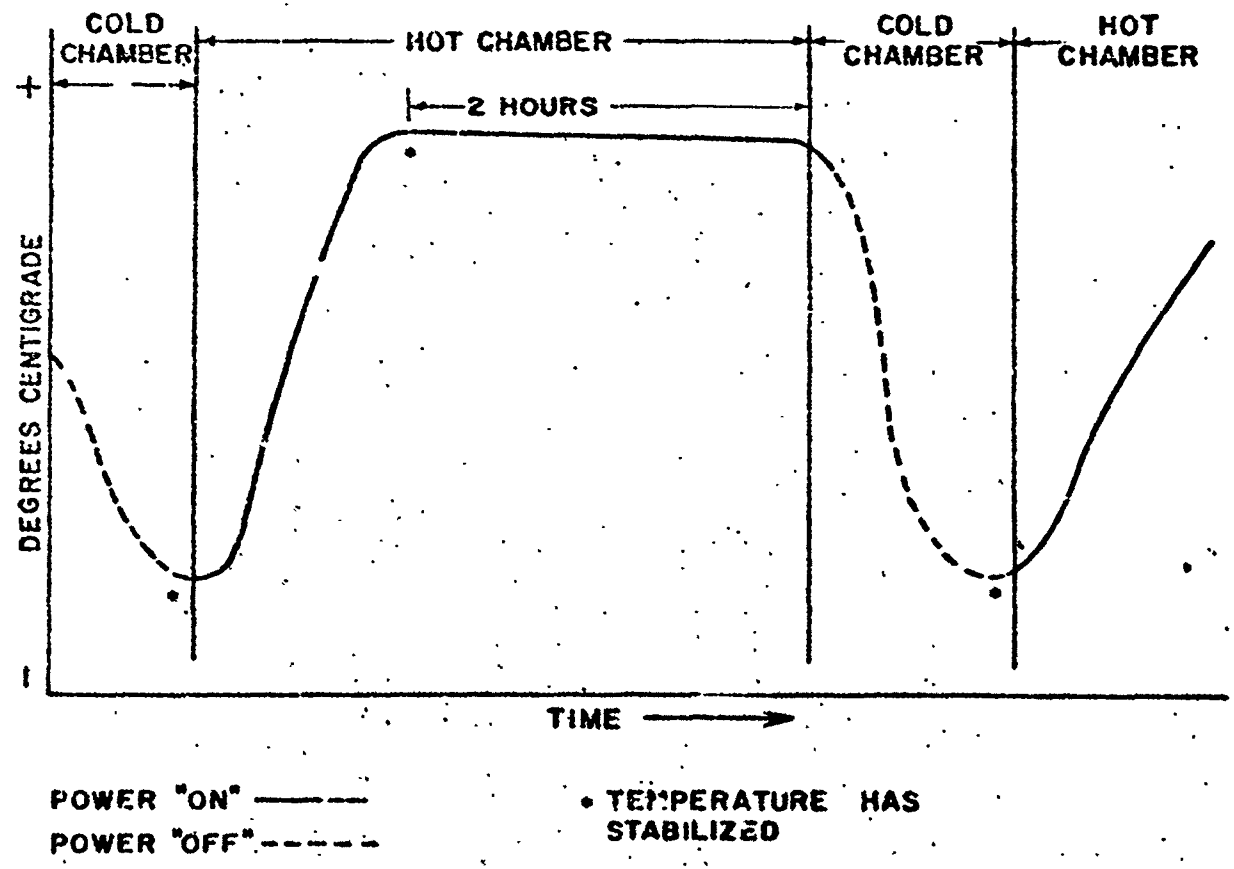

Figure 2. Temperature—Time and "ON-OFF" Cycle

a. Line number
b. Consecutive number of failures observed
c. Date and time of failure observation
d. Accumulated operating time on equipment #1 at time failure in column (b) was observed
e. Same as (d) for equipment # 2
f. " " " " " # 3 if. 3 units under test
g. " " " " " # 4 " 4 " " "
h. " " " " " # 5 " 5 " " "
i. " " " " " # 6 " 6 " " "
j. " " " " " # 7 " 7 " " "
k. " " " " " # 8 " 8 " " "
l. " " " " " # 9 " 9 " " "
m. " " " " " #10 " 10 " " "
n. Total of columns (d) through (m)
o. Column (n) divided by contract specified mean-time-between-failures. See Table 3, Note 1.

(4) The test shall begin only after both the equipments to be tested and the test instrumentation facilities have had suitable operational check-out.

(5) Under no condition is the test to be terminated because of decision to accept or reject the equipment in accordance with subsequent criteria until each equipment under test has accumulated an operating time equal to or greater than three times the specified mean-time-between-failures. Evidence subsequent to the first decision event may reveal the necessity for and direction of investigation to reconcile any apparent conflicts.

(6) At the instance of each failure a log entry is to be made on a single line with observed data for each of the columns listed in paragraph 3.

(7) Log data from columns (b) and (o) (paragraph (3)) at the completion of each set of entries following an observed failure are to be compared with Table 3 to determine if a decision is possible as to whether the sample has passed or failed the test requirement. When a decision is indicated by Table 3 the test is to be discontinued provided the requirement of paragraph 5 is met. Otherwise the test shall continue (with log entries as appropriate) until the requirement of paragraph 5 is met, whereupon the test is to be discontinued. Log data accumulated during such test extension interval are to be used for information only and are not to be used as a basis for altering a decision from Table 3 possible at an earlier time.

(8) On the occasion of a failure, the failed equipment is to be removed and repaired without interruption of the test of equipments continuing to meet test performance requirements. Upon decision that a failed and repaired equipment has been returned to representative operative condition it shall be returned to test without interruption to the equipments continuing the test.

(9) The absence of one or more equipments for the purpose of failure repair shall not affect the ability to make decisions from log data and Table 3.

TABLE 3

RELIABILITY TEST CRITERIA

Time	Failures		
Normalized Test Time See Note 1	Reject Decision If below noted failure occurs on or before corresponding time, Equipment fails. See Note 2	Accept Decision If no more than number of failures below occur by the time shown, Equipment passes. See Note 2	Continue Test If number of failures fall in range below at time shown, continue test.
0.5	6	-	0 - 5
1.3	7	-	0 - 6
2.1	8	-	0 - 7
2.9	9	-	0 - 8
3.7	10	-	0 - 9
4.4		0	1 -10
4.5	11		1 -10
5.2		1	2 -11
5.3	12		2 -11
6.0		2	3 -12
6.1	13		3 -12
6.8		3	4 -13
6.9	14		4 -13
7.6		4	5 -14
7.8	15		5 -14
8.5		5	6 -15
8.6	16		6 -15
9.3		6	7 -16
9.4	17		7 -16
10.1		7	8 -17
10.2	18		8 -17
10.9		8	9 -18
11.0	19		9 -18
11.7		9	10-19
11.8	20		10-19
12.5		10	11-20
12.6	21		11-20
13.3		11	12-21
13.4	22		12-21
14.1	-	12	13-22
14.2	23	-	13-22
14.9		13	14-23
15.0	24	-	14-23
15.7	-	14	15-24
15.9	25	-	15-24
16.6	-	15	16-25
16.7	26	-	16-25
17.4	-	16	17-26
17.5	27	-	17-26

TABLE 3 (Con't.)

RELIABILITY TEST CRITERIA

Time	Failures		
Normalized Test Time See Note 1	Reject Decision If below noted Failure occurs on or before corresponding time, Equipment fails. See Note 2	Accept Decision If no more than number of failures below occur by the time shown, Equipment passes. See Note 2	Continue Test If number of failures fall in range below at time shown, continue test.
18.2	-	17	18-27
18.3	28	-	18-27
19.0	-	18	19-28
19.1	29m	-	19-28
19.8	-	19	20-29
19.9	30	-	20-29
20.6	-	20	21-30
20.7	31	-	21-30
21.4	-	21	22-31
21.5	32	-	22-31
22.2	-	22	22-32
22.3	33	-	23-32
23.0	-	23	24-33
23.1	34	-	24-33
23.8	-	24	25-34
24.0	35	-	25-34
24.7	-	25	26-35
24.8	36	-	26-35
25.5	-	26	27-36
25.6	37	-	27-36
26.3	-	27	28-37
26.4	38	-	28-37
27.1	-	28	29-38
27.2	39	-	29-38
27.9	-	29m	30-39
28.0	40	-	30-39
28.7	-	30	31-40
29.5	-	31	32-40
30.3	-	32	33-40
31.1	-	33	34-40
31.9	-	34	35-40
32.6	[illegible]	35	36-40
33.0	41	40	-

Note 1: Normalized time is the accumulated test time of all equipments totalled and measured in multiples of contract specified MTBF. Normalized time multiplied by contract specified mean-time-between-failure equals total equipment operating hours. If this product is divided by number of equipments under life test the quotient will equal the average test time of each set, or the approximate operating time of the life test.

TABLE 3 (Con't.

Note 2: Under no conditions is the life test to be discontinued because of a decision to fail or pass the test per columns 2 and 3 of table until each equipment has accumulated an operating time at least equal to three times the contract specified mean-time-between-failures.

Note 3: The circled ○ points in the chart represent the average duration of test before decision, for equipment that is just outside the marginal region. The marginal region is considered from 0.67 to 1.0 times the contract specified mean-time-between-failures.

Note 4: The m superscripts denote the average duration of test before decision for equipment whose actual mean-time-between-failures is approximately midway in the marginal region (0.83 times contract specified mean-time-between-failures).

(10) When an accept decision is made because of accumulated operating time, an entry is to be made on a separate line in the log of failures, with notation in column (b) indicating that an accept decision rather than a failure occurrence has occasioned the log entry.

d. Data Handling

The recommended rules and procedures for data handling, to be set forth in this section, have been established subject to certain basic premises which govern the methods for reliability testing covered in this report. To better appreciate data handling rules and procedures the pertinent basic premises follow:

(1) The equipment to be tested shall be of the type which, having failed can be repaired and returned to satisfactory operating condition without replacement of the entire equipment. Thus an equipment comprising two unrepairable hermetic major units, together with the means for necessary interconnection will qualify, since in the typical case it can be presumed that an equipment failure can be remedied by replacement of one or the other (not both) of the two major units. The test of "unrepairable" (only replaceable) equipment necessitates some alteration of the reliability test for the confidence stated.

(2) The recommended sequential test measures the MTBF with respect to the acceptable minimum of the sample (of equipments) selected for test with 90% confidence. In the absence of manufacturing control procedures to guarantee lot homogeneity, it can therefore only determine capability of the manufacturing process (rather than product acceptability). Because of the impossibility of substantial process control during pilot production the test can be assumed to be a measure of reliability capability only. When applied to regular production under close process control rather than pilot production, a random sampling process can yield a measure of the reliability from a production lot.

(3) The recommended test does not directly lead to a numerical measure of reliability but rather establishes with 90% confidence that the tested units equal or exceed the minimum specified numerical MTBF. By secondary calculation, the data available from the tests may be used to yield a reasonable estimate of the actual numerical MTBF.

(4) The recommended test does not evaluate the magnitude or the duration of any early failure period in the sample being tested, nor does it establish the onset of wear-out. It is presumed that the equipment manufacturer will take active measures to perform any debugging necessary prior to the test in order to gain assurance of passing the test. Should the tested sample pass the test even though desirable debugging had not been performed, it may be categorically concluded that the equipment has higher reliability than the minimum required.

(5) The recommended test does not, nor is it intended to, take the place of a comprehensive performance test, or a type test. Those performance parameters monitored during the sequential test are selected as a practical sample of such critical and comprehensive performance parameters such as are most likely to indicate every instance of equipment failure.

(6) The recommended test and the associated data handling procedure do not have a primary responsibility for indicating causes and remedies for unreliability. However, the data are handled in such a way as to give the manufacturer maximum information with respect to remedial action in the case of failing to pass the test.

(7) Data are handled and recorded with sufficient comprehensiveness to permit at least one cross check of every data entry in order to identify any recording errors in data entries, thus permitting an improved basis for the arbitration of resulting data disputes.

(8) Since the test method outlined herein establishes reliability acceptance in terms of the equipment failure pattern, and since the true count of failures is dependent upon adherence by the repair activity to certain rules to be set forth, it is essential that all equipment repair during the test be performed by the least prejudiced and best qualified repair personnel and that such work be performed under the surveillance of the inspector in charge or his delegate.

Recommendations for data handling are made on the basis of minimum data recording essential to the above premises. Any additional data or data processing above and beyond that recommended herein is permissible and need be governed only by the desire to perform an efficient and rapid reliability test.

Data taken during the test should be at least that necessary to complete four kinds of data forms. The four data forms are identified as follow:

1. Log of Failures
2. Operation Sheet
3. Failure Report
4. Equipment Repair Sheet

Log of Failures

The Log of Failures is a form intended to contain all of the information needed to reach a decision as to whether the tested sample passes or fails the test. It is intended that a preprinted form, as described below (as well as in the previous section on test procedure), be used in order that operating personnel conducting the test may make all entries directly and obviate the need for reprocessing these data prior to a pass or fail decision. The Log of Failures form is laid out with appropriate heading followed by columns and lines, one column for each kind of data, and a separate line for each of the failures observed prior to test conclusion.

The heading of the Log of Failures form should contain customary identification, including complete reference to the test and test conditions, test facilities, tested equipment including equipment serial numbers, date of beginning and end of test, name or identification of data recorder, and page number where more than one sheet is needed for the test. Much of this information can be governed by reference to applicable secondary documentation if assurance exists that such secondary documentation has been prepared prior to initiation of the test.

Following the heading, the Log of Failures form should be ruled into the necessary number of columns, 15 columns being required for the simultaneous tests of ten equipments. The number of required columns varies linearly for intermediate numbers of equipments. The columns should contain abbreviated headings in accordance with the following list:

a. Line number
b. Consecutive number of failures observed
c. Date and time of failure observation
d. Accumulated operating time on equipment #1 at time failure in column (b) was observed
e. Same as (d) for equipment #2
f. " " " " " #3 if 3 samples under test
g. " " " " " #4 if 4 " " "
h. " " " " " #5 " 5 " " "
i. " " " " " #6 " 6 " " "
j. " " " " " #7 " 7 " " "
k. " " " " " #8 " 8 " " "
l. " " " " " #9 " 9 " " "
m. " " " " " #10 " 10 " " "
n. Total of columns (d) through (m)
o. Column (n) divided by contract specified mean-time-between-failures.

Under the column headings the form should be ruled with a number of equally spaced horizontal lines, with sufficient spacing to permit each line to be used for a separate equipment failure. The data recorded are not of the nature to require any totals at the bottom of any columns. Data recording shall comply with the requirements set forth in the previous section "Test Procedure".

Operation Sheet

The Operation Sheet is designed to permit data recording of such a nature as to form a log of the significant activity of the test operators. It provides means to cross check for the existence of any failure inadvertently omitted from the Log of Failures. Further, it permits means for arbitrating any contention that observed equipment failure was in truth the fault of the test facility rather than the tested equipment. It establishes the presence on the desired routine basis of operating personnel throughout the duration of test.

The heading of the Operation Sheet should contain means for identification of the test, identification of the equipments under test, date applicable to data (below), and page number. Reference to secondary documentation to shorten heading entry is permissible on the same basis as described for the Log of Failures.

Under the heading the Operations Sheet should be divided into columns in accordance with the following:

a. Line number.
b. The 2nd column should be for local time of the data entry.
c. One or more columns, as deemed necessary, should be provided for repeated monitoring of critical environmental parameters and power supply parameters.
d. A group of columns should be provided for each equipment performance parameter monitored on a repeated basis during the test.
e. Each column group, as described in (d) above should contain as many columns as there are equipments assigned to simultaneous test (from 2 to 10). The width of each column should be sufficient to permit the entry of a numerical value for the performance parameter monitored, or a check mark if more applicable. The numerical parameter is preferable to the check mark because of its greater guarantee of operator attention. The last column should be for the name or initials of the data recorder making the data entry.

Beneath the column heading, The Operations Sheet should be ruled with horizontal lines to permit one line to be used for each observation of the sample under test. It is presumed that equipment operating in the absence of failure will be routinely checked on some periodic basis such as once each hour, or once each 15 minutes, etc. It has been found that periodic data entry permits far more accuracy than other techniques such as "continuous scrutiny with data entry only upon occasion of irregularity." Should attention be drawn to equipment failure between intervals of regular data taking, the next available line on the Operations Sheet should be used for the entry so occasioned. It is intended that the operations sheet provide adequate information from its original, as kept by the operator, and not require reprocessing prior to utilization.

Failure Report

The use of a failure report to sufficiently describe all pertinent circumstances attendant to equipment failure is believed mandatory in order to guarantee proper isolation and count of unrelated although simultaneous equipment failures (which must be counted as separate failures in accordance with the rules for data handling which follow the description of the required data forms). Furthermore, the use of an adequately complete failure report will permit maximum benefit to the equipment manufacturer and his design staff if remedy is needed because of failure to pass the Reliability Test. The Failure Report form should be preprinted for ease of data entry, and all forms must possess a preprinted serial number for reference purposes and accountability. The form should be designed to permit initial data entry by the test operator, subsequent data entry by equipment repair personnel, and final data entry by engineering design and staff activities. Accordingly, these respective portions of the Failure Report form are identified by I, II, III.

I. Reported by the Test Operator

A. Equipment Failure Identification

1. Date and time of failure.
2. Test sequence identification at time of failure.
3. Identification of failing equipment by Model and Serial Number.
4. Name of observer.
5. Specific identification of test instrumentation and facility applicable to failing equipment.
6. Total test time accumulated by failing equipment at time of failure.

B. Failure Symptoms

Both variables and attributes data on both abnormal and normal performance parameters, both immediately before and immediately after failure.

C. Reference to Other Failure Reports

List other equipment failures, if any, observed simultaneously with the subject equipment failure. (These data are valuable to guard against reasons for failure external to the tested equipment.)

II. Reported by Repair Personnel

A. General

1. Time and date failed equipment received by repair personnel.
2. Name or names of repair personnel.

B. Confirmation of Symptoms

1. Method of test employed.
2. Identification of test instrumentation and facility used.
3. Both variable and attributes data (as applicable) on all performance parameters checked.
4. Comments on discrepancies between symptoms observed by repair personnel and symptoms observed by test operator.

C. <u>Identification of Failed Part or Component</u>

1. Part name, catalog number, manufacturer, and circuit symbol which must uniquely identify the failed part within the overall equipment.
2. Method of part test used to establish part failure.
3. Identification of test instrumentation employed.
4. Variables data on significant performance parameters of failed part.

D. <u>Multiple Part Failure</u>

1. Identification, similar to (C), of each additional failing part which can be proven to be a secondary failure and occasioned by part failure identified under (C). The actual or suspected mechanism of secondary failure should be briefly described.

2. Identification, similar to (C), of each additional failing part which cannot be proven to be a secondary failure and occasioned by the part failure identified under (C). The repairman is authorized and directed to initiate an additional failure report for each additional though unrelated parts failure found. Reference to these failure reports should be included on the original failure report.

E. <u>Identification of Repairs</u>

1. Identification and past history (new, burned-in, life tested, etc.) of each replacement part used for repair, with specific reference (viz., circuit symbol) to the failed part that each replaces.

2. Definitive description of control adjustments needed to reobtain satisfactory equipment performance, with justification for adjustments (other than operator controls) in terms of failed or replaced parts.

3. Variables and attributes data for equipment performance following repair.

4. Accumulated operating time for equipment during this repair cycle.

F. <u>Interpretation of the Reason for Failure by Repair Personnel</u>.

G. <u>Failure Number Assignment</u>
A separate failure report must exist for every primary (unrelated) failure, and within the reliability test of a sample of equipments each failure must be

numbered consecutively. Since it is presumed that a single repair activity will process all failed equipments, it is probably convenient for consecutive failure numbering to be assigned by the repair staff.

III. Reported by Engineering Design and Staff Personnel

A. Component Analysis

Results of analysis of the failed part or parts including a description of the analysis and specific findings as to the contributory causes of failure. The electrical and physical conditions to which the component was exposed must be related to the failure as significant or insignificant as causative agents.

B. Design Analysis

Results of mechanical and/or electrical design analysis including a description of the analysis and specific findings as to the contributory causes of failure. Any significant external conditions should be related to the failure as causative or non-causative.

C. Recommendations for Corrective Action

The joint, coordinated recommendations of the component and design personnel must be presented to permit specific consideration for assignment by management of the responsibility for taking corrective action.

Equipment Repair Sheet.

The Equipment Repair Sheet is designed to permit keeping the entire test history of each tested equipment on a single sheet, in order that widely divergent differences in test behavior between equipments may be easily recognized. Additionally, the use of this form will be of some assistance for the recognition of subsequent failures produced by an earlier and unremedied cause. Furthermore, this form assists in meeting the requirement for sufficient data collection for cross-checking purposes.

The heading of the Equipment Repair Sheet should contain complete identification of the specific equipment to which it refers, including the basic equipment serial number as well as serial numbers of major units. The heading should also contain complete reference to the test to which the equipment is being subjected. The test position occupied by the equipment during test should be identified. Notation should be entered concerning any significant past history of the particular equipment prior to the reliability test. Lastly, the date of initiation of the test should be entered.

Below the heading, the Equipment Repair Sheet should be divided into columns as follows:

A. Date and time equipment removed from test for repair.

B. Date and time equipment returned to test.

C. Elapsed operating-time-meter reading when equipment removed from test for repair.

D. Approximate accumulated operating time during repair.

E. Identification number of the failure necessitating repair.

F. Reference to all other failure reports, if any, initiated during repair.

Under the column headings the form should be ruled with a number of equally spaced horizontal lines with sufficient spacing to permit the use of a single line for each instance of repair. It is intended that upon completion of the test the several equipment repair sheets for the several equipments tested may be scrutinized simultaneously for a comparison of the number of failures suffered by each equipment, and the total time consumed in making repairs. In addition, it will be possible to provide continuous accountability for each tested equipment during the test by surveillance of the Equipment Repair Sheet in conjunction withthe Operation Sheet.

Failure Tags

An Equipment Failure Tag is to be affixed to a failed equipment by the test operator immediately upon failure detection. The tag must reference page and line number of the pertinent entry in the Operation Sheet and the Log of Failures, and must show the Failure Report form serial number. Space must be provided for entry by the repair activity of the page and line number of the appropriate entry in the Equipment Repair Sheet, and the Failure Report form(s) serial number(s) for any additional part or component failures detected during repair. This tag is to be removed by the test operator upon the equipment's return to test following repair whereupon the tag is to be delivered to the local authorized government representative.

Other failure tags are to be permanently affixed to failed parts and components by the repair activity and these tags are to reference the serial number of the applicable Failure Report form.

Use of Forms

Prior to beginning the test, but after selection of the equipments to be tested, heading information is to be inserted on the Log of Failures form, Operation Sheet, and Equipment Repair Sheets (one equipment repair sheet for each equipment to be tested). The periodicity for performance checking of the equipments during the test must be established. Beginning with initiation of the test, the Operation Sheet is to be continuously maintained concurrently with the measurements and readings taken. At the instance of the first observed failure the test operator must make an entry in the Log of Failures, suitable entry on the Operation Sheet, and initiate a Failure Report. The failed equipment should then be removed from test, without disturbing the remaining equipments, and delivered to the repair activity together with the partially completed Failure Report. During and at the conclusion of necessary repairs (and ultimate verification of adequate performance) the repair personnel must make applicable entries on the previously initiated Failure Report, must initiate additional Failure Reports for additional independent failures found, if any, and must make an entry in the appropriate Equipment Repair Sheet. Thereupon, the equipment is to be returned to the test. Upon re-installation of the repaired equipment in the test facility, the test operator should make an entry in the Operation Sheet to indicate satisfactory operation. The occasions of subsequent failures are to be handled in identical manner. At the time of each entry by the test operator in the Log of Failures, he should check the test chart to determine if a decision to pass or fail the tested sample can be made, or if the test must continue. At such time as a decision can be reached, and provided each of the equipments have accumulated a test operating time equal to or greater than three times the contract specified mean-time-between-failures, the test can be discontinued. If a decision is possible, but one or more of the tested equipments have not accumulated sufficient operating time, only those equipments requiring the additional operating time need be continued on test. Such equipments as are then deleted from tests should be referenced to the repair activity in order that the appertaining Equipment Repair Sheets may be closed out with appropriate entry.

Subsequent to the repair of equipment failures the repair activity should forward the pertinent failure reports, together with the failed parts or components, to the components staff, who in turn will re-forward the failure reports to the design group. (In the absence of a components staff and/or design group the reports should be forwarded to the cognizant engineer). At the completion of the test all forms should be reviewed by the local authorized government representative and then released to the design group.

Rules for Data Handling

The following rules are mandatory for governing the use of collected data and the manner in which it is collected if the decision reached from the reliability test is to be valid. Inasmuch as all rules are subject to interpretation, it is intended that the most obvious interpretation shall apply, and disputes shall be referred to the local authorized government representative for decision. The following rules are applicable:

(1) An equipment failure shall be defined as in Section I.A.2. Inability by the repair activity to confirm the existence of equipment failure observed during equipment reliability test shall be insufficient grounds for deletion of such claimed failure in the count of total failures. It is intended only that confirmation of failure by the repair activity will permit better assessment of needed repairs and indication of any possible fault in the testing facility. Lack of failure confirmation should instigate close review of the test facility, and if the latter can be shown to be both at fault and to completely account for the failure, to the satisfaction of the local authorized government representative, then and only then can the count of such failure be eliminated.

(2). The actual failure of parts or components can only be established if the repair activity can unmistakably demonstrate that such items no longer meet one or more specification requirements. The existence of an equipment failure under conditions where no part or component can be demonstrated to be beyond specification limits, must be classified as either a design or workmanship failure. As such, it shall be counted in the total number of equipment failures, but details of the circumstances shall be deferred for close study to the design or quality control activity, as the case may be.

(3) Determination by the repair activity that more than one item in a failed equipment is both beyond specification limits and will independently prevent satisfactory equipment performance shall occasion the repair or replacement of each such item. Each such repaired or replaced part or component shall be counted as a separate equipment failure (although the several were observed simultaneously) unless it can be demonstrated beyond any question or doubt that the failure of one item in turn produced the failure of one or more other items. If such proof can be demonstrated each dependent failure may be classified as a secondary failure, and as such is not to be counted in the failure totals. Adequate proof, necessary to establish the secondary aspect of certain of the multiple failures observed simultaneously will be at the discretion of the local authorized government representative. At least one primary (and countable) part or component failure must exist at each instance of equipment repair where secondary failures are claimed.

(4) No part, component, or item may be replaced in any equipment involved in reliability test unless every such part, component, or item can be proven to be outside of specification tolerance. Such parts or components as have deteriorated for any reason but do not fail outside of specification tolerance) cannot be replaced. Each inadvertent replacement under such conditions shall be counted as a primary failure and shall be called to the attention of the local authorized government representative. When an equipment failure is found to exist, and

no part or component can be proven to be outside of specification limits, then the equipment shall be repaired to return it to adequate operating condition, and the specification for each item repaired or replaced shall be altered such as to reflect out-of-tolerance condition to the satisfaction of the local authorized government representative. The failure count for such repaired or replaced items shall be in accordance with rule (3) above.

(5) No preventive maintenance is allowable during reliability test nor during actual equipment repair unless specifically authorized by contract with respect to this test. (Readjustment of operator controls is not considered preventive maintenance). Anticipation of failure shall in no case be justification for any preventive maintenance.

(6) All questions and disputes arising shall be referred to the local authorized government representative for decision.

(7) In initiating the test, the selected equipment sample shall be installed in the test facility and operated for only that length of time necessary to establish that the facility is working properly, and that adequate facility adjustments and calibrations exist. Up to this point accumulated equipment operating time does not count toward the test (and similarly any equipment failures may be repaired without failure count). Thereafter the test shall begin and all operating time in the test facility shall be counted. If, during the course of the test, facility difficulties are encountered necessitating equipment operation in the facility for experimental purposes, the tested equipment(s) shall be replaced with other like equipment(s) not under test for such experimental period.

(8) It shall be permissible for the repair activity to operate any equipment following repairs thereto for any desired length of time (prior to resumption of test) as may seem pertinent to guarantee that the true cause of equipment failure has been established and eliminated. This shall not be construed to grant permission for the repair activity to inordinately delay returning to the test such equipment or equipments as appear to have abnormally high rates of failure.

(9) Requirements for action on data taken shall be in accordance with the instructions enumerated under the heading "Use of Forms."

(10) It shall be permissible for the contractor, prior to the test, to perform any desired debugging operations, preventive maintenance, or repairs.

(11) Rules and procedures for needed repair, replacement, and/or calibration of the test facility, to be made during the test, must be anticipated and established, subject to the approval of the procuring agency prior to initiation of the test. Approval of additional rules needed during the test may be delegated to the local authorized government representative.

(12) Any data taken during the test which require arbitration and/or resolution must be resolved to the satisfaction of the local authorized government representative following the data occurrences. No data once resolved may be altered, although additional clarifying data entry may later be made in order to assist in the consideration given by the local authorized government representative.

(13) No official tests may be re-run on the same or a new sample from the same pilot production lot unless positive action consisting of design change, modification, or rework actually related to observed failures from the first test has been applied. The benefit of early unofficial test is to indicate the need for re-work prior to submission for official test. No action taken (repair, re-work, etc.,) with respect to any or every equipment in a lot, following an official failure to pass the test, can be considered as justification for avoidance of a subsequent official test in order to establish acceptance.

(14) Rules governing anticipatible interruption to test shall be established prior to initiation of test insofar as possible, and once established should be followed except by permission of the local authorized government representative. Test validity is not abridged by testing on a single shift basis nor by interruption over weekends. Failed equipment removals should be made so as to minimize effect on remaining equipments (such as at the appropriate time during a cycle of temperature extremes).

2. Longevity Evaluation Methods and Procedures

Reference to Figure 1 and the definitions and other considerations presented in Part I of this report indicate that equipment longevity may be evaluated in either of two ways. Equipment longevity may be measured to be that total normal operating period terminating at the onset of wearout where the actual average MTBF no longer meets the specified MTBF; the terminating criteria here is the undesired change in failure rate. Also, when a minimum equipment longevity is specified, the equipment may be evaluated to prove its acceptability for this specified length of useful operating life by operating for such a period and determining that the average MTBF does not fall short of that specified during such operation. Here, the terminating criteria is the specified longevity period provided, of course, that the actual average MTBF does not previously fall below that MTBF specified. It is anticipated that the latter type of test will be called for most often. In either case the limiting MTBF for the longevity test and the method for assessing the resultant MTBF must be specified.

Whereas the reliability-index-test operating period on each equipment is relatively short, usually not exceeding three to five failure periods on the average, the longevity test operating period (on each equipment) requires not less than approximately twenty and upward failure periods. During the pilot production contract period, there may be insufficient time available in which to complete the longevity tests without so providing in the contract. However, since it is desirable to initiate the beginning of the longevity test at the earliest possible date, thus providing for earliest resultant decisions at end of test, the longevity test should start during pilot production and continue through production and be so specified in the contracts. The longevity evaluation methods and procedures established herein provide for this extension or overlap since the evaluation technique is identical for both pilot production and production thereby becoming directly applicable to either or both -- singly or together.

(a) Sample Selection

Possibilities for sample selection are limited by the small number of equipments usually available early in the contract period and by the destructive nature of the tests. Equipments may be selected in any sequence desired. Each should have demonstrated its ability to perform properly. When circumstances demand, it shall be permissible to select an equipment (and associated reliability data) having successfully completed the Reliability Index Evaluation of Part II.B.1.

The contracting agency shall make an election as to the number of equipments to be assigned to the longevity test. It is to be noted that the confidence level of test outcome will vary directly with the number of equipments on test. This factor must be weighed against the length of operating time either specified or expected and the relative degree of equipment destruction involved in the test. As a limit, the minimum number of equipments on test should never be less than two. Furthermore, except for repair or emergencies, not less than this number of equipments shall be under test (once started) at all times during the entire duration of contract, unless otherwise specified therein. Accordingly, a newly selected test equipment will replace each longevity tested equipment immediately upon the completion (acceptance or rejection) of that tested equipment. See, also, the Discussion Section III.B. later.

(b) Environmental Specification and Test Conditions

The longevity test environment and related conditions shall be identical in all details to those specified by the contracting agency for the Reliability Index Evaluation, see II.B. 1-6. This is a requirement in order to gain the benefits of test standardization whereby feed-back data may be applied and the opportunity is provided to compare even unlike equipments under the same standardized conditions.

(c) Test Procedure

This is a test procedure not unlike that stipulated for the Reliability Index Evaluation except that in order to show equipment longevity capability (generally with few test equipments) it is not practical to use the sequential analysis (and Table 2) as specifically described in Section II.B. 1-c. The longevity test procedure must additionally provide information on the early wearout type of failures, not ordinarily found in the Reliability Index Evaluation, thus providing needed operational repair and maintenance logistic (and possibly modification) information. Furthermore, the procedure is the same regardless of which test termination criteria is specified. Specifically the test procedure is based on a time between failure averaging technique which describes the extent of MTBF change. Under the specified test conditions the technique provides a determination of approximate equipment MTBF at the time of each failure. Should the equipment MTBF so determined be found less than that specified for the test, during the longevity test terminated by a specified longevity interval, the equipment is rejected as failing to pass test. If the determined MTBF was equal to or greater than that originally specified for the test throughout the specified longevity interval, then the equipment would be accepted. Similarly, when the test termination criteria is onset of wearout, this longevity interval is measured to be that period terminated when the time between failures averaging technique first describes the MTBF to be just less than that specified for test.

1. The sample of equipments for longevity test may be selected in any manner at the contractor's discretion.

2. The selected equipments shall be fitted with elapsed operating time meters which will indicate the total hours of test time accumulated by the equipment to which attached.

3. Logs shall be set up for use during the test, one for each equipment and assigned by equipment serial number, which have columns assigned to the following:

(a) Test position number.

(b) Consecutive number of failures observed.

(c) Date and time of failure observation.

(d) Accumulated operating time at time of corresponding failure in column (b).

(e) Column (d) less twelve times the limiting test MTBF.*

(f) Number of failures occurring within the time interval between columns (d) and (e), by inspection.

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*The value of limiting test MTBF shall be taken as 0.5 times that contract specified MTBF.

(g) Accumulated operating time at failure number column (b) minus twelve (i.e., accumulated hours indicated in column (d) for the twelfth previous failure).

(h) Time interval for last 12 failures = column (d) - column (g).

(i) Test MTBF = column (h)/12.

(j) Remarks -- This column should have ample space to describe the technical details involved by virtue of the failure; i.e., type, value and rating of failed component(s); location(s) in circuit; probable cause(s) of failure; repair action taken, etc. More details as necessary may be kept in an additional failure detail log (Log of Failures) assigned to this specific equipment. Cross reference shall be the consecutive failure number.

4. Criteria for equipment failure, during longevity test, shall be established by contractual agreement prior to test in accordance with the Definition Section I.A.2.

5. The test shall begin only after both the equipments to be tested and the test instrumentation facilities have had suitable operational check-out.

6. Should equipments having satisfactorily completed the Reliability Index Evaluation be selected for this longevity test, all previous operating and failure history must be transferred to the logs of paragraph 3 above and be found complete and acceptable therein.

7. At the instance of each failure a log entry is to be made on a single line with observed data for each of the columns in paragraph 3 above.

8. On the occasion of a failure, the failed equipment is to be removed and repaired without interruption of the test of other equipments on test which are continuing to meet test performance requirements.

9. Upon the decision that a failed and repaired equipment has been returned to representative operative condition it shall be returned to test without interruption to the equipments continuing the test.

10. The absence of one or more equipments for the purpose of failure repair shall not affect the ability to make decisions from the log data previously obtained.

11 The early indicator for continuing test will be the value of the number indicated in column (f) of the log in 3 above. Values 12 or less indicate the specified test MTBF limit has been met or exceeded and test should continue (unless the limiting specified total operating time has been reached). Values 13 or greater indicate that

the specified test MTBF limit has not been met and either the equipment failed to have the specified longevity or that the onset of wearout has been reached. Similarly, column (i) yields the resultant test MTBF, which may be directly compared with the limiting test MTBF.

12. While the test MTBF (column (i)) thus obtained is used as the measuring criteria for continuation or termination of test, it also is a mathematically smoothed trend indicator of reliability index. As such, a plot of these values with time will yield a smoothed plot of the equipment life characteristic. (The time coordinate value shall be taken as the mean value of the interval, column (h)).

13. The information given in columns (e) and (f) is useful immediately by the data taker for status of test determination. However, they are valid only after 12 failures have occurred; accordingly, in this early period they shall not be used. Similarly, column (i) also is valid only after twelve failures. However, the approximate trend of MTBF may be determined in this early period by dividing the value of column (d) by that corresponding in column (b). In this early period an insufficient test MTBF should be recognized as occurring in the "de-bugging" period and therefore not be used as a longevity test limiting criteria.

(d) Data Handling

The recommended rules and procedures for longevity test data handling, as set forth herein, have been established to not only provide longevity test criteria but also to provide reliability failure data and related information leading to a more complete understanding of the basis on which improved reliability is founded.

1. The pertinent basic premises of the longevity test data handling rules and procedures are in accord with those of the previously described premises for Reliability Index Evaluation. Specifically items 1, 6, 7, and 8 under the heading, II.B. 1-d (Data Handling), apply equally here.

2. The recommended test does not immediately lead to a numerical measure of the (lot) longevity but rather establishes either the fact that the tested units themselves equal or exceed the specified longevity, or that they indicate the onset of wear-out at a particular time interval.

3. It is essential that all equipment repair, during the longevity test, be performed by the least prejudiced and best qualified repair personnel and that such work be performed under the surveillance of the authorized government representative (the inspector in charge or his delegate when applicable).

4. Recommendations for data handling are made on the basis of prescribing the minimum data handling essential to the above premises. Recording of data or data processing additional to that recommended herein is permissible and need be governed by the desire to perform a more efficient and complete longevity test.

5. Data taken during the longevity test shall be at least that necessary to complete five kinds of data forms. The five data forms will be identified as follows:

(a) Longevity Log of Failures.

(b) Operation Sheet.

(c) Failure Report.

(d) Equipment Repair Sheet.

(e) Failed component summary analysis.

Longevity Log of Failures

The Longevity Log of Failures is a form containing all information necessary to reach a decision as to whether the tested sample passes or fails the longevity test. In addition to those items listed in Section II.B.2-c - 3, it shall have a heading containing customary identification, including complete reference to the test and test conditions, test facilities, equipment type, date of beginning and of end of test, name or identification of data recorder, and page number. As before much of this can be placed in secondary documentation provided such is prepared prior to initiation of test.

The Longevity Log of Failures preferably shall be a preprinted form. Following the heading, the form should be ruled into the necessary ten columns, the last column (remarks) should be as large as practical. Column headings should be abbreviated in keeping with the content of the column.

Under the column headings the form shall be ruled horizontally with a number of equally spaced lines. Each line allowing sufficient space to permit recording of all data pertaining to a separate equipment failure. Totals are not required at the bottom of the page. Page to page carry over of data may be made in a straight-forward manner as from line to line. Data recording shall comply with the requirements set forth in the previous section, II.B.2-c (Longevity Test Procedure).

Operation Sheet

The Operation Sheet is designed to permit data recording of such a nature as to form a log of the significant activity of the test operators. It provides means to cross check for the existence of any failure inadvertently omitted from the Longevity Log of Failures. Further, it permits means for arbitrating any contention that observed equipment failure was in truth the fault of the test facility rather than the tested equipment. It establishes the presence on the desired routine basis of operating personnel throughout the duration of test.

The heading of the Operation Sheet should contain means for identification of the test, identification of the equipments under test, date applicable to data (below), and page number. Reference to secondary documentation to shorten heading entry is permissible on the same basis as described for the Longevity Log of Failures.

Under the heading the Operations Sheet should be divided into columns in accordance with the following:

(a) Line number.

(b) The 2nd column should be for local time of the data entry.

(c) One or more columns, as deemed necessary, should be provided for repeated monitoring of critical environmental parameters and power supply parameters.

(d) A group of columns should be provided for each equipment performance parameter monitored on a repeated basis during the test.

(e) Each column group, as described in (d) above should contain as many columns as there are equipments assigned to simultaneous test. The width of each column should be sufficient to permit the entry of a numerical value for the performance parameter monitored, or a check mark if more applicable. The numerical parameter is preferable to the check mark because of its greater guarantee of operator attention. The last column should be for the name or initials of the data recorder making the data entry.

Beneath the column heading, The Operations Sheet should be ruled with horizontal lines to permit one line to be used for each observation of the sample under test. It is presumed that equipment operating in the absence of failure will be routinely checked on some periodic basis such as one each hour, or once each 15 minutes, etc. It has been found that periodic data entry permits far more accuracy than other techniques such as "continuous scrutiny with data entry only upon occasion of irregularity." Should attention be drawn to equipment failure between intervals of regular data taking, the next available line on the Operations Sheet should be used for the entry so occasioned. It is intended that the operations sheet provide adequate information from its original, as kept by the operator, and not require reprocessing prior to utilization.

Failure Report

The use of a failure report to describe sufficiently all pertinent circumstances attendant to equipment failure is believed mandatory in order to guarantee proper isolation and count of unrelated although simultaneous equipment failures (which must be counted as separate failures in accordance with the rules for data handling which follow the description of the required data forms). Furthermore, the use of an adequately complete failure report will permit maximum benefit to the equipment manufacturer and his design staff if remedy is needed because of failure to pass the Longevity Test. The Failure Report form should be preprinted for ease of data entry, and all forms must possess a preprinted serial number for reference purposes and accountability. The form should be designed to permit initial data entry by the test operator, subsequent data entry by equipment repair personnel, and final data entry by engineering design and staff activities. Accordingly these respective portions of the Failure Report form are identified by I, II, III.

I. Reported by the Test Operator

A. Equipment Failure Identification

1. Date and time of failure.

2. Test sequence identification at time of failure.

3. Identification of failing equipment by model and serial number.

4. Name of observer.

5. Specific identification of test instrumentation and facility applicable to failing equipment.

6. Total test time accumulated by failing equipment at time of failure.

B. Failure Symptoms

Both variables and attributes data on both abnormal and normal performance parameters, both immediately before and immediately after failure.

C. Reference to Other Failure Reports

List other equipment failures, if any, observed simultaneously with the subject equipment failure. (These data are valuable to guard against reasons for failure external to the tested equipment.)

II. Reported by Repair Personnel

A. General

1. Time and date failed equipment received by repair personnel.

2. Name or names of repair personnel.

B. Confirmation of Symptoms

1. Method of test employed.

2. Identification of test instrumentation and facility used.

3. Both variable and attributes data (as applicable) on all performance parameters checked.

4. Comments on discrepancies between symptoms observed by repair personnel and symptoms observed by test operator.

C. Identification of Failed Part or Component

1. Part name, catalog number, manufacturer, and circuit symbol which must uniquely identify the failed part in the overall equipment.

2. Method of part test used to establish part failure.

3. Identification of test instrumentation employed.

4. Variables data on significant performance parameters of failed part.

D. Multiple Part Failure

1. Identification, similar to (C), of each additional failing part which can be proven to be a secondary failure and occasioned by part failure identified under (C). The actual or suspected mechanism of secondary failure should be briefly described.

2. Identification, similar to (C), of each additional failing part which cannot be proven to be a secondary failure and occasioned by the part failure identified under (C). The repairman is authorized and directed to initiate an additional failure report for each additional though unrelated parts failure found. Reference to these failure reports should be included on the original failure report.

E. Identification of Repairs

1. Identification and past history (new, burned-in, life tested, etc.) of each replacement part used for repair, with specific reference (viz., circuit symbol) to the failed part that each replaces.

2. Definitive description of control adjustments needed to reobtain satisfactory equipment performance, with justification

for adjustments (other than operator controls) in terms of failed or replaced parts.

3. Variables and attributes data for equipment performance following repair.

4. Accumulated operating time for equipment during this repair cycle.

F. Interpretation of the Reason for Failure by Repair Personnel

G. Failure Number Assignment

A separate failure report must exist for every primary (unrelated) failure, and within the reliability test of a sample of equipments each failure must be numbered consecutively. Since it is presumed that a single repair activity will process all failed equipments, it is probably convenient for consecutive failure numbering to be assigned by the repair staff.

III. Reported by Engineering Design and Staff Personnel

A. Results of, or Comments From, Analysis of the Failed Part by the Components Staff

B. Comments Based on Failure Analysis by the Design Group

C. Determination of Part Failure Category; i.e., Primary or Secondary Failure, by Design Group with Approval of Authorized Government Inspector

Optimum subsequent use of part failure data will require determination of failure category, primary or secondary, for each failing part. Since secondary failures may be eliminated or reduced by improved design of the part (or associated circuit) initiating the primary failure, the parts in the secondary failure category may not necessarily in themselves be directly contributing to the cause of failure and the attendant reduced equipment MTBF. The more important redesign or modification viewpoint being determination and elimination of cause of the associated primary part failure. This will be covered in more detail later under Failed Component Summary Analysis.

Equipment Repair Sheet

The Equipment Repair Sheet is designed to permit keeping the entire test history of each tested equipment on a single sheet, in order that widely divergent differences in test behavior between equipments may be easily recognized. Additionally, the use of this form will be of some assistance for the recognition of subsequent failures produced by an earlier and unremedied cause. Furthermore, this form assists in meeting the requirement for sufficient data collection for cross-checking purposes.

The heading of the Equipment Repair Sheet should contain complete identification of the specific equipment to which it refers, including the basic equipment serial number as well as serial numbers of major units. The heading should also contain complete reference to the test to which the equipment is being subjected. The test position occupied by the equipment during test should be identified. Notation should be entered concerning any significant past history of the particular equipment prior to the test. Lastly, the date of initiation of the test should be entered.

Below the heading, the Equipment Repair Sheet should be divided into columns as follows:

A. Date and time equipment removed from test for repair.

B. Date and time equipment returned to test.

C. Elapsed operating-time-meter reading when equipment removed from test for repair.

D. Approximate accumulated operating time during repair.

E. Identification number of the failure necessitating repair.

F. Reference to all other failure reports, if any, initiated during repair.

Under the column headings the form should be ruled with a number of equally spaced horizontal lines with sufficient spacing to permit the use of a single line for each instance of repair. It is intended that upon completion of the test the several equipment repair sheets for the several equipments tested may be scrutinized simultaneously for a comparison of the number of failures suffered by each equipment, and the total time consumed in making repairs. In addition, it will be possible to provide continuous accountability for each tested equipment during the test by surveillance of the Equipment Repair Sheet in conjunction with the Operation Sheet.

<u>Failure Tags</u>

An Equipment Failure Tag is to be affixed to a failed equipment by the test operator immediately upon failure detection. The tag must reference page and line number of the pertinent entry in the Operation Sheet and the Log of Failures, and must show the Failure Report form serial number. Space must be provided for entry by the repair activity of the page and line number of the appropriate entry in the Equipment Repair Sheet, and the Failure Report form(s) serial number(s) for any additional part or component failures detected during repair. This tag is to be removed by the test operator upon the equipment's return to test following repair, whereupon the tag is to be delivered to the authorized government representative. Other failure tags are to be permanently affixed to failed parts and components by the repair activity, and these tags are to reference the serial number of the applicable Failure Report form.

Failed Component Summary Analysis

Failed Component (part) Summary Analysis report forms provide basic data for determination of the reliability capability or performance within each part category. AOQL's and need for improved design are determined therefrom. Correlation is provided between field and factory part failure rates, etc. Forms need not be pre-printed.

The heading of the Failed Component Summary Analysis form (equipment sheet) should contain means for identification of the test, type and serial number of the equipment, date of start and stop of the test, and statement of the environment test condition level. Other pertinent information may be added or kept on secondary documentation as desired.

Under the heading the Failed Component Summary Analysis form should be divided into columns in accordance with the following:

a. Description of part failed.
b. Number of primary failures.
c. Number of secondary failures.
d. Total failures.

The width of the first column should be wide enough to contain description of the failed parts such as, power transformer, tube, transistor, capacitor-mica, capacitor-paper, etc. The second and third columns should be wide enough to contain counting marks and totaling number of failed parts in either category for the parts listed in column one. The last column will contain only the total number, the sum of columns (b) and (c).

Beneath the column headings the form shall be ruled horizontally to permit one line to be used for the failure summary of each type of part. One mark shall be made corresponding to each part failure in the proper category column.

Upon the completion of each form as above (for one equipment), the totals therefrom shall be transferred to a totalizing form similar to this but providing total contract (rather than equipment) part failure data. Upon completion of contract, and at any previous intervals, as may be specified by the contracting agency, the final or interim totalized part failure data may be forwarded to the cognizant agency in letter and table (as above) form. Here, of course, heading information pertinent to the contract would be given.

Use of Forms

Prior to beginning the longevity test, but after selection of the equipments to be tested, heading information is to be inserted on the Log of Failures form, Operation Sheet, and Equipment Repair Sheets (one equipment repair sheet for each equipment to be tested). The periodicity for performance checking of the equipments during the test must be established. Beginning with initiation of the test, the Operation Sheet is to be continuously maintained concurrently with the measurements and readings taken." At the instance of the first observed failure the test operator must make an entry in the Log of Failures, suitable entry on the Operation Sheet, and initiate a Failure Report. The failed equipment should then be removed from test, without disturbing the remaining equipments, and delivered to the repair activity together with the partially completed Failure Report. During and at the conclusion of necessary repairs (and ultimate verification of adequate performance) the repair personnel must make applicable entries on the previously initiated Failure Report, must initiate additional Failure Reports for additional independent failures found, if any, and must make an entry in the appropriate Equipment Repair Sheet. Thereupon, the equipment is to be returned to the test. Upon reinstallation of the repaired equipment in the test facility, the test operator should make an entry in the Operation Sheet to indicate satisfactory operation. Once each day, or at other appropriate intervals, the person in charge of test will review the above mentioned sheets for overall accuracy, proper inclusion and correlation of data, etc. Subsequent to the agreed determination of part failure category, he shall make corresponding entry on the Failed Component Summary Analysis Sheet for that equipment. Subsequent to completion of test for a particular equipment, pass or fail, he shall transfer the part failure data from the equipment sheet to the totalizing sheet.

The occasions of subsequent failures are to be handled in identical manner. At the time of each entry by the test operator in the Log of Failures, he should check to determine if a decision to pass or fail the tested sample can be made, or if the test must continue. At such time as a fail decision can be reached, and provided that equipment has accumulated a test operating time equal to or greater than twelve times the contract specified mean-time-between-failure, the test on that equipment can be discontinued. Such equipments as are then deleted from tests should be referenced to the repair activity in order that the appertaining Equipment Repair Sheets may be closed out with appropriate entry. All other equipments operating on test are unaffected by the fail to pass test decision for a specific equipment except for resultant decisions affecting the lot; i.e., upon the fail to pass test decision for a specific equipment, the test shall continue (with a newly selected equipment replacing the failed equipment) until such time as a decision effecting the lot is made.

Subsequent to the repair of equipment failures the repair activity should forward the pertinent failure reports, together with the failed parts or components, to the components staff, who in turn will re-forward the failure reports to the design group. (In the absence of a components staff and/or design group the reports should be forwarded to the cognizant engineer). At the completion of the test all forms should be reviewed by the authorized government representative and then released to the design group.

Rules for Data Handling

The following rules are mandatory for governing the use of collected data and the manner in which it is collected if the decision reached from the longevity test is to be valid. Inasmuch as all rules are subject to interpretation, it is intended that the most obvious interpretation shall apply, and disputes shall be referred to the authorized government representative for decision. The following rules are applicable:

1. Inability by the repair activity to confirm the existence of equipment failure observed during test shall be insufficient grounds for deletion of such claimed failure in the count of total failures. It is intended only that confirmation of failure by the repair activity will permit better assessment of needed repairs and indication of any possible fault in the testing facility. Lack of failure confirmation should instigate close review of the test facility, and if the latter can be shown to be both at fault and to completely account for the failure, to the satisfaction of the authorized government representative, then and only then can the count of such failure be eliminated.

2. The actual failure of parts or components can only be established if the repair activity can unmistakably demonstrate that such items no longer meet one or more specification requirements. The existence of an equipment failure under conditions where no part or component can be demonstrated to be beyond specification limits, must be classified as either a design or workmanship failure. As such, it shall be counted in the total number of equipment failures, but details of the circumstances shall be deferred for close study to the design or quality control activity, as the case may be.

3. Determination by the repair activity that more than one item in a failed equipment is both beyond specification limits and will independently prevent satisfactory equipment performance shall occasion the repair or replacement of each such item. Each such repaired or replaced part or component shall be counted as a separate equipment failure (although the several were observed simultaneously) unless it can be demonstrated beyond any question or doubt that the failure of one item in turn produced the failure of one or more other items. If such proof can be demonstrated, each dependent failure may be classified as a secondary failure, and as such is not to be counted in the failure totals of other than the Component Failure Summary Analysis sheet. Adequate proof, necessary to establish the secondary aspect of certain of the multiple failures observed simultaneously will be at the discretion of the authorized government representative. At least one primary (and countable) part or component failure must exist at each instance of equipment repair where secondary failures are claimed.

4. No part, component, or item may be replaced in any equipment involved in test unless every such part, component, or item can be proven to be outside of specification tolerance. Such parts or components as have deteriorated for any reason but do not fall outside of specification tolerances cannot be replaced. Each inadvertent replacement under such conditions shall be counted as a primary failure and shall be called to the attention of the authorized government representative. When an

equipment failure is found to exist, and no part or component can be proven to be outside of specification limits, then the equipment shall be repaired to return it to adequate operating condition, and the specification for each item repaired or replaced shall be altered such as to reflect out-of-tolerance condition to the satisfaction of the authorized government representative. The failure count for such repaired or replaced items shall be in accordance with rule (3) above.

5. Except for changes made as a result of a lot decision no preventive maintenance is allowable during longevity test nor during actual equipment repair. (Readjustment of operator controls is not considered preventive maintenance.) Anticipation of failure shall in no case be justification for any preventive maintenance.

6. All questions and disputes arising shall be referred to the authorized government representative for decision.

7. In initiating the test, the randomly chosen equipment sample shall be installed in the test facility and operated for only that length of time necessary to establish that the facility is working properly, and that adequate facility adjustments and calibrations exist. Up to this point accumulated equipment operating time on the randomly chosen equipment does not count toward the test (and similarly any equipment failures may be repaired without failure count). When the equipment selected for longevity test is one having satisfactorily completed the Reliability Index Evaluation it shall be repaired as necessary, all previous operating time and failure data shall be transferred to the longevity test forms and found acceptable where all primary failures are counted. Thereafter, the test shall begin, and all operating time in the test facility shall be counted. If, during the course of the test, facility difficulties are encountered necessitating equipment operation in the facility for experimental purposes, the tested equipment(s) shall be replaced with other like equipment(s) not under test for such experimental period.

8 It shall be permissible for the repair activity to operate any equipment following repairs thereto for any desired length of time (prior to resumption of test) as may seem pertinent to guarantee that the true cause of equipment failure has been established and eliminated. This shall not be construed to grant permission for the repair activity to inordinately delay returning to the test such equipment or equipments as appear to have abnormally high rates of failure.

9. Requirements for action on data taken shall be in accordance with the instructions enumerated under the heading "Use of Forms". Lot decisions, however, are described under Section II.B. 2-e. "Test Results and Conclusions" are discussed with an application examples under Section III.B.3.

10. It shall be permissible for the contractor, prior to the test, to perform any desired debugging operations or repairs, on any sample randomly selected from the line.

11. Rules and procedures for needed repair, replacement, and/or calibration of the test facility, to be made during the test, must be anticipated and established subject to the approval of the procuring agency, prior to initiation of the test. Additional rules needed during the test shall be developed entirely at the discretion of the authorized government representative.

12. Any data taken during the test which require arbitration and/or resolution must be resolved immediately following the data occurrences. No data once resolved may be altered, although additional clarifying data entry may later be made in order to assist in the consideration given by the authorized government representative.

13. In the case of a lot decision, because of failure to pass test, requiring positive action consisting of design change, modification, or rework actually related to observed failures, all equipments on test must undergo the required action prior to continuing test. It shall not be permissible to restart test with new (untested) but properly modified equipments.

14. When equipments under test are modified as in paragraph 13, above, they shall not be rejected as failed on the basis of any previous data but only after at least twelve new failures have occurred, as if a new test were being initiated, see Section II.B. 2-c(3).

15. Rules governing anticipatible interruption to test shall be established prior to initiation of test insofar as possible, and once established should be followed except by permission of the authorized government representative. For example, test validity is not abridged by testing on a single shift basis nor by interruption over week-ends. Failed equipment removals should be made so as to minimize effect on remaining equipments (such as at the appropriate time during a cycle of temperature extremes).

e. Test Results and Conclusions

During the longevity test, whenever a decision is reached that a tested equipment has either passed or failed the test, that decision shall be used to influence a general decision for the entire lot. A lot decision based on the completion of test of a single equipment is statistically almost meaningless (there is 90% probability that the percentage of equipments in the lot which would yield a contrary decision is above 5% and below [illegible]%, and for repeated trials, as many lots would be above 29% as would be below [illegible]). To enable a lot decision to the effect that there exists a 90% confidence that less than 10% of the equipments in the lot would fail a longevity test if so tested, all equipments would have to be tested and all found to pass the test. However, if only 22 equipments are tested and all pass, there is 90% confidence that the percentage of failing equipments in the lot is less than 10%.

The procurement contract shall specify the number of equipments to be longevity tested; and preference shall be given to the test of twelve or more equipments. When circumstances favor the test of fewer than twelve equipments, the number specified for test shall not be less than two, and the test history of those tested shall be reviewed by both the contractor and the contracting agency to determine from consideration of the kinds of failures observed as to whether equipment redesign or modification should be required for future procurement even though all equipments tested are found to satisfactorily pass the test. The contracting agency shall give consideration to the maximum percentage of short lived equipments tolerable to supply and maintenance, expected duration of proposed longevity tests with respect to procurement schedule and budget, the total number of equipments to be procured, the contractor test facilities available, and the destructive nature of the tests.

When the contract specifies that the required number of equipments to be longevity tested are to be tested in 2 or more successive groups, test of a later group beginning only after decision on an earlier group test, then if all the equipments in the initial group fail the test, equipment redesign or modification approved by the procuring agency must be effected before further test. If only a portion of the initial group fails, or if any equipments in later groups fail, complete test data shall be reviewed by both the procuring agency and the contractor, and a decision shall be made to either (1) redesign or modify the equipment, (2) require longevity test of an increased number of equipments, or (3) lower the longevity requirements specified by contract.

Of prime importance to the contracting agency with respect to acceptable equipment are those data in the Failed Component Summary Analysis and related Failure Logs. Such data provide basic information for the most economical means for establishing minimum spare, replacement, and repair parts requirements to provide for the necessary and subsequent operational maintenance. It is to be noted that this technique for factual and economical logistic prediction has never heretofore been practiced, and that the test herein described provides an ideal means both practical and economically feasible.

Of prime importance to both the contractor and the contracting agency with respect to unacceptable equipment are those data enumerated above because they identify limited life characteristics for critical parts, components, and material, thus indicating specific areas for redesign or modification. Such life data will usefully contribute to the background of reliability information on parts and materials, of great benefit to future endeavors.

C. Production Tests

1. Reliability Index Evaluation Method and Procedures

In the technique presented in this section for determining that the reliability index (MTBF) equals or exceeds the contract specified minimum value for each produced equipment with known high probability and low risks the following basic concepts are emphasized:

(1) For those equipments actually tested, a sample of failure occurrences is observed, and the sequential sampling test of Section II.B.1 is used to evaluate the relationship of the MTBF of the equipments in the tested sample to the contract specified minimum MTBF with specified risks (10% risk of wrong rejection decision on 1.0 $\bar{\theta}$, and 10% risk of wrong acceptance decision on a lower limit of 0.67 $\bar{\theta}$).

(2) In order to relate observations from tested samples to other but untested equipment from simultaneous production, a continuous attributes sampling plan is employed wherein decision as to acceptability of untested equipment is derived from data on the tested sample. In this sampling plan risks are established which are judged as the best compromise between size and duration of total production and value and cost of sample testing. The level of risk established by the initial sampling test as well as the somewhat higher risk associated with the continued sampling, are explained in Section III.C.2.

a. Sample Selection

Selection of samples from equipment production upon which to perform reliability tests is made in accordance with a plan which initially, and thereafter whenever any sample equipment is found to be substandard (low MTBF), provides a 10% user's risk of accepting equipment lots with no more than 10% substandard equipments included. The sampling plan operates on a continuing basis at a reduced sampling level so long as no substandard equipments are identified, in order that any shift from the production of acceptable equipments to the production of sub-standard equipments will be observed, and tightened sampling resumed.

The sampling plan is designed, taking into account contract specified $\bar{\theta}$ and monthly production rate, so that test results may be obtained in the shortest period of time, taking into account both the time to accumulate a test group of a sufficient number of equipments to permit a short test as well as the probable length of actual test considering the number of equipments accumulated. In no case is the number of equipments required for a test group allowed to fall below that number which would cause the probable test time to increase above 500 hours, the test time available in one month of 24-hour 5-day weeks. In no case is the number of equipments required for a test group allowed to be less than four, in order to keep the level of user's risk during reduced sampling level within reasonable bounds.

The selection of equipment samples for test, rather than being made randomly, is always made consecutively with respect to the sequence of equipment availability from production. Thus the first production test to be made is made upon a group of N equipments comprising the first N equipments to become available from production. At any later time if a test is required either on the basis of the requirement for testing one group of equipments once each month, or for any other reason, then the equipments chosen for the test will be the desired number chosen consecutively, from those not already shipped, with respect to earliest date of receipt from production.

The sampling plan requires that a minimum of the first 22 equipments produced must all be tested and found satisfactory before the shipment of any untested equipments is permitted. For such contracts as procure 22 or fewer equipments, all must be tested prior to shipment. The detection by test of any substandard equipment (low MTBF) has the effect of immediately halting shipment of untested equipments and requiring that the next consecutive 37 equipments must be tested and found acceptable before resuming shipment of untested equipments. If two or more sub-standard equipments are detected through test, shipping of untested equipments having been halted and not yet resumed because of the first sub-standard equipment found, then the 50 consecutive equipments must be found acceptable following the last substandard equipment before shipping of untested equipments may resume.

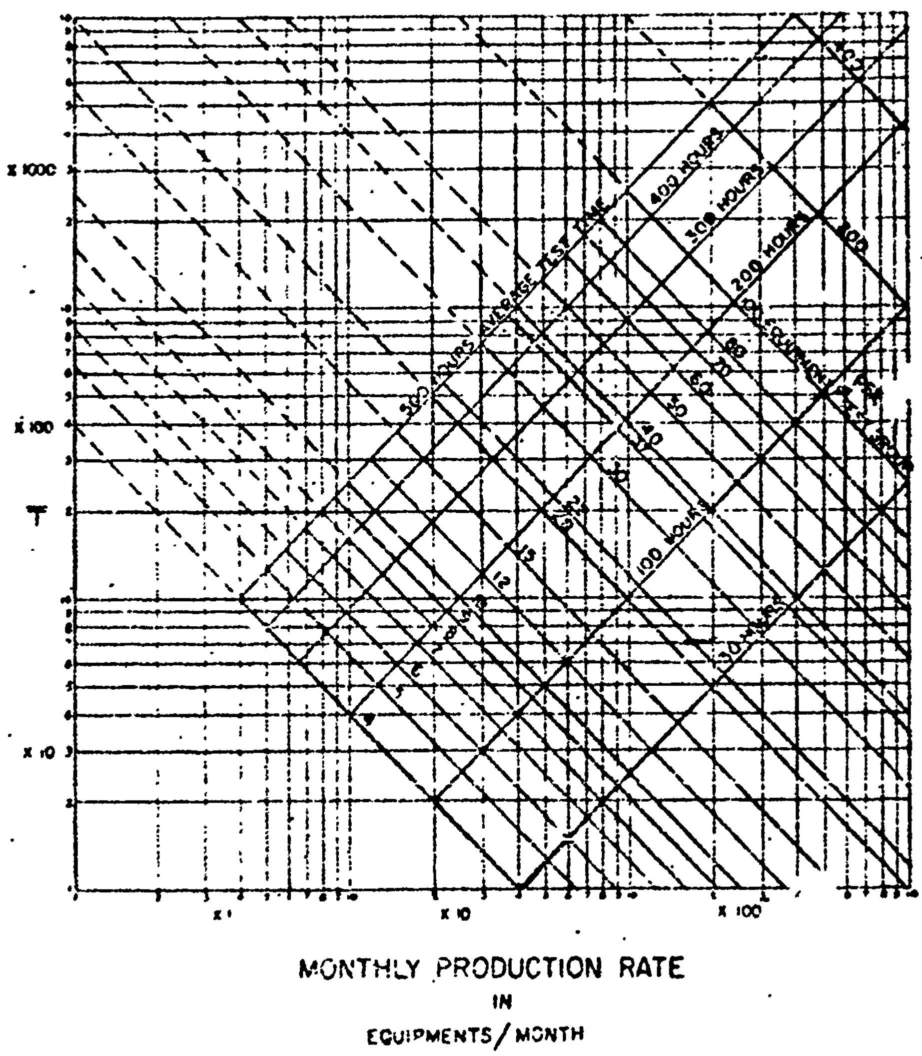
All reliability tests of equipment samples must be performed upon groups of equipments, and since the size of the group together with the contract specified $\bar{T}$ (minimum MTBF) determines the probable length of test, the size of the groups shall be chosen in accordance with Figure 3. The graph of Figure 3 relates T, and monthly production rate, to both the number of equipments per test group for earliest test decision, and to probable length of time for test of that group size. The initial production test, and the test following the detection (through test) of any substandard equipment, shall always be performed upon a group of equipments of size chosen from Figure 3, entering the graph for the applicable $\bar{T}$ and monthly production rate. For example, if $\bar{T}$ were 100 hours, and monthly production rate 150 equipments per month, the size of the test group would be 24 equipments. If the contract $\bar{T}$ were again 100 hours, but the monthly production rate were only 2 equipments per month, the test group size would be chosen at 4, the minimum number allowed for test, rather than 3 as might be extrapolated from the graph. However, one exception to the foregoing rule for size of test group is permitted. Following detection of a substandard equipment, the test group size may be increased by the addition of any number of equipments in numerical sequence already on hand and otherwise ready for shipment. Additional shortening of test time is thereby possible when available test facilities permit.

For such procurement as specifies values for $\bar{T}$ and monthly production rate, the intersection of which falls within the solid zone to the right of [illegible] hours average test time and 4 equipments per test group of Figure 3, then shipment without test of all equipments in excess of the number required for a monthly sample test is permitted, provided unacceptable equipments are not found among those in the sample tested. Such shipment of untested equipments is in accordance with the rules stated above. The number of equipments to be selected for the monthly sample test shall be as specified by contract, or if not specified, any number between the minimum number found on the solid line portion of the graph of Figure 3 for the contract $\bar{T}$ (which is that number requiring an expected test time of 500 hours and independent of productions rate), and the number established by Figure 3 for the contract $\bar{T}$ and the monthly production rate. For example, in the absence of specification to the contrary, if $\bar{T}$ is 100 hours, and the monthly production rate is 150 equipments, then the monthly test may be of any number of equipments between 4 and 24. If $\bar{T}$ instead were 200 hours, the number could be chosen between 8 and 33.

The sequential test method of Section II.B.1, which is used for testing the equipment samples chosen in accordance with the foregoing, permits an acceptance or rejection decision for the entire group under test. However, for the reliability testing of production equipment it is necessary to identify within a test group following a rejection decision just which equipment or equipments are substandard. Such identification is made in the following manner. Following a rejection decision, the group shall be continued on test just as if no decision had yet been reached. However, the data on the group's Log of Failures shall be analyzed immediately. The failure data on each equipment separately, and one such set of data at a time, shall be censored from the group's Log of Failures to determine if the removal of any one equipment's failure data (together with that equipment's accumulated operating time) will prevent the rejection decision previously reached. If it be determined that such censorship for one or more specific equipments individually does in fact prevent the rejection decision, then such tentatively revised remaining data shall be scrutinized to determine if an acceptance decision could have been made at any prior time. If such acceptance decision is possible because of censorship of data from but one specific equipment, then that specific equipment shall be set aside as an unsatisfactory unit and the remaining equipments released for delivery without further test as acceptable units. If such acceptance decision is possible because of censorship of data from any of several specific equipments individually, then each of these specific equipments shall be set aside as unsatisfactory units, the remaining group released from further test as satisfactory, and the record altered to note the presence of a double group failure. If, as will be more common, censorship of data from one or several specific equipments individually permits elimination of the initial rejection decision for the group but does not yet permit an acceptance decision, then the entire group including these identified equipments shall be continued on test until the next opportunity for either an accept or reject decision based on combined data less one censored data set, the censored data set being any one of those data sets which prevent the earlier reject decision. If this next opportunity for decision is to accept, then the equipment responsible for the censored data is to be set aside as unsatisfactory, and the remainder of the group released as acceptable. If censorship of data from more than one equipment each permits both elimination of the initial reject

FIG. 3

TEST GROUP SIZE & TEST TIME VERSUS PRODUCTION RATE & $\overline{T}$



decision as well as justification of the later accept decision, then each such responsible equipment is to be set aside as unsatisfactory, the remainder released as satisfactory, and a double group failure recorded. If the opportunity for next decision is for a reject decision, and such decision cannot be prevented by the selection of any one set of data for censorship from those sets which will prevent the earlier decision, then a double group failure is to be recorded, and simultaneous censorship of data sets from more than one equipment is permitted. At the time of initial group reject decision, if it is found that the censorship of no single set of data will prevent the reject decision, then simultaneous censorship of more than one set of data is permitted, and a double group failure is to be recorded. By this means determination shall be made as to which equipment's or equipments' data to withdraw from a group in order to permit conclusion of test with accept decision based on the remaining equipments within the group. Determination that more than one equipment within the group is responsible for an adverse decision shall result in the recording of a double group failure (even though the unsatisfactory equipments number more than two). Obviously following a double group failure, shipment of untested equipments may only resume after 50 consecutive equipments are tested and found satisfactory.

To illustrate the operation of this sampling plan, Figure 4 has been prepared, showing a variety of typical and alternative situations.

b. Environmental Specification and Test Conditions

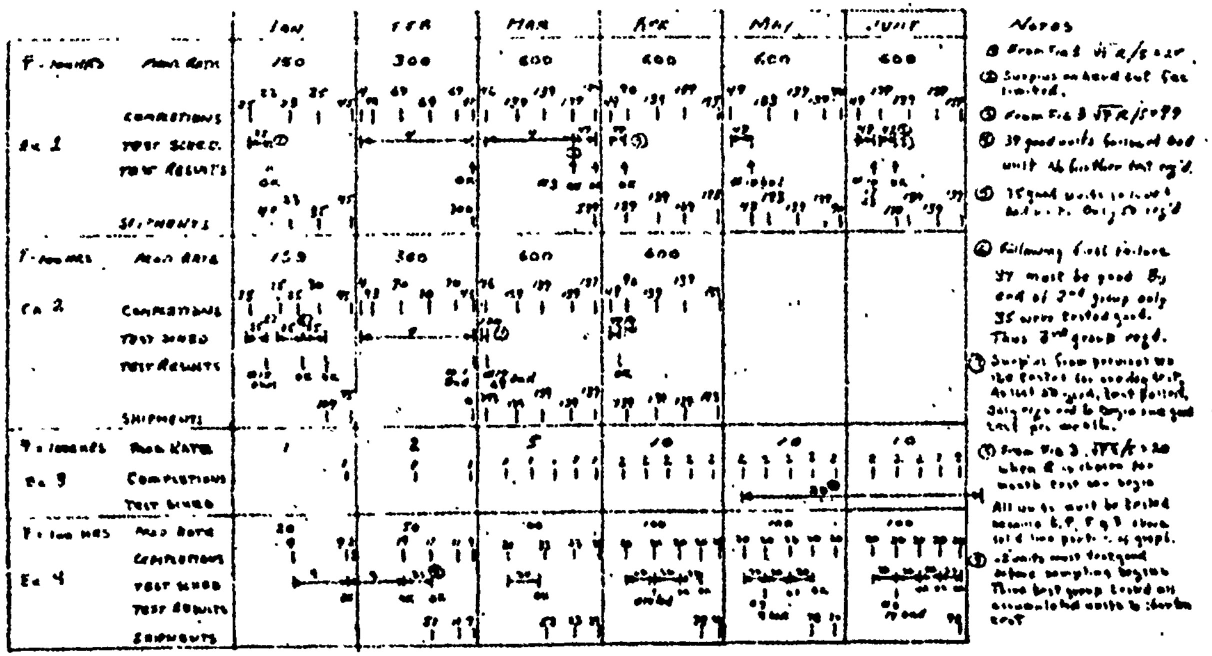
The environmental specification and test conditions for the reliability index evaluation of production equipments is identical to the environmental specification and test conditions for the reliability index evaluation of pilot production equipments, and is described in Section II.B.1-b herein.

c. Test Procedure

This is a testing procedure based on sequential analysis to determine if, under specified test conditions, a given group of equipments exhibits a mean-time-between-failures which is equal to or greater than a specified minimum value.

(1) The group of equipments for reliability index test is to be selected in accordance with the instructions given .. Section II.C.1-a, Sample Selection, herein.

(2) The selected equipments shall be fitted with elapsed operating time meters which will indicate the total hours of test time accumulated by the equipment to which attached.



TYPICAL EXAMPLES OF RELIABILITY INDEX EVALUATION ON PRODUCTION CONTRACTS FIG 4

(3) A log shall be set up for use during the test which has columns assigned to the following:

a. Line number
b. Consecutive number of failures observed and identification of failing equipment.
c. Revised consecutive failure number after data censorship.
d. As many columns as there are equipments in the group under test, each column recording accumulated operating time on one equipment at the time of failure in column b.
e. Total of all columns under item d above.
f. Revised total of columns under item d above after one or more of these columns has been censored.
g. Column e divided by contract specified MTBF. See Table 3, Note 1.
h. Column f divided by contract MTBF.

(4) The test shall begin only after the equipments to be tested as well as test instrumentation facilities have had suitable operational check-out.

(5) The test is to be terminated immediately upon a decision to accept in accordance with subsequent criteria. The test is not to be terminated because of a decision to reject in accordance with subsequent criteria, but is to be continued as outlined in Section II C-1a, until through the means of censorship of the data from one or more equipments a decision to accept is reached in accordance with subsequent criteria.

(6) At the instance of each failure a log entry is to be made on a single line with observed data for each of the columns listed in paragraph (3) except columns c, f, and h.

(7) Log data from columns b and g (paragraph (3)) at the completion of each set of entries following an observed failure are to be compared with Table 3 to determine if a decision is possible as to whether the group has passed or failed the test. In addition, when it is anticipated that the accumulated operating time, in the absence of a simultaneous failure, has reached a point permitting a decision to pass the test, a log entry may be made to collect such operating time and terminate the test. When the data from columns b and g, in conjunction with Table 3 indicate the group has passed the test, the test is to be terminated. When such data indicate the group has failed the test, the test is to be continued, with a running analysis to determine if the censorship of any one column under item d (paragraph (3)) and the related failure or failures in column b, both cancel the reject decision and permit an accept decision. Columns c, f, and h, are to be used for this analysis. If a second reject decision is reached in spite of the most advantageous censorship of the data from a single equipment, the test is to be continued, and thereafter it is permissible to censor any two or more columns under item d (paragraph (3)) and related failures in column b, until a decision to accept the equipment is reached.

(8) On the occasion of a failure, the failed equipment is to be removed and repaired without interruption of the test of equipments continuing to meet test performance requirements. Upon decision that a failed and repaired equipment has been returned to representative operative condition it shall be returned to test without interruption to the equipments continuing on test.

(9) The absence of one or more equipments for the purpose of failure repair shall not affect the ability to make decisions from log data and Table 3.

(10) When an accept decision is made because of accumulated operating time, an entry is to be made on a separate line in the Log of Failures, with notation in column (b) indicating that an accept decision rather than a failure occurrence has occasioned the log entry.

d. Data Handling

Data handling for the reliability index evaluation of production equipment is to be in accordance with that prescribed in Section II.B.1-d, which applies to pilot production, except that the Log of Failures is to be in accordance with the description given in Section II.C.1-c (3) previous. Any action taken in accordance with rules set forth in Section II.B.1-d (10) shall be uniformly applied to every equipment produced, rather than only to those chosen for test. In paragraph II.B.1-d (13), the words "pilot production" may be stricken from the first sentence.

III. DISCUSSION

A. Basic Reliability Theory

The interest herein in the reliability of electronic equipment lies in its means for relating failure-free operation probability with the use conditions that are expected to describe a given mission. Reliability is defined generally as follows:*

> The reliability of an equipment is the probability that it will perform a required task under specified conditions for a required period of time.

In contrast to the general concept of reliability, there are reliability considerations under specialized, limited conditions. One of these of concern here is Inherent Reliability. This is defined as follows:

> The inherent reliability of an equipment is the probability that it will deliver specified performance without failure under specified test conditions for a required period of time.

* See Table I.

The use of a numerical value to this probability permits quantitative assessment of reliability. The numerical value is always less than unity. Quantitative future prediction of failure-free operation during contemplated missions can only be based on careful statistical assessment of past equipment operation. Desirable values close to unity require large quantities of carefully obtained statistical data. In general, most electronic equipment during its useful life is expected to survive a number of failures through the medium of repair. Observation of the frequency or rate of past failures during operation under actual or simulated conditions of expected application provides the most significantly useful data item for future failure prediction (i.e., reliability calculation). In order to employ a unit of measure of this observable data item which varies directly with (and can be easily related mathematically to) reliability the reciprocal of failure rate has been chosen and has been termed "mean-time-between-failures" (MTBF) determined by averaging statistical quantities of data.

Considerable data collected in recent years from many electronic equipments in service use have adequately established the fact that during the useful life (before wear-out) of electronic equipment those with the highest obtainable reliability still show probability of occasional failure and such failures are distributed randomly in time, and the frequency of occurrences is independent of equipment age. Equipment with lower reliability often shows failure occurrence having a non-random pattern, but nearly always such failures are relatable to undesirable application or conditions with the equipment, and could be remedied to produce the random failure pattern and increased equipment reliability. With this consideration it seems proper that any requirements for equipment reliability (numerically expressed) to be achieved through design, development, or production, be based on the exclusion of non-random failure. Such requirement necessitates that the equipment manufacturer either eliminate the probability of non-random failure through careful engineering, or reduce the level of random failures to such an extent that residual non-random failure probability does not prevent achievement of the specified reliability. In fact it could be shown that specifications for minimum acceptable mean-time-between-failures (and thus minimum acceptable reliability) as well as tests based upon the existence of only random failures will guarantee the desired equipment reliability even though all failures are not random, and that the only effect of the presence of non-random failures is additional effort required by the manufacturer to meet the reliability specifications.

In order to place the foregoing discussion in the proper perspective it is important to consider the overall equipment life. Figure 1 in Section I shows such a life characteristic curve as previously explained. During the initial hours of equipment life there is often found a short period of time during which average failure rate is not constant, having started at some particular value and decreased with time until a lower and relatively constant level is reached. Common practice has been to identify this initial period of decreasing failure rate as the early failure period ("debugging period" or burn-in). Its duration and the slope of the curve are peculiar to the equipment design and the manufacturing method employed. Its existence is attributable to the presence of material and parts which represent "weak sisters" among their kind and experience abnormally short life. In some cases, but not all these parts should have been removed by inspection rejection. In some cases the defects are difficult or impossible to identify initially. Common examples are: foci of corrosion, strain, structural change (crystallization), etc.

Following the early failure period soundly designed equipment in proper application should show the normal operating period evidenced by nearly constant failure rate, as previously discussed. During this period the failures occurring must be attributed to either of two causes, external influences or internal factors. Under external influences could be listed vagaries of application such as momentary environmental extremes of all kinds, but difficult to connect with specific failures. Under internal factors can be listed residual initial defectives unrecognized during the early failure period, as well as items succumbing to early wear-out but few in number and so distributed as to produce failures apparently random in time of occurrence.

The final portion of the life characteristic curve is termed the wear-out period, during which time the wear-out of various items occurs so closely related in time as to make the time dependence of the failure rate significant and observable. Often the beginning of the wear-out period is indicated by the beginning of failures among parts having a mean life expectancy short compared to the life of the equipment before obsolescence -- for example, electrical brushes, bearings, and other electro-mechanical parts or mechanical parts, or electrolytic capacitors, batteries, etc. Wear-out failures contributing to are most frequently associated with the consumption of materials through mechanical or chemical action. Preventive maintenance procedure permitting the replacement of such items before actual failure occurrence is often sufficient to significantly defer the onset of the wear-out period, at least insofar as increasing failure rate rather than some other criterion such as maintenance costs is the means of distinguishing wear-out.

By assuming it is proper for equipment manufacturers to operate their product sufficiently prior to delivery to carry it beyond the early failure period, and by assuming that separate means will be employed to verify that equipment wear-out will occur only after sufficient normal operating life, it is possible to specify desired reliability index only in terms of the failure rate (or preferably the mean-time-between-failures) characteristic during the normal operating period, the central dominant portion of the life characteristic curve. The level of the MTBF curve during this period is considered to be a function of three major factors. These are (1) long time, intrinsic quality, (2) engineering accomplishment, (3) the environmental conditions, both physical and personnel.

Specified requirements for minimum acceptable mean-time-between-failures thus are achieved by factors within the control of the contractor in the case of the first two of these factors. The contractor must insist on adequate specifications of the conditions of environment in order properly to achieve them under the conditions of the reliability test and the equipment use.

To analyze the time distribution of failures, it must be possible to measure intervals of time-between-failures. Two simplifying assumptions are helpful:

Assumption 1: Any failure occurs at a discrete point in time.

Assumption 2: The time of failure occurrence is the instant of initial detection of the failure.

The chance or random manner of failure distribution in time is describable by a Poisson Process. The Poisson distribution may be expressed as follows:

$$P_n = \frac{\left(\frac{t}{\bar{T}}\right)^n e^{-t/\bar{T}}}{n!} \qquad (1)$$

where P_n is the probability of n failures occurring in time, t, and $\bar{T}$ is the mean-operating-time-between-failures.*

To determine the probability of failure-free operation, during a given time, i.e., the reliability of the equipment, the expression (1) reduces to:

$$n = 0;\ P_0 = e^{-t/\bar{T}} \qquad (2)$$

Reliability, from expression (2), is a function of the period of time, t, that operation is required and the mean-operating-time-between-failures, $\bar{T}$. This relation is shown in Figure [illegible]. The required operating time is a variable which depends on the specific mission. The mean-operating-time-between-failures, on the other hand, is constant for an equipment in a given environment, and is the basic yardstick used for reliability measurement herein.

Figure [illegible] illustrates graphically how remarkably the reliability index of an equipment model must be improved in relation to the mission length in order to achieve higher reliabilities in the region of 95 to [illegible] percent. For example, if the equipment $\bar{T}$ is increased from a value equal to the mission length to a value ten times as great as the

*Mean-operating-time-between-failures elsewhere is referred to only as mean-time-between-failures, (MTBF). Correspondingly $\bar{T}$ represents the required operating hours.

mission length, the reliability (or the probability of no failure) increases correspondingly from 37% to 90%. However, to achieve a reliability of 99% requires an equipment $\bar{T}$ 100 times greater than the mission time.

The mean-time-between-failures of an equipment may be determined from laboratory test, field test, or field operational data and may be computed as follows:

$$\hat{T} = \frac{t_i}{F} \qquad (3)$$

where t_i is the total operating time for each equipment under investigation and F is the total number of failures.

B. Selection of Test Methods

1. Pilot Production Reliability Index Evaluation

The testing of complex electronic equipments in larger numbers and for relatively longer periods of time compared to present practices, will inevitably present numerous new problems to the procurement agencies and the manufacturers. Some increases in the costs of manpower, facilities, and equipment as well as the time required before an equipment can be delivered must be expected.

Let it be recognized, however, that in the absence of more simple means of determining the reliability of the procured equipment, testing is essential. It is the only way today that the procurement agency can have any degree of assurance that equipment meets specified reliability requirements.

The Task Group considered two basic approaches to reliability testing. One was the determination of the equipment's actual mean-time-between-failures. The other was the determination that the equipment mean-time-between-failures was equal to or better than a specified value by means of sequential test techniques. In the latter case the actual value for the equipment is not primarily determined. As the pilot reliability test is for capability only, there is no need to consider lot sampling.

Calculation of equipment actual mean-time-between-failures is frequently made where the observed equipment is in field use, its operation not under the control of the calculator, and a wealth of chronologically recorded failure information is available. For a pre-set confidence and precision of measurement it is merely necessary to process the required number of data, or at most await the acquisition of additional data. For a finite number of equipments under observation, the duration of the observation period will be equal to the mean-time-between-failures multiplied by the quotient of the required number of pieces of data divided by the number of equipments observed. Thus this observation interval can only be measured in terms of the mean-time-between-failures yet to be calculated, and thus the waiting time

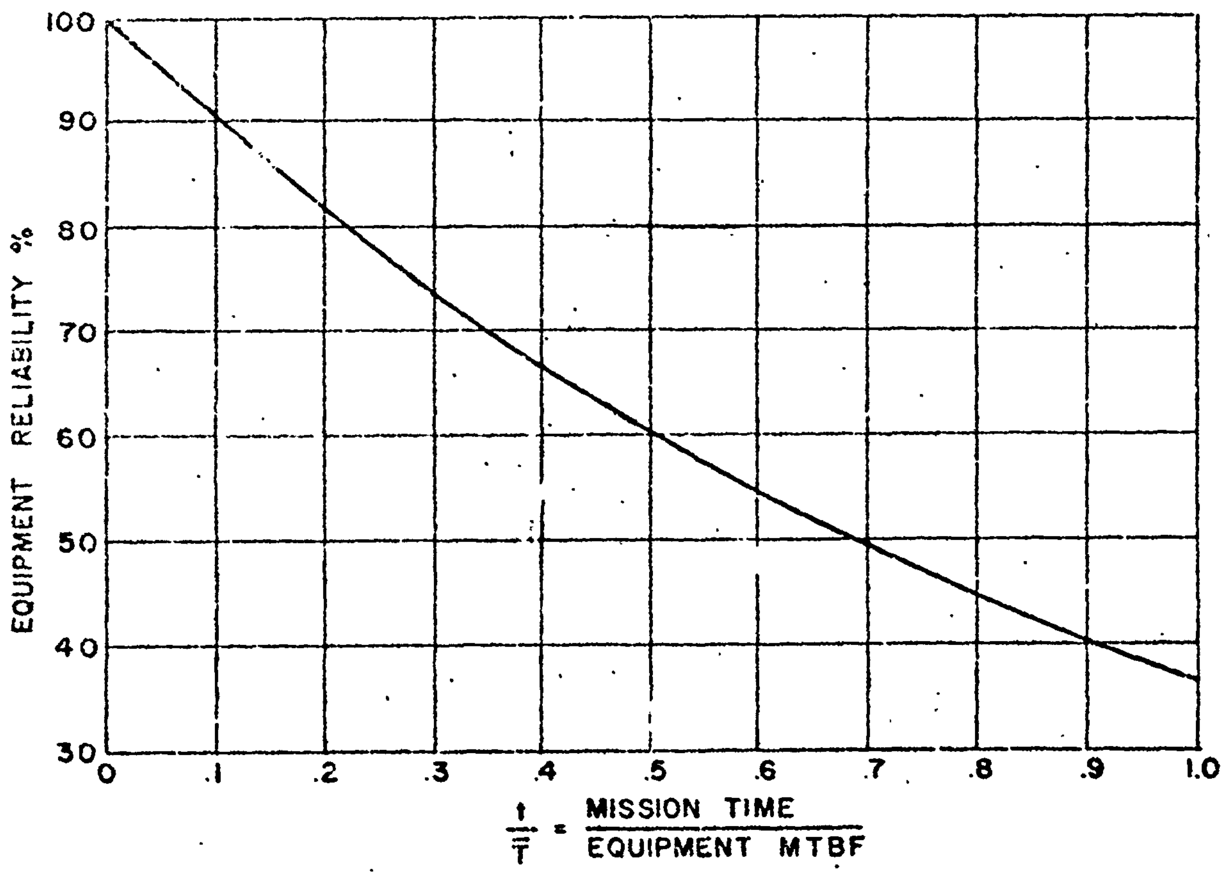


Figure 5. Equipment Reliability as a Function of $t/\bar{T}$

Reliability $= P_0' = 100 e^{-\frac{t}{\bar{T}}}$

is unknown for scheduling purposes. For after-the-fact reliability calculations such procedures have yielded sound measures of reliability of equipment in the field where the data were more or less unlimited.

In the case at hand, authorization for equipment production will be withheld pending determination that the equipment reliability index is sufficiently high. That the actual reliability index may be higher than necessary does not effect authorization for production, its main effect being on the economies of competitive manufacture, plus possible logistical value to the customer for other application.

After investigation it was concluded that the duration of the reliability test could be estimated for scheduling purposes based on the minimum acceptable mean-time-between-failures and sufficient time to allow for the occurrence of the required number of failures for the desired confidence and precision of measurement. Test results from unacceptable equipment would yield a calculated mean-time-between failures with higher than required confidence and precision of measurement (because of the larger number of failure observations) if the test was continued for the total scheduled period. Test results from equipment which is more reliable than required would yield a longer calculated mean-time-between-failures than the specified minimum and there would be too few failure observations during the scheduled period of test to permit the desired confidence and precision of measurement. However, with the actual number of failure observations obtained, the precision of measurement can be lowered sufficiently to permit obtaining the desired high level of confidence, and it will be found that the lower limit of the confidence interval is no lower than the lower limit obtained from the test of an equipment with just the minimum acceptable mean-time-between-failures. Thus the test run for a predetermined length of time as described above is valid.

The next consideration was to determine if there was any possible way to shorten the scheduled length of test without lowering the confidence in the decision to accept or reject the reliability level of the equipment. A study of sequential testing techniques showed that a sequential test could be performed with selected confidence level to determine if the mean-time-between-failures were above or below a predetermined value (viz., the specified value). For such a test the average duration of the test would be approximately 30% of the duration for the more common or standard evaluation techniques mentioned above. However, on occasion, circumstances would require an extension of the sequential test to reach a decision and the total duration then might be extensive. Careful study has led to a decision to recommend a truncated sequential testing method such that the maximum duration (for decision possible) is no more than [illegible] of that for the standard technique. The likelihood for requiring such a lengthy test is no more than a few percent and the confidence of the result is not affected by truncation. There is similarly some (low) likelihood of a very short test with decision reached in 8% of that duration required for the standard technique. Thus while the average time for the truncated sequential test is approximately 30% of that required for the standard technique, the limiting values are 8% and 60%. Discussions of the details of this test method are contained in the following section.

2. Production Reliability Index Evaluation

The foregoing Section describes the finally selected means for sufficiently accurate, expedient, and economical determination of the adequacy of MTBF, with respect to a contract specified lower limit, for equipments which are submitted to a specified sequential test. If each and every production equipment were subjected to such testing the mission of the Task Group with respect to production equipment would be satisfied. However, two questions, one of basic importance, and the other of secondary importance can logically be raised, and solution to the problems thus created has led to extensive further consideration. These questions, in simple form can be stated thus:

(1) For quantity production and high production rate, is there not means to test but a sample of the produced equipments and yet maintain adequate confidence that every untested equipment is equally satisfactory, and that the reliability index is not deteriorating as production proceeds?

(2) If tests are conducted on grouped equipments to shorten the testing time, rather than on equipments singly, is it possible to be confident that the presence of certain equipments of high MTBF within the group will not mask the presence of certain other equipments of unsatisfactorily low MTBF within the group, and if a group is found unsatisfactory can its contents be economically sorted to separate satisfactory from unsatisfactory equipments?

Because question (2) although of secondary importance is still of primary interest, it will be discussed first. Study of the sequential test method prescribed for pilot-production testing reveals that although the sequential test operates in large part on the average MTBF exhibited by the equipment group, still this type of test is quite sensitive to the presence of equipments with extremely low values of MTBF, and this is in part demonstrated by the shorter testing time required for reject decision. In fact it is believed possible to show that the presence of low MTBF equipments within a group will create larger probability of reject decision than the probability of accept decision because of the presence of high MTBF equipments. Studies of series of data from various extended life tests reveal that a group of equipments producing a reject decision can be sorted into acceptable and unacceptable sub-groups through trial censorship of data sets from individual equipments, one set at a time. In fact a [illegible] conclusions from extended life test data based on sequential analysis of the type employed for the pilot production sequential test are astonishingly consistent and rigorous in spite of various censorship techniques, and confidence limits calculated from a posteriori decisions are consistent and realistic. It would appear that this type of sequential analysis places some reliance upon extreme value theory. Accordingly, Section II.C.1 has been prepared based upon a data censorship method for culling unsatisfactory equipments from a rejected group so as to permit the group remainder to be considered satisfactory with a minimum of additional testing, and only such extension of testing as is required to maintain the initial confidence in the segregation is performed.

Study of question (1) has led to the conclusion that it is not possible to sample some of the failures (from the equipments on test) from some of the equipments (from the production lot) to yield conclusions about all of the failures in all of the equipments without getting into considerable difficulty with respect to assessment of risk or establishment of true confidence. It is to be noted that sampling of failures from only the equipments on test constitutes sampling in the time domain of a variable which can be reasonably assumed to follow an exponential distribution. On the other hand, selecting a sample of equipments from which to draw conclusions about all of a lot of equipments involves sampling in the population domain, and the variable, MTBF, for this sampling process certainly does not follow an exponential distribution in the population domain, and can be assumed to follow a gaussian distribution only by hypothesis. With great desire to minimize the quantity of data required from the population domain (in order to confine test requirements to practical magnitude) through optimum choice of a sampling plan, it has been disappointing to find that a sequential analysis by variables of a mean (MTBF) against a lower limit with unknown sigma has not yet been developed. With the thought that such a sequential plan might possibly be developed, and might be combinable with the sequential plan already chosen for the time domain to yield a streamlined overall test, this problem has been referred to consulting statisticians, and they feel that in the near future they may be able to develop such a novel plan.

To satisfy requirements in the immediate instance, a simple attributes sampling plan has been chosen for population sampling. In the chosen plan each equipment within a test group which passes the sequential test is judged good, and specific equipments are separated from rejected test groups and are judged bad, so that the remainder of the rejected test group can be judged good. Thus of all equipment tested in groups, the number of bad equipments are discernible from the number of good equipments. Accordingly, at any point in production testing a sample size n for an acceptance number c (number of bad equipments) can be established such that there is 90% confidence that the percentage of defective equipments (judgeable as bad were they all to be tested) does not exceed 10%. Then, with the initial t[illegible] sample chosen from the first equipments to be produced, it is required that a sample size of n for c equal zero be tested and all found good before any untested equipments are permitted to be released for delivery. If a bad equipment is found before completing the test of 22 equipments, a requirement is made that the next n equipments all be good, where n is now selected for c equal one, before untested equipments can be delivered. If two or more bad equipments are found, then the following n equipments must all be good, where n is chosen for c equal two, before untested equipments can be delivered. To protect against deterioration of MTBF as production progresses, a minimum sample is required for test each month so long as no bad equipments are found, and should any bad equipment be found then the requirement for n good equipments is repeated prior to delivery of any untested equipment. Values of $n = 22$ for $c = 0$; $n = 37$ for $c = 1$; and $n = 50$ for $c = 2$ were obtained from graphs of the incomplete beta function for $I_c = 0.9$ which are available in standard reference sources. Such values assure 90% confidence that the percent defective in the overall population is not greater than 10%.

The number of equipments to be grouped for a single test is established on the basis of two principles:

For once-a-month sample tests, the number of equipments in a test group shall be at least sufficient to give average expectation of a test decision in 500 hours of test operation or less, a testing time achievable by 24-hour operation each day, five days per week, in one month's time.

Expected test time in hours equals $20\bar{T}/N$ with $\bar{T}$ in hours.

To meet requirements for 22 (or 37 or 50) good equipments to establish confidence, group sizes shall be chosen to give earliest test results, and $N = \sqrt{TR/5}$ is the result of equating waiting time for equipment availability (in terms of production rate R) to expected average duration of test (equal to $20\bar{T}/N$ hours or $\bar{T}/25N$ months on a 500 hour month basis), and solving for that value of N (in terms of $\bar{T}$ and R) which gives the minimum total elapsed time (waiting time plus expected test time). Earliest test results are emphasized so that sub-standard equipment may be most quickly recognized and remedial action instituted.

3. Longevity Evaluation

It becomes reasonable to expect that longevity requirements will not be as uniformly included in every procurement contract as reliability index requirements. The extended testing time needed together with the destructive nature of longevity testing can become significant deterrents for small lot, short run, repetitive contracts where the number of equipments available for test assignment prevent lot longevity conclusions with high statistical confidence, especially if longevity is already qualitatively known for the equipment type from earlier testing. However, as there has been no previous testing background built around test procedures as herein described, longevity requirements should be given most careful consideration for the vast majority of all procurement. To provide the greatest probability for favorable consideration, this section will discuss preferred means for determining how to exercise the contracting agency's options with respect to the numerical value of the longevity requirement to be specified, and the number of equipments to be assigned to longevity test. Thus an optimum balance may be obtained between the confidence level of test conclusions, their value to the equipment user, and the testing cost in time and dollars.

The preferred numerical longevity requirement, in terms of length of equipment operating life before MTBF degradation, is related to expected equipment calendar life before obsolescence, and the operational or repeated mission usage rate (hours per year). Table 4 is an estimate of expected operational usage in hours per year for a few categories of electronic equipment, which may be used as a guide, and is illustrative of the rather wide variation that may be found among electronic equipment in general. In arriving at a numerical longevity requirement, available background on the state-of-the-art for the equipment type being considered should be taken into account.

Decision as to the number of equipments for assignment to longevity tests must take into account the relationship between the statistical confidence in quantitative lot conclusions for the number of equipments tested, and the expected elapsed time duration for each longevity test. Table 5 is a convenient conversion table for relating the total test hours available as a function of various working schedules. While it will be often considered desirable to require that longevity testing be conducted on a continuing basis for the duration of the contract, later produced equipments being put on test at the conclusion of test of earlier equipment, Table 5 may be used to determine the number of equipments to be tested simultaneously so that at the end of the contract a sufficient total number of equipments will have been tested to provide the desired level of confidence for a lot conclusion as to longevity adequacy.

As in reliability index evaluation, two confidence levels (or sets of risks) function simultaneously in longevity testing. The first confidence level is associated with the measurement of MTBF during test in order to determine that MTBF degradation remains tolerable. In essence this is the confidence level associated with the conclusion reached on each tested equipment as to whether it passed or failed its test. The testing technique prescribed directs that MTBF be determined by a procedure which, in effect, averages twelve consecutive intervals between failures. For this type of sampling test, wherein a single variable (MTBF) is under surveillance, confidence level is described in terms of the probability that the tested equipment's true MTBF is contained in the interval described by the computed MTBF value plus or minus a particular tolerance in percent. When MTBF is computed by averaging twelve observed consecutive intervals (between failures) the following statement as to confidence can be made: The tested equipment's true MTBF will lie in the interval established by the computed MTBF plus or minus 50 percent, nine times out of ten (or with 90% probability). With this confidence level are associated certain values for producer's and user's risk. As (in a above) one time in ten the true MTBF will be outside of the interval computed, there is up to ten percent chance (user's risk) that the MTBF will truly be too low even though the calculation yields a value sufficiently high to justify a pass decision for the test. Conversely there

TABLE 4

*Estimated
Equipment Operating Time
Average Hours/Year

		Type	Max.	Nominal	Min.
Airborne (carrier & Land based opera-tional)	War	C&N	1000	700	250
		Radar	800	500	200
		Elect.	1200	800	300
	Peace	C&N	650	400	130
		Radar	500	350	100
		Elect.	750	500	150
Airborne Non-Opera-tional (Adm. & Trans-port)	War	C&N	2500	1300	400
		Radar	2000	1100	350
		Elect.	2800	1500	500
	Peace	C&N	1800	800	180
		Radar	1500	750	150
		Elect.	2000	1000	200
Ships	War	C&N	4500	3000	2000
		Radar	5000	4000	[illegible]
		Elect.	7000	5000	[illegible]
	Peace	C&N	3500	2500	2000
		Radar	3000	2000	1500
		Elect.	4000	3000	2000
Stations	War	C&N	8500	8000	5000
		Radar	8500	8000	5000
		Elect.	8500	8000	6000
	Peace	C&N	8500	8000	3000
		Radar	8500	8000	3000
		Elect.	8500	8000	4000

*Actual Combat Life Expectancy Excluded.

is a ten percent chance (producer's risk) that the equipment's true MTBF is satisfactorily high even though the calculation and test result show the equipment to have failed the test. The confidence may be improved and the risks reduced by averaging more than twelve intervals between failures in computing the MTBF for test decision. In the presence of a gradually shrinking MTBF, adding earlier intervals tends to raise the computed MTBF, while adding later intervals (extending the test) tends to lower the computed MTBF. Accordingly, when a decision based on twelve intervals is in dispute, and it is desirable to recompute the MTBF by averaging more than twelve consecutive intervals, half of those to be added should immediately precede the original twelve, and the remaining half should follow the original twelve by extending the test. Table

TABLE 5

***Time Available in Various Work Periods in Hours**

Period:		1 day	1 week	1 month	2 mos.	3 mos.	6 mos.
	8 hr.day	8	40	168	336	504	1,008
5 day	12 hr.day	12	60	252	504	756	1,512
week:	24 hr.day	24	120	504	1008	1512	3,024
	8 hr.day	8	56	235	470	705	1,410
7 day	12 hr.day	12	84	353	705	1068	2,115
week:	24 hr.day	24	168	705	1410	2115	4,230

Period:		9 mos.	1 yr.	2 yrs.	5 yrs.	10 yrs.
	8 hr.day	1,512	2,016	4,032	10,080	20,160
5 day	12 hr.day	2,268	3,024	6,048	15,120	30,240
week:	24 hr.day	4,536	6,048	12,096	30,240	60,460
	8 hr.day	2,115	2,820	5,640	14,100	28,200
7 day	12 hr.day	3,183	4,230	8,460	21,150	42,300
week:	24 hr.day	6,345	8,460	16,920	42,300	84,600

*Based on 4.2 weeks = 1 month (approx. 10 days per year allowed for vacations, etc.)

6a gives the relationship between probability or confidence (risk is calculated by subtracting this value from one) and precision of measurement (i.e., the ±50% associated with averaging twelve). It should be noted that Section II.B. 2-c terminates the test when the calculated MTBF falls below 50% of the value specified by contract, this 50% being chosen to match the 50% precision of measurement associated with 90% confidence and 12 interval averaging. If the tested equipment's calculated MTBF by chance exceeded its true MTBF by just 50% and the calculated value just equalled 50% of the contract value, then the true value would be only 33% of the contract value, and this degradation has been judged acceptable for the procedure shown and is not classified as a risk. If sixteen or nineteen intervals were averaged instead of twelve, then (from Table 6a) for 90% confidence the precision of measurement is 40% and the true MTBF for passing equipment could only be as low as 36% of the contract specified value; more importantly, the table shows that the confidence is now 95% (5% risk instead of 10%) for the original 50% precision of measurement.

TABLE 6a

K% (Precision of Measurement)	*Confidence Level for Failure Interval Averaging the Required Number of Failure Intervals to be Observed to Attain a Confidence Level of:					
	60%	70%	80%	90%	95%	99%
20	19	28	43	68	97	166
30	9	13	20	32	45	74
40	6	8	12	19	27	44
50	4	6	9	13	18	31
70	3	4	6	8	11	18
100	2	3	4	5	6	10

*Values calculated using Student's "t" Distribution

TABLE 6b

90% Confidence Level for Lot Sampling

Boundaries for Lot Percent Unsatisfactory*

Equipments Failing	Equipments Tested				
	2	6	12	22	50
0	3.5-54%	1.5-28%	0.8-16%	0.4-9.5%	0.2-4.4%
1	20-80%	9-45%	4-27%	2-16%	1-7.4%
2		17-60%	9-36%	5-21%	2-10%

*Values are taken from charts for the solutions of the incomplete beta function.

The second confidence associated with longevity testing relates to general decisions concerning entire lot acceptability based on the test of but a few equipments. Table 6b relates this statistical confidence level to the number of equipments tested, and the relationship for practical purposes may be considered independent of the size of the total lot (thus independent of the number of equipments to be delivered untested). This table is entirely based upon 90% confidence or probability (and thus 10% user's and producer's risk) and shows the upper and lower limits, in percent of unsatisfactory equipments in the total lot, between which 90% probability exists as to the true percentage of unsatisfactory equipments in the lot, all as a function of the number of equipments tested, and the number of these found to fail the test. Thus if twelve equipments are tested and all pass, there is 90% probability that there are at least 0.8% of the lot which would fail the test and at worst no more than 16% which would fail the test. If in a test of 50 equipments, two fail the test, then the entire lot possessed between two and ten percent equipments which would fail the test, with 90% probability (or in nine out of ten such occasions). If only two equipments were tested and one failed, and the entire lot were rejected, (from the table) there is only one chance in ten that fewer than 20% of the equipments in the lot would be bad.

An example of the application of Tables 4, 5, and 6 to a hypothetical anticipated procurement may best serve to illustrate the foregoing considerations. Suppose an airborne radar is to be procured which will have an MTBF of 100 hours or more (as determined from mission requirements). The initial order is to be for 100 equipments with deliveries scheduled over one year. No longevity background exists and adequate longevity is considered vital. Obsolescence consideration establishes that the war-time life should be four years. Inspection of Table 4 reveals that operational requirements are at the rate of 800 hours per year or 3200 hours total for a 4-year life. The contract will specify 3200 hours as minimum for the longevity test (at the end of which the MTBF shall not have dropped below 50 hours, per Section II.B. 2-c). Allowing for "on-off" cycling in accordance with operational use and the conditions for test, and repair time, a total test time of 4000 hours is anticipated. Such a test would require two years based on an 8-hour day, 5-day week, from Table 5. However, because of the desire for earliest longevity information in view of the absence of past longevity data, it is preferable to schedule the test on a 3 shift 24-hour day, 7 day week basis in order to complete the first test in six months (also from Table 5). Thus two such tests are possible within the one-year delivery schedule.

A 3200 hour life on equipment with initially minimum acceptable MTBF (100 hour) will produce an average of 32 failures if no MTBF degradation takes place, 40 failures if maximum permissible degradation occurs but not until the very end of the test, and 44 failures if continuous straight line degradation occurs. From this observation it can be concluded that averaging of more than twelve failure intervals for higher confidence in the fail or pass decision concerning each tested equipment is not practical because the average would then be made over too great a portion of the useful life. If the equipment turns out to have an MTBF well above that minimum specified, such as 200 hours, such that an average of only 16 failures will be observed, it may be noted from Table 6a that the averaging of the last eight failure intervals, if found to yield 200 hours, still gives 90% confidence that the true MTBF is above 60 hours (200 hours minus 70% of 200 hours), and any rapid degradation near the end of the test would automatically yield more failure intervals for inclusion in the average, thus improving the precision of measurement.

In reaching a decision as to the number of equipments to assign to longevity test, perusal of Table 6b shows that to hold 90% confidence that less than 10% of the lot (10% of 100 equipments equals 10 equipments) is below longevity requirement necessitates test of 22 equipments or 22% of the production output. Presuming that this loss (and cost) of production output may not be justified, since there is no background data to indicate anticipated longevity trouble, it may be more practical to consider testing no more than twelve equipments, in two successive groups of six each. If all six in the first group pass the test, it can be immediately stated that there is 90% probability that only between 2 and 28 equipments would fail the test. Similar findings on the second group reduce the probable number of unsatisfactory equipments, and even if one equipment is found to fail in the second group, there is 90% probability that only between 4 and 27 equipments would fail. If one or more equipments failed in the first group, the number to be tested in the second group could be increased. If scrutiny of test data from a perfect score first group indicated little or no degradation from an initially very high MTBF, decision might be made o waive test of the second group. Test of the second group, besides increasing the confidence in overall test results, monitors any trend between early production and later production, as well as evaluates any effect from the multitude of minor design changes that often creep into production.

If procurement quantities and production scheduling should be extended for two years more, and provided longevity findings were excellent, a typical contract decision might be to test two more equipments from the second lot on an 8-hour day, 5-day week basis, taking the full two-year period as a means for monitoring the longevity realized by the initially produced units from the second lot. Further test of previous passing equipments could be extended to determine just where the onset of wear-out would take place.

Importantly, the failure data obtained in the longevity test, when fully and properly analyzed, yields much useful information as previously discussed. In particular, the non-random failures, while lowering the MTBF, indicate design and production weaknesses which may be immediately rectified by either applying improved design technique or prescribing routine maintenance schedules and procedures. The choice will be made or at least influenced, by the contracting agency through consideration of the time and regularity of occurrence of the non-random failures. All such data and related information is vital to the national defense in order to obtain continuing reliability by means of general application of such knowledge to all related future similar developments. Also, by providing for eventual correlation of field and factory failure rate data, through feed-back means, such correlation will guarantee that future production reliability will be maintained throughout the operational application period.

C. Mathematical Relations

1. Pilot Production Reliability Index Evaluation

The reliability test requirement for pilot production equipment is for the measurement of capability only. This is interpreted to mean the determination that the mean-time-between-failures averaged for the specified sample (between 2 and 10 equipments), equals or exceeds the required contract specified minimum mean-time-between-failures. These tests do not provide a basis for drawing any reliability conclusions concerning the remainder of the pilot production lot (if any).

Prediction of what the mean-time-between-failures for any equipment will be during future operation requires trial operation of the equipment for a long enough time interval to observe the times of occurrence of a sufficient number of actual failures to permit statistical assessment with desired confidence. Thus a sample of times between failure occurrences is taken from which is computed a mean, which is in turn assessed for its validity in relation to its representation of the value during normal operational use. This sampling problem (in the time domain rather than in the more customary population domain) is aptly suited to solution by a special type of sequential analysis (sequential life tests in the exponential case[1]).

Best known sampling plans assess a product by attributes (criteria each of which evaluate the product only in terms of good or bad) and such plans have an advantage in that many different kinds of attributes can be assessed simultaneously in the same sampling operation. Less regularly used are sampling plans which assess a product in terms of variables (criteria each of which is a continuously varying parameter upon which are imposed limits or tolerances of acceptability) and variables sampling plans do not conveniently consider several variables criteria simultaneously, the sampling calculation being repeated instead for each variable. However, where there is but a single criterion (the case at hand), a variables sampling plan has the advantage of requiring less data than an attributes sampling plan.

Product acceptability, as judged by a sampling plan is commonly established by statistically estimating the fraction of the total lot which is defective, and in a variables plan so designed, the average value of the variable and its dispersion are used in a calculated estimate of the fraction of the lot for which the variable is outside of acceptable tolerance limits. In statistical

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[1] "Sequential Life Tests in the Exponential Case", by B. Epstein and M. Sobel, Annals of Mathematical Statistics, Mar 1955, pp 82-93.

assessments of a product, not performed to establish acceptability, but rather for information only (and thus under conditions where there are no specified tolerance limits for acceptability for the variable) it is customary to describe conclusions in terms of arbitrarily chosen limits of the variable often termed confidence interval or precision of measurement, and to state the probability that the variable is within these limits (which is the same as saying what fraction of the lot can be expected to lie outside of this interval). As an example it might be stated that the mean-time-between-failures was estimated to be 100 hours with 90% confidence and ± 20% precision of measurement. This is interpreted to mean that 90% of the time the variable's mean is between 80 and 120 hours, or if 80 and 120 hours were considered lower and upper limits, then 10% fraction defective will exist. In the case at hand it is more direct to determine acceptability in terms of a single limit to answer the question, "what percent of the time will the mean-time-between-failures exceed, say, 80 hours?" For contracting purposes this question is converted to the demand, "Establish that 90% of the time the mean-time-between-failures exceeds a particular contract value, $\bar{T}$."

The sequential sampling plan chosen has the advantage that it can establish compliance with such a contractual requirement very quickly for equipment whose mean-time-between-failures greatly exceeds the required minimum. In fact the cost of the test will vary in proportion to the closeness with which the equipment's $\bar{T}$ approaches the required $\bar{T}$. By truncating, as will be described, the sequential test will always be more economical than any other statistical type of assessment.

In statistical assessment there are only two risks present. The first risk is that good equipment will be considered bad (producer's risk). The second risk is that bad equipment will be considered good (consumer's risk). The second risk has been already stated in the preceding paragraph, though in different words, to the effect that since there need be only 90% certainty (90% of the time) that the required $\bar{T}$ is exceeded, there is willingness to consider that $\bar{T}$ is always exceeded when in reality 10% of the time it may not be. The first risk can be thought of in regards to how long shall the test continue when the equipment $\bar{T}$ is so marginal that a wrong decision (bad when really good) might be made from a short test. In order to hold acceptably low first risk, (to satisfy the producer), and yet retain test economy, certain empirical limitations have been established.

It has been decided to require by contract that the minimum acceptable mean-time-between-failures, T_1, will be 50% greater than actually desired as a minimum. This value T_1, spelled out in the contract, is associated with a first risk, α, of 10%, to establish by the sampling plan recommended that there is only a 10% chance of rejecting (as bad) equipment which meets (or exceeds) this figure. The plan actually rapidly reduces the risk below 10% in proportion to the extent that the equipment $\bar{T}$ exceeds T_1. The plan is designed to allow only 10% second risk (β) that the plan will accept (as good) equipment whose $\bar{T}$

equals or falls below T_2. T_2 -- the value actually required as a minimum is equal to 2/3 $\bar{T}_1$, and is not identified in contractual requirements. In effect this means that equipments whose $\bar{T}$ falls between $\bar{T}_2$ and $\bar{T}_1$ can be either rejected or accepted in accordance with chance operation of the test without concern to either the producer or consumer. Under this arrangement it is possible to make certain statements concerning the expected magnitude of the sequential test which will permit testing time to be scheduled even though in a sequential test the testing time required is a variable and depends upon intermediate test results.

With the sequential sampling plan recommended for pilot production, the following conditions will prevail:

(a) If the actual $\bar{T}$ of the equipment is equal to $\bar{T}_1$ (contract value), the average test duration will be 20 $\bar{T}_1/N$ hours, where N is the number of equipments on test. If $\bar{T}$ is significantly greater than $\bar{T}_1$, the average test duration will be less than this figure and will approach as a limit 4 $\bar{T}_1/N$ hours.

(b) If the actual $\bar{T}$ is equal to 2/3 $\bar{T}_1$ (equal to $\bar{T}_2$), the average test duration will be 15 $\bar{T}_1/N$ hours. If $\bar{T}$ is significantly less than 2/3 $\bar{T}_1$, the average test duration will be less than this figure and will approach 0 hours.

(c) If the actual $\bar{T}$ is approximately 0.81 $\bar{T}_1$ (midway between $\bar{T}_1$ and $\bar{T}_2$), the average test duration will be 19 $\bar{T}_1/N$ hours to reach a reject decision and 28 $\bar{T}_1/N$ hours to reach an accept decision.

The table establishing sequential test criteria for accept and reject decisions has been calculated from two equations:

$$T = 0.81 F_r - 4.4$$

$$T = 0.81 F_a + 4.4$$

where F_r = number of failures to permit a reject decision in normalized time T, and

F_a = maximum allowable number of failures in normalized time T which permits an accept decision.

T can be converted to real time by multiplying its value by $\bar{T}_1/N$ where $\bar{T}_1$ is the contract specified value in hours and N is the number of equipments on simultaneous test. These two equations are derived in accordance with the sequential analysis theory set forth in the following paragraphs.

In Section III-A the Poisson distribution, which favors the most acceptable equipment, states that the probability P_n of n failures occurring in time t if $\bar{T}$ is the equipment's true mean-time-between-failures is given by

$$P_n = \frac{\left(\frac{t}{\bar{T}}\right)^n e^{-t/\bar{T}}}{n!} \qquad (1)$$

When an equipment sample has been in operation for a particular time interval t, and a certain number of failures n have taken place, this equation (1) should show the highest value if the correct and true value of $\bar{T}$ for the equipment in question is inserted in the formula, and should yield lower values of P_n for values of $\bar{T}$ either significantly higher or significantly lower than the true value. In fact, equation (1) can be applied first with its $\bar{T}$ equal to $\bar{T}_2$ (that value for which a reject decision should be made) and the probability calculated. Next, a second calculation can be made with $\bar{T}$ equal to $\bar{T}_1$ (that value for which an accept decision should be made) and the probability again calculated. If from the first calculation the probability that the equipment $\bar{T}$ is $\bar{T}_2$ is found to be much greater than the second calculated probability (that the equipment $\bar{T}$ is $\bar{T}_1$) it is likely that the equipment should be rejected. If the second probability is much greater than the first, perhaps the equipment should be accepted. The problem now is to decide limits for these ratios of these two probabilities that are consistent with the two risks α and β previously described, so that whichever decision is made, it will not violate the preassigned risks. When such relationship is established for the probability ratio with respect to α and β, then a test may be begun, and at the time of each successive failure the probability ratio can be calculated (using the observed values for n and t) and a decision made at the first opportunity which will not violate α or β.

Equation (1) when rewritten with $\bar{T}$ equal to $\bar{T}_2$ for the numerator of the ratio equation, and then rewritten with $\bar{T}$ equal to $\bar{T}_1$ for the denominator of the ratio equation, and with usual algebraic cancellation appears as:

$$P_r = \frac{P_n \bar{T}_2}{P_n \bar{T}_1} = \left(\frac{\bar{T}_1}{\bar{T}_2}\right)^n \frac{e^{-t/\bar{T}_2}}{e^{-t/\bar{T}_1}}$$

or further simplified

$$= \left(\frac{\bar{T}_1}{\bar{T}_2}\right)^n e^{-(1/\bar{T}_2 - 1/\bar{T}_1)t}$$

Epstein and Sobel[1] have shown a good approximation of limiting values for this ratio in simple terms of α and β which permit decision without violation of the prescribed risks. In simple terminology, so long as the ratio P_r is <u>larger</u> (likelihood of $\bar{T}_2$ versus $\bar{T}_1$) than the ratio of the risk (β) of accepting a bad equipment ($\bar{T}_2$) to the probability ($1-\alpha$) of accepting a good equipment ($\bar{T}_1$), then a decision to accept is not justified. Conversely, so long as the ratio P_r is smaller (likelihood of $\bar{T}_1$ versus $\bar{T}_2$) than the ratio of probability ($1-\beta$) of rejecting a bad equipment ($\bar{T}_2$) to the risk (α) of rejecting a good equipment ($\bar{T}_1$) then a decision to reject is not justified. So long as neither decisions are justified the test should continue. This can be written as an inequality formula as follows:

$$\frac{\beta}{1-\alpha} < P_r < \frac{1-\beta}{\alpha}$$

So long as neither inequalities is violated the test continues. The moment either inequality is violated, a decision is made and the test halted. If it is the first inequality which is violated first the decision is to accept. If the second, the decision is to reject.

The following algebra reduce this inequality formula to the equations for Table 2 in Section II B-1c:

$$\frac{\beta}{1-\alpha} < \left(\frac{\bar{T}_1}{\bar{T}_2}\right)^n e^{-(1/\bar{T}_2 - 1/\bar{T}_1)t} < \frac{1-\beta}{\alpha}$$

taking the natural logarithm throughout:

$$\ln\left(\frac{\beta}{1-\alpha}\right) < n \ln\left(\frac{\bar{T}_1}{\bar{T}_2}\right) - \left(\frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1}\right)t < \ln \frac{1-\beta}{\alpha}$$

dividing by $\frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1}$ throughout:

$$\frac{\ln \frac{\beta}{1-\alpha}}{\frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1}} < n\,\frac{\ln\left(\frac{\bar{T}_1}{\bar{T}_2}\right)}{\frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1}} - t < \frac{\ln \frac{1-\beta}{\alpha}}{\frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1}}$$

changing sign and adding $(n)\left(\frac{\ln \frac{\bar{T}_1}{\bar{T}_2}}{\frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1}}\right)$ throughout:

$$\frac{-\ln \frac{\beta}{1-\alpha} + n \ln\left(\frac{\bar{T}_1}{\bar{T}_2}\right)}{\frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1}} > t > \frac{-\ln \frac{1-\beta}{\alpha} + n \ln\left(\frac{\bar{T}_1}{\bar{T}_2}\right)}{\frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1}}$$

The left hand term when equated to t gives the equation for accept decisions, and the right hand term similarly the reject decision. Inserting numerical values:

$$\bar{T}_2 = 0.67\ \bar{T}_1 \quad \text{thus}\ \frac{1}{\bar{T}_2} - \frac{1}{\bar{T}_1} \quad \frac{1.5}{\bar{T}_1} - \frac{1}{\bar{T}_1} = \frac{.5}{\bar{T}_1}$$

$$\alpha = \beta = 0.1 \quad \text{thus}\ \frac{\beta}{1-\alpha} = \frac{1}{9} \quad \text{and}\ -\ln\frac{1}{9} = \ln 9$$

thus for acceptance

$$t = \frac{\ln 9 + n \ln 1.5}{\frac{.5}{\bar{T}_1}}$$

or normalizing for T_1 and letting $n = F_a$

$$\frac{t}{\bar{T}_1} = T = 0.81\ F_a + 4.4$$

and for rejection $\frac{1-\beta}{\alpha} = \frac{0.9}{0.1} = 9$ and $n = F_f$

$$T = 0.81\ F_f - 4.4$$

These are the numerical equations previously established for the table in Section IIB 3.

Epstein and Sobel[1] has shown that the most probable number of failures (E) required for decision if the true $\bar{T}$ of the equipment equals $\bar{T}_1$, $\bar{T}_2$, or S where

$$S = \frac{\ln \dfrac{\bar{T}_1}{\bar{T}_2}}{\dfrac{1}{\bar{T}_2} - \dfrac{1}{\bar{T}_1}}$$

(and defines a point at the approximate geometric mean of $\bar{T}_1$ and $\bar{T}_2$) can be approximately calculated from the formulae:

$$E_{\bar{T}_1} \simeq \frac{(1-\alpha) \ln\left(\dfrac{\beta}{1-\alpha}\right) + \alpha \ln\left(\dfrac{1-\beta}{\alpha}\right)}{\ln \dfrac{\bar{T}_1}{\bar{T}_2} - \left(\dfrac{\bar{T}_1}{\bar{T}_2} - 1\right)} \simeq 19$$

$$E_{\bar{T}_2} \simeq \frac{\beta \ln\left(\dfrac{\beta}{1-\alpha}\right) + (1-\beta)\left[\ln\left(\dfrac{1-\beta}{\alpha}\right)\right]}{\left(\ln \dfrac{\bar{T}_1}{\bar{T}_2}\right) - \left(\dfrac{\dfrac{\bar{T}_1}{\bar{T}_2} - 1}{\dfrac{\bar{T}_1}{\bar{T}_2}}\right)} \simeq 24$$

$$E_S \simeq \frac{\left[-\ln\left(\dfrac{1-\beta}{\alpha}\right)\right]\left[\ln\left(\dfrac{\beta}{1-\alpha}\right)\right]}{\left(\ln \dfrac{\bar{T}_1}{\bar{T}_2}\right)^2} \qquad 29$$

The forementioned number of failures (19, 24, and 29) can be compared with the Table 2 to determine approximate test times of 20T, 15T, 19T, and 28T, the latter two being S values for reject and accept, respectively. Minimum test time (for equipment whose $\bar{T}$ is either ∞ or 0) can be determined by inspection of the Table, and is found to be the time of first opportunity for decision.

[1] "Sequential Life Tests in the Exponential Case", by B. Epstein and M. Sobel, Annals of Mathematical Statistics, Mar 1955, pp 82-93

Since it is possible in a sequential test to find it necessary to continue the test for an extended period when an earlier decision is not possible, it is of interest to consider truncating the test at a pre-selected time in case no decision is made sooner, and to specify arbitrary means for decision at the time of truncation. The obvious question raised relative to such truncation is the effect if any on the two risks, α, and β, both of which have been fixed at 10%. A paper published by Epstein[2] can readily be applied to this truncation question. He has found that errors of approximation in using the simplified formula for sequential test design, as have been used herein, err in the safe direction such that the true risk is actually lower than the values assigned when conditions are such as to suggest truncation. Accordingly, in the published paper[2] the point for truncation is selected such that true α is maintained at its assigned value, 10%, and true β is held equal to or less than its assigned value, 10%. Table 1 of the paper [2] shows that for the T_1/T_2 ratio chosen (1.5) and $\alpha = \beta = 0.10$ the truncation should be made at 41 failures (to fail the test) or T = 33 time units (to pass the test) whichever comes first. Under such truncation α will always equal 10% and β will never exceed 10%. Thus the sequential test requirement can be accomplished in no more than 60% of the time required for normal test, and on the average in less than 30% of the time required for normal test.

2. Production Reliability Index Evaluation

The previous section establishes the risks and confidences applicable to the sequential test, with respect to the actual equipments tested. This section is concerned with the operating characteristic (which defines risk) of the continuous attributes sampling plan employed to permit decision as to acceptability of a lot of equipments when only a portion are actually tested. Also the means for choosing that number of equipments which permit a group sequential test yielding results at the earliest moment are described.

The operating characteristic of a sampling plan is the probability of lot acceptance versus the lot percentage unsatisfactory equipments. The user's risk is customarily specified from scrutiny of the operating characteristic curve as that percentage of unsatisfactory equipments within a lot for which there is a 10% probability of lot acceptance. The producer's risk is the risk of an adverse decision on a good lot, and is also obtained from the operating characteristic curve, usually by noting what percentage of unsatisfactory equipments within a lot give 90% probability for lot acceptance (and hence 10% probability of lot rejection).

The operating characteristic of the continuous attributes sampling plan described in Section II.C 1-a can be calculated in the following way. The probability

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[2] "Truncated Life Tests in the Exponential Case," by B. Epstein, Annals of Mathematical Statistics, vol. 25, pp 555-564.

of acceptance is the sum of probabilities for acceptance by all of the independently alternative courses of events. Thus, acceptance can be determined by finding (1) no reject in 22 equipments, or (2) one reject in 22 and no reject in the following 37, or (3) one reject in 22, one reject in the next 37, and no reject in the next 50, or (4) one reject in 22, one reject in the next 37, one reject in the next 50, and no reject in the next 50, etc. Fortunately the probabilities associated with each of these successive alternatives rapidly decrease to insignificance so that only the first eight such alternatives significantly contribute to the total probability of acceptance.

The probability of finding exactly zero defectives in a group of 22 units can be found in a table of terms of Poisson's Exponential Binomial Limit. Similarly, the probability of exactly one defective in 22, can be multiplied by the probability of exactly zero in 37 to give the value for the second alternative. This process can be repeated for each term of each successive alternative, and the equation representing the process can be written:

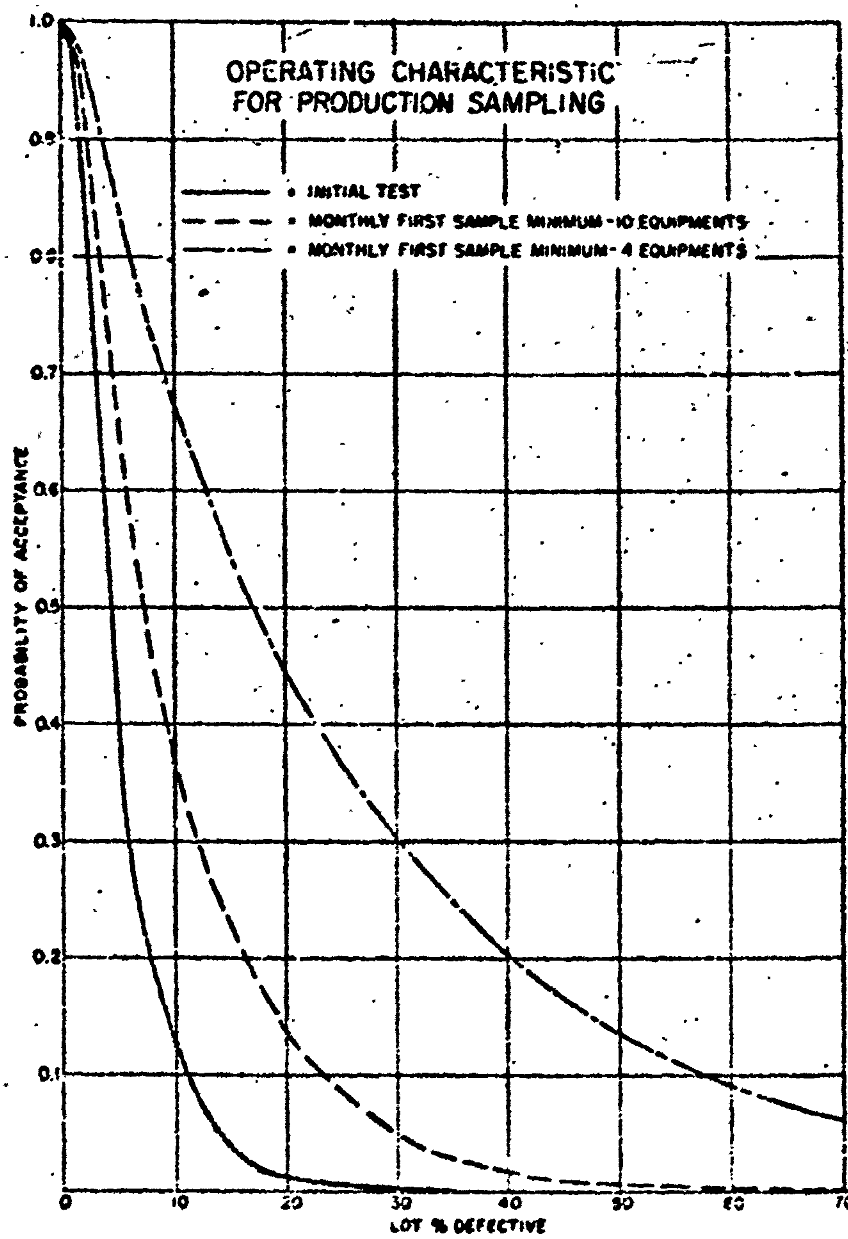
$$
\begin{aligned}
P_T = {} & P_{(0/22)} + \\
& P_{(1/22)} \times P_{(0/37)} + \\
& P_{(2/22)} \times P_{(0/50)} + \\
& P_{(1/22)} \times P_{(1/37)} \times P_{(0/50)} + \\
& P_{(1/22)} \times P_{(1/37)} \times P_{(1/50)} \times P_{(0/50)} + \\
& P_{(1/22)} \times P_{(1/37)} \times P_{(1/50)} \times P_{(1/50)} \times P_{(0/50)} + \\
& P_{(1/22)} \times P_{(1/37)} \times P_{(1/50)} \times P_{(1/50)} \times P_{(1/50)} \times P_{(0/50)} + \\
& P_{(1/22)} \times P_{(1/37)} \times P_{(1/50)} \times P_{(1/50)} \times P_{(1/50)} \times P_{(1/50)} \\
& \times P_{(0/50)}
\end{aligned}
$$

The operating characteristic has been plotted as one of the three curves in Figure 6.

For monthly sampling as described in Section II.C 1-a there is no longer a requirement for the acceptance of 22 consecutive equipments, the group being on occasion as few as 4. Such a change from 22 to 4, requires that all terms of the previous equation based on a group size of 22 be replaced with a group size of 4. The equation as written has all such terms in a column at the left. By appropriately revising this column, the operating characteristic for a monthly sampling of

4 equipments has been calculated and is also plotted in Figure 6. Since the user's risk is significantly increased with a group size of 4, a third operating characteristic for a monthly group size of 10 has also been computed and plotted in Figure 6. Procuring agencies may elect to specify a size of monthly sample consistent with the magnitude of risk they are willing to assume.

FIG. 6



It should be noted that the likelihood of the reliability index of production equipments which have passed the initial reliability test (22 equipments, etc.) suddenly dropping and thereby unduly risking shipment of substandard equipments under the Q.C. for the monthly sample, is rather slight provided changes in design, changes in material, etc., are classified as reason for requiring retest of a minimum of 22 equipments.

The number of equipments to be grouped for test to permit earliest test decision may be calculated by writing the equation for waiting time to accumulate equipments plus probable duration of test, then solving for a minimum in the customary fashion, thus:

$$t = \frac{N}{R} + \frac{\bar{T}}{25N} \text{ in months}$$

where N is number in test group, R is production rate in equipments per month, and $\bar{T}/25N$ is a conversion to test time in months based upon 500 hours test per month from the formula $20\bar{T}/N$ where the test time is in hours. $\bar{T}$ is still expressed in hours.

$$\frac{dt}{dn} = \frac{1}{R} - \frac{\bar{T}}{25N^2} = 0$$

and $N = \sqrt{\bar{T}R}/5$

These formulae are the basis for calculating the graph of Figure 4.

D. Selection of Test Conditions and Procedures

The four levels of stress severity for environmental test conditions were chosen as a practical compromise to cover a wide range of actual environmental conditions. Of the two major environmental factors which most often degrade reliability; i.e., temperature and vibration, only temperature was varied in the various severity levels. In some cases, where the final use involves other important factors such as extreme vibration, other stress levels may have to be used. In most cases, however, the capability of an equipment to withstand the vibration can be determined by conventional type tests. The special reliability tests can then prove the stability of the product quality under various extremes of one major variable, "temperature".

The appropriate standard level for use on any specific project should be selected by the contracting agency to simulate roughly the extreme conditions of end use. The level thus selected will then apply to all subsequent production of the same item so that uniform reliability comparison is possible. There is no intention that these conditions will exhaust the various combinations of environment that could be included for the reliability testing of occasional specific equipments. Humidity, altitude, shock, and extreme vibration may all be required in some cases. The specified stress levels are to be considered as minimum requirements and should be extended only with full recognition of the attendant cost and time delay, and loss of standardized test benefits.

The practical consideration of size of environmental test facilities required to test that optimum number of equipments which will yield earliest test results (never less than 4) must be included in the contractual negotiations. Also, the delay in delivery to permit testing in groups smaller than optimum, in order to minimize cost of test facilities, may be significant.

For simplification of the standard test set-up, cycling of the input voltage was not specified. The specified high side input voltage is good for use in detecting hot spots and early burn-out. In some cases, however, the use of some low side input voltage test time is beneficial. This is particularly true in regard to detecting poor tubes wherein emission is low. A cycled input voltage from high to low value as specified for the equipment is easy to provide when a-c inputs are used, but much more difficult when d-c inputs are used. Added emphasis on equipment operation at low input should be included in applicable type tests.

It can be argued that a humidity environment is essential to reliability tests and should be included in the specified levels. In the majority of cases humidity is a slow acting factor and it is felt that humidity troubles which do not show up in the type tests would not often be detected in the reliability tests. For this reason humidity is excluded. However, if equipment is designed to operate while dripping wet, this condition can be met by moving the equipment between the hot chamber and the cold chamber through a humid atmosphere. A similar effect can be obtained when using a single chamber for both heat and cold tests providing care is taken to restore a high humidity to the chamber on each heat cycle. A precaution in this direction should be observed. If low humidity is required throughout the temperature test cycle care should be exercised to drain off the moisture which is condensed on each cold half of cycle.

The details of any variations from the specified severity level conditions should be clearly defined in the contract.

E. Relationship to Other Task Groups

While the reliability evaluation methods proposed herein in no way are dependent for validity upon the findings of any other Task Group, it has been recognized from the start that the mutual success of all of the Task Groups is essential to the yield of maximum reliability benefit to the military services from the efforts of Task Group 3. The nature of such indirect dependency is set forth in the probable descending order of significance in the following paragraphs.

1. User's Minimum Acceptable Reliability Index

It is anticipated that Task Group 1 will assess tactical requirements and will convert all applicable factors into a single numerical figure for minimum MTBF for each equipment category or type. This figure, which will hereinafter be identified as T_1, becomes the basic parameter from which to ultimately derive $\bar{T}$, the minimum specified MTBF for Task Group 3 evaluations.

2. Reliability Degradation Related to Maintenance

It is anticipated that Task Group 9 will consider possible reduction in reliability from that value attained during manufacture because of various aspects of field maintenance, such as practical maintenance routines, maintenance personnel training, and field test equipment deficiencies. It is presumed that a multiplying coefficient, K_9, representative of the reciprocal of expected reliability degradation through field maintenance can be developed for each significant equipment category, such that MTBF prior to maintenance, T_9, is equal to T_1 multiplied by K_9 (viz., $T_9 = K_9T_1$).

3. Reliability Degradation Related to Storage

It is anticipated that Task Group 8 will consider possible reduction in reliability as a function of storage conditions and storage time, for significant equipment categories. It is presumed that such factors can be taken into account to yield a reciprocal multiplying coefficient, K_8, such that MTBF prior to storage, T_8, is equal to MTBF required after storage, T_9, multiplied by K_8, thus yielding the equation

$$T_8 = K_8 T_9 = K_8 K_9 T_1$$

4. Reliability Degradation Related to Transportation

It is anticipated that Task Group 7 will consider possible reduction in reliability as a function of expected conditions of transportation and handling, for significant equipment categories. It is presumed that this factor can be inversely represented by a coefficient, K_7, such that MTBF before transportation and handling, T_7, is equal to MTBF after transportation and handling, T_8, multiplied by K_7, thus yielding the equation

$$T_7 = K_7 T_8 = K_7 K_8 T_9 = K_7 K_8 K_9 T_1$$

5. Relationship of $\bar{T}$ to T_1

As previously stated the minimum MTBF specified by contract for pilot production and production evaluation, $\bar{T}$, must be chosen to be 50% greater than the MTBF actually required in the delivered equipment, T_7. Thus $\bar{T}$ can be related to T_1 by the equation

$$\bar{T} = 1.5\ T_7 = 1.5\ K_7\ T_8 = 1.5\ K_7\ K_8\ T_9 = 1.5\ K_7\ K_8\ K_9\ T_1$$

6. Relationship of Minimum MTBF for Development

It is anticipated that Task Group 2 will conclude that the minimum acceptable MTBF of equipment measured during the development stage, T_2, must bear some fixed relationship to the minimum acceptable MTBF for pilot production and production equipment ($\tilde{T}$), such relationship being of the form of a multiplying coefficient, K_2, either greater or less than unity, and varying among significant categories of equipment. Thus it is presumed K_2 can be chosen as to permit

$$T_2 = K_2 \tilde{T}$$

7. Relationship to Task Groups 4, 5, and 6.

The procedure prescribed by Task Group 4, when followed by a contractor during equipment design and development, should establish with relatively high confidence, (1) the probability of passing the reliability tests for development equipment prescribed by Task Group 2, and (2) the probability of passing the reliability tests for pilot production prescribed by Task Group 3 herein. Additionally, the Task Group 4 procedure should permit rapid identification of areas for initial redesign attention in those cases where the reliability as evaluated by Task Group 2 or 4 tests is found to be insufficient.

The recommendations of Task Group 5 should ultimately result in the yield of refined reliability data for parts and components which permit improved accuracy and confidence for the reliability predictions made in accordance with the Task Group 4 procedure.

The findings of Task Group 6 are presumed to be of assistance to the implementation by contracting procedures of the findings of each of the other Task Groups.

IV. CONCLUSIONS

The members of Task Group 3, assisted by expert consultants, have gathered, reviewed, developed, and largely confirmed such information as permits them unanimously to agree upon the following major conclusions:

1. Practical means exist for performing quantitative evaluation of pilot production and production models of electronic equipment which will determine conclusively whether or not the equipment meets the specified minimum acceptability figure for reliability.

2. The testing methods, set forth in Section II of this report and discussed in Section III, while ultimately requiring conversion to doctrinal forms such as Directives, Instructions, Memoranda, MIL Standards, or MIL Specifications, fulfill the basic objectives of this Task Group's assigned mission and satisfy the criteria laid down by the Task Group. Importantly, they conform to the following:

a. Decision bases are clearly defined and do not depend upon the judgment or experience of any agency or personnel.

b. The technique employed for evaluation, while presently judged completely practical and efficient, easily lends itself to future improvement as experience and advancing state-of-the-art permit.

c. The methods and procedures are independent of and can accept any numerical values of mean-time-between-failure specified for an electronic equipment and therefore are independent of variations in operational requirements.

d. The methods while developed to permit maximum benefit when applied in conjunction with the findings of the other AGREE Task Groups, can be implemented without support from these other groups by permitting the procuring agency to establish, arbitrarily or otherwise, a value for minimum reliability acceptability.

e. The methods set forth are, within the extent of the ability of the Task Group and its consultants, optimum with respect to ease of specification and administration and with respect to economy of both funds and time schedule.

f. The test methods if administered as prescribed herein are suitable for immediate implementation with or without a period of trial use, by any or all of the procuring services.

3. The testing methods, set forth herein in compliance with the evaluation mission assigned, provide specific test routines for (a) reliability index evaluation of pilot production equipment, (b) reliability index evaluation of production equipment, and (c) longevity evaluation of pilot production and/or production equipment. This separation of test routines permits, respectively, (a) establishment of capability for meeting minimum reliability requirement, based upon the greatest testing economy with respect to number of equipments tested and testing time required, as judged most desirable for pilot production equipments; (b) statistically conclusive proof that an acceptable percentage of quantity produced equipments each meet a minimum reliability requirement, with maximum economy of test cost and time; and (c) conclusive proof that equipment reliability does not degrade during the desired equipment life below a prescribed minimum level.

4. The testing methods set forth herein are developed in such a manner that they are reasonably immune to tampering by the contractor or by prejudiced testing personnel. In addition, selected redundancies in data handling render the testing methods reasonably self-checking and immune to errors in data recording. Specific means for accomplishing the evaluations are described. These means take the form of detailed testing methods, circumscribed by complete rules for administration and procedure. Parameters for election by a procuring agency are only those which must relate (1) conditions of equipment end-use to the testing procedure, and (2) conditions of procurement volume and scheduling to the testing sequence. Factors which cannot affect evaluation conclusions but can affect testing convenience are left for election by the procuring agency or the contractor.

5. The testing method as herein prescribed for the evaluation of pilot production equipment is well suited to permit mandatory requirement for minimum reliability of pilot production equipment prior to authorization of regular equipment production. The testing time required to prove compliance is believed to be considerably less than required by any other known presently used technique yielding equivalent quantitative assessment, and is considered compatible with typical scheduling. The number of equipments required for test is so minimized as to be quite compatible with the volume of pilot production equipments customarily procured. The nature of the prescribed test is such as can reasonably be considered non-destructive to the equipments tested, thus not compromising equipment intended use or application.

6. The testing method as herein prescribed for the evaluation of production equipment is adjustable in accordance with rules set forth to be compatible with any combination of procurement quantity, production rate, and equipment complexity. Where production rate is moderate or high, the testing method employs a sampling technique permitting uniform high confidence with respect to the reliability of each delivered equipment, yet requiring the actual test of but a sample fraction of these equipments on a continuing basis that is sensitive to any later reliability deterioration. Adjustment of the testing routine in accordance with production rate permits continuous yield of reliability acceptability in the shortest elapsed intervals, thus augmenting early remedial action of any observed shortcomings.

7. The testing method as herein prescribed for the evaluation of reliability longevity permits initiation of test either at the time of pilot production evaluation or at the time of initial production evaluation. The anticipated duration of the longevity test period is such as is likely to be incompatible with the scheduled period for pilot production alone, and yet be of sufficient importance to the equipment program to warrant findings at the earliest practicable date. Accordingly, where pilot production and production equipments are reasonably similar, and where longevity evaluation is desirable, the evaluation should be begun early in the program during the pilot production phase, and transition to production should not await longevity findings.

8. Statistical elections with respect to the testing methods herein prescribed, have all been made on the basis of 10% user's risk, 10% producer's risk, and 90% confidence. Formulae are included herein for altering the test method to employ other levels of risk and confidence. It is the belief of the Task Group that the risks and confidence chosen are aptly suited to the Task Group mission.

V. RECOMMENDATIONS

1. Task Group 3 recommends that the material included herewith in its Final Report be referred by AGREE to OASD (ENG) for review and comment by the procuring branches of the three military services with respect to the practicality for:

   Trial implementation on several selected contracts for pilot production electronic equipment within a prescribed time interval; Mandatory implementation on a wholesale basis on contracts for pilot production electronic equipment; Trial implementation on production contracts for electronic equipment which follow implemented pilot production contracts with the same contractor; And mandatory implementation on both following and new production contracts.

2. Task Group 3 recommends that AGREE urge OASD (ENG), at the earliest practical date and independent of the previous recommendation above, to select a limited group of pilot production contracts for electronic equipment, placed by a variety of procuring branches of the three services with a variety of contractors, upon which to make mandatory the compliance with the herein prescribed method for reliability evaluation of pilot production equipment.

3. Task Group 3 recommends that AGREE urge OASD (ENG), at the earliest practical date and independently of the two previous recommendations above, to select a limited group of production contracts for electronic equipment upon which to make mandatory the compliance with the herein prescribed methods for reliability evaluation of production equipment, without regard to whether or not pilot production versions of the same equipment have been evaluated in accordance with the herein prescribed method. It is further urged that a selected portion of the chosen production contracts be subjected to the longevity evaluation procedure prescribed herein.

4. It is recommended that OASD (ENG) arrange to review the test elections made by the procuring agency, under paragraphs 2 and 3, and to review both progress and ultimate findings of the contractors in order to insure that the method is applied as intended and that the results satisfy the original requirements of the Task Group mission. If each or several of the three previous recommendations above are independently and simultaneously implemented, it is recommended that the running observations and findings from each be used to provide running benefit to the others, to the end that recommendation 5, below, can be safely implemented at the earliest possible date.

5. Task Group 3 recommends that AGREE urge CASD (EMG) to follow up the above recommendations at the earliest practicable time with mandatory requirements for reliability index evaluation as prescribed herein (or logical extension thereof) on all pilot production and production procurement by any of the military services for electronic equipment. It is suggested that longevity evaluation as prescribed herein be left discretionary with the procuring services.

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REPORT OF TASK GROUP NO. 4

10 January 1957

Prepared by M. C. Batsel

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In connection with the study of the task assigned to Task Group No. 4 to investigate and recommend methods of specifying development procedures to insure that equipment designs will have the inherent reliability required, a review of publications and the previous work in connection with the problem was conducted. The procedure is intended for use in connection with contracts for the development and design of equipment planned for production. It is assumed that previous Research and Development work has established the necessary background knowledge to permit the program to be carried out without research to determine means for accomplishing the performance of the function.

Information obtained through field trips arranged previously by A.G.R.E.E. was taken into account in attempting to u[illegible]tal the numerous factors which enter into the complex proble[illegible]use of its complexity, there is required an orderly consi[illegible]on and coordination of all factors affecting the reliability of systems in the planned use.

In visits to several military equipment installations and discussions with the people using the equipment, it was found that there was considerable criticism of the designs, which indicated to them that the designer had no knowledge of the environmental, maintenance, and operating problems. The most successful designers of commercial products are the engineers who have a thorough knowledge and understanding of the user's situation. For these reasons, we consider that the first requirement to be stated in the procedure is that the contractors' engineers be made thoroughly familiar with the user's situation.

There is another difference in the problem of adapting the equipment to the end-user's requirements in case of military equipment as compared to commercial. In the case of military equipment, a specific number of equipments is ordered by contract; and the equipment is usually manufactured before there is feedback from the user to the producer, of the equipment short-comings. In the case of commercial equipment, feedback begins with the first shipments of equipment so that the design weaknesses can be corrected before large scale production takes place.

The designer of military electronic equipment is, in some respects, confronted with a problem similar to that confronting civil engineers who must design bridges, buildings, etc., and who must be certain that the structure will be safe. It is their practice to make a study of all of the factors which have a [illegible] on the type of design that is required. There is data regarding the basic characteristics of materials and the specifications used for procuring materials can be relied upon to assure that the materials meet a specified degree of uniformity in regard to strength, elasticity, etc. The civil engineer, however, must estimate the effect of his particular use of the materials upon the safety of the structure he designs. Some of these effects are intermittent weather-loading, vibration, corrosion, etc.

The procedure developed by Task Group No. 4 formulates the broad problem of designing systems to provide for the required systems reliability. It requires all of the factors that affect the system reliability be taken into account when planning the proposed design. An understanding of the broad problem clarifies the nature of the many subsidiary problems and thus leads to their solution. Experience has shown that once a problem is understood progress has been amazing.

The nature of the problem indicates that more responsibility should be placed on the contractor and the design engineers for equipment that will be satisfactory to the user and that less reliance would be placed on detailed specifications supplied by the procurement agency.

The procuring agency must specify the required reliability. The specification is meaningless unless the requirement is stated in quantitative terms.

The procedure explains briefly the nature of the engineering problem involved. It states that the contractor must obtain an understanding of the function to be performed by the equipment, environment in which the equipment must perform, the capability of operating personnel, and human engineering factors that must be considered to provide for the most effective use of the equipment.

The procedure consists of two basic phases. Phase I is a feasibility study to be terminated by a report. The report is required to contain information that can be used to evaluate the contractor's understanding of the problems and the probability of equipment being developed that will meet the military departments' requirements. Phase II relates to design and construction of the prototype models. This phase is to be undertaken only after the Phase I report has been evaluated, compromises reached if required, and the scope of the design program is understood.

In order for the contractor and his design engineers to arrive at the inherent equipment reliability required, it is necessary to estimate the effectiveness of the operating personnel in the operating environment, maintainability of the equipment in end use, probability of deterioration of reliability due to the environment in which the system will operate, deterioration and storage, shipping and handling. It is realized that there is little or no statistical information available at present in regard to these effects. If, during the design of the equipment, the field problems are carefully considered, the deterioration in reliability of use should be a relatively small factor. The essential requirement is for the design engineer to study the problems and to plan his design so as to minimize failures due to field conditions. There are programs in effect that will provide statistical information in regard to these factors when the studies have been completed. (ARINC Reliability Assurance Program being conducted for the Air Force is one, and Vitro Reliability Studies current for BuShips is another.)

The procedure outlines a method of analyzing a system to determine the reliability requirements for parts if the system is to meet the reliability specification. When the requirements for parts reliability are understood and are stated in terms of permissible failure rates, the problem is then resolved into one of determining whether or not parts can be obtained that can be used in the assembly in such a manner that the required reliability can be met. At the present time, there are few specifications in existence that require testing to determine, within a degree of assurance, that parts will meet a specified failure rate when used under specified conditions. The use of this procedure will result, we believe, in the development of suitable specifications. Parts failure rate data have been collected through field failure reports and life tests that have been conducted on equipments. If this data indicates that available parts reliability is inadequate, the engineer will necessarily have to arrange for specifications and tests to prove that parts can be obtained that he can use in such a way that the requirement is met. Task Group No. 5 has made recommendations regarding parts specifications.

The report, upon completion of Phase I, should indicate the study that has been made by the contractor in regard to all of the requirements, the type of design contemplated, and should state whether or not the contractor's analysis indicates that the requirements can be met. On the basis of this report, the procuring agency should be able to evaluate the probability of the proposed design meeting the requirements, including reliability. Before proceeding with the design program, there should be agreement between the procuring agency and the contractor that requirements can be met and that there is a high probability of equipment being produced that will have the specified reliability.

Phase II of the procedure relates to the design and construction of the prototypes. Certain requirements are outlined in connection with the selection of parts, criteria are given for assembly design techniques, and stress is placed upon the selection of design techniques that will satisfy the requirements for reliability and maintainability. Some requirements are stated in regard to environmental considerations, mechanical structures, and manufacturing techniques. It is contemplated that the prototypes will be evaluated in accordance with the procedure developed by Task Group No. 2.

Upon completion of the evaluation, the contractor is required to submit a report describing various characteristics of the equipment, an analysis of the evaluation tests, and recommendations or suggestions for improvements. The report should contain comments or recommendations in regard to plans for installation, operation and maintenance, which will influence the reliability in operation.

In following the procedures and recommendations of the Task Groups of A.G.R.E.E., there will be a progressive refinement of the degree of assurance that the reliability of equipment will be known before production starts. There should be a high degree of assurance that equipment can be produced that will meet the operational and reliability requirements. The orderly analysis of the problem and study of the reliability requirements, consultations with parts manufacturers in regard to the reliability of the parts they manufacture, and a careful consideration of the application of parts in the circuitry and environment, we believe, will be responsible for a great improvement in reliability. The analysis based upon parts failure rates will also show up the weak areas of the design.

The component reliability problem emphasizes the need for the military agencies to coordinate test requirements that will assure design engineers of the type of information they require.

When parts reliabilities are required that are orders of magnitude greater than failure rates on parts in equipment in use or that obtained through life tests on existing equipments, it will be necessary to take into account the need for time and money to develop and procure parts having the required reliability.
As in the case with all new attempts to create an orderly procedure, there will be doubts in regard to the validity of the information available and perhaps in the ability of a contractor's engineers to obtain adequate information. In time, more adequate information will become available; and the estimated reliability of equipment, during the design stage, will become sufficiently accurate to permit the military departments to plan programs based upon the use of the equipment, with the required degree of certainty of success.

Taking into account the above factors, we recommend that the military services adopt the procedure with the realization that the predictions at the end of Phase I should be used with the understanding that the conclusion reached is in the nature of an "educated" guess of the probability of the system or equipment proposed meeting the specifications. The accuracy of prediction will improve as more data becomes available for the use of design engineers. In time the design of electronic equipment will be based on data obtained from handbooks as is the case in other branches of engineering. Until the data on parts and techniques is generally available, engineering departments of electronic manufacturers will, no doubt, collect and organize information in convenient form for their own use.

Those interested in a general discussion of the "Elements of Reliability Prediction" will be interested in reading ARINC Monograph No. 4 (NObsr-64508).

Section 1

SCOPE AND DEFINITIONS

1.1 SCOPE

This is a procedure for the development and design of equipment to insure required inherent reliability.

1.2 APPLICATION

This procedure is to be applied specifically to the development and design of all electronic equipment, whether for use in aircraft, shipboard, ground, or other categories of special use and/or expendability.

1.3 GENERAL CONSIDERATIONS

1.3.1 The design of equipment that will have a specified reliability is a systems engineering problem. This procedure is based on working back from the overall functional and reliability requirements of the equipment to provide an understanding of the problems involved in accomplishing the required performance. In the development stages, an estimate of the chance of success is essential at the time tentative designs are being evaluated. The performance of the system or equipment, functional and reliability-wise, shall be specified in the contract. The reliability shall be specified in terms of equipment failure rate, probability of survival for a specified length of time under a set of specific environmental conditions, or other quantitative expression.

1.3.2 The contractor must obtain an understanding of the function to be performed by the equipment, the environment in which the function must be performed, the capability of the operating personnel, and human engineering factors that must be considered to provide for the most effective use of the equipment. It requires the contractor to take into account the maintainability of the equipment and to plan the design so that time lost from operation due to maintenance will be a minimum. When equipment is being developed that is a part of a complete system, there should be an exchange of information that will allow trade-off studies to be made relating both Inherent and Use Reliability of different system configurations to system weight, maintenance time, maintenance procedure, ground support equipment required, and other factors that affect the performance, reliability and cost of the complete system.

1.3.3 The development procedure consists of two basic phases. Phase I is a feasibility study to be terminated by a report, as called for in paragraph 3.1.4. The report will be used to evaluate the contractor's understanding of the problems and the probability of an equipment being developed that will meet the military departments' desired performance, including reliability, maintainability, etc. Phase

II relates to the design, construction and evaluation of the prototype model. This procedure will assist in the prevention of program delays that would result if an understanding of the problem and the probability of successful compliance with the desired reliability were not analyzed at the beginning of the program.

1.4 TYPES OF EQUIPMENT AFFECTED

1.4.1 AIRCRAFT EQUIPMENT. Probability of mission accomplishment is the most important consideration for airborne electronic equipment. Normally this type of equipment is characterized by design features which make it possible through checks which can be made periodically or before take-off to determine that the equipment is in normal condition and that there is a high degree of assurance that the equipment is capable of performing in accordance with the specification or contract requirement. Significant requirements for airborne equipment are a minimum of time to prepare the aircraft for the missions and for preflight functional test and service that will insure a successful mission.

1.4.2 GROUND AND SHIPBOARD EQUIPMENT. A low failure rate over a long period of time is the prime consideration in ground and shipboard equipment. This type of equipment is normally characterized by design features which result in an ease and speed of maintenance with the minimum requirements for skilled maintenance personnel.

1.4.3 SPECIAL GROUND EQUIPMENT FOR CONTROLLED ENVIRONMENT. Highly complex (from the standpoint of numbers of parts) equipment, such as computers and large complex systems, require ultra-conservative circuit design in terms of parts application and may require controlled environments in order to meet a high operational reliability for continuous operation over extended periods.

1.4.4 REDUNDANCY OF EQUIPMENT. Some operational requirements can only be met by equipment which is extremely small, light weight and which, as a result, may have a reduced inherent reliability. When two or more such equipments are to be used operationally in a redundant manner, the evaluation of their operational effectiveness is determined by the reliabilities of the several equipments or systems instead of the single unit.

1.5 DEFINITIONS

For the purpose of this procedure, the following definitions shall apply:

1.5.1 OPERATIONAL RELIABILITY - R_1. Operational Reliability is the probability that the system will give specified performance for a given period of time when used in the manner and for the purpose intended. It consists of the Inherent Equipment Reliability as degraded by various application factors peculiar to each particular field condition (Use Reliability). The Operational Reliability is thus peculiar to individual situations and is not a measure of Inherent Equipment Reliability. As the conditions of use approach those under which the Inherent Equipment Reliability was measured and as the operation and maintenance approach the quality of that provided during the factory evaluation, then the Operational Reliability will approach the Inherent Equipment Reliability.

1.5.2 USE RELIABILITY - R_U. Use Reliability is the probability of each of those applicable functions shown in Figure I being carried out, performing, or affecting performance in the manner planned.

1.5.3 INHERENT EQUIPMENT RELIABILITY - R_I. Inherent Equipment Reliability is the probability of the equipment performing properly when operated under contractually stated operational conditions, utilizing supporting equipment and procedures in the manner intended. The reliability is measured by the failure rate of the equipment when operated under specified conditions for sufficient time to obtain a failure rate that is approximately constant. Usually there is an initially high failure rate period during which marginal parts are eliminated. Following this, there is an operating period during which the equipment exhibits a fairly constant failure rate. A final period occurs when the normally short-life parts, such as rotating parts, batteries, etc., start to wear out.

1.5.4 SYSTEM. A system is defined as any combination of complete operating equipment, components, accessories, or parts so interconnected or interrelated in such a manner as to perform a specific operational function or functions.

1.5.5 COMPLETE OPERATING EQUIPMENT. A complete operating equipment is defined as an equipment together with the necessary parts, accessories, and components, or any combination thereof, required for the performance of a specified operational function.

1.5.6 EQUIPMENT. An equipment shall consist of one or more components capable of performing specified functions.

1.5.7 COMPONENT. A component is defined as an article which is normally a combination of parts, sub-assemblies, or assemblies, and is a self-contained element of a complete operating equipment, performs a function necessary to the operation of that equipment. Examples: indicator unit, power unit, receiver, transmitter-tuning units, rotating antenna, modulator unit, amplifier unit, etc.

1.5.8 ASSEMBLY. An assembly is defined as an article which consists of parts and sub-assemblies, or a combination thereof, and as such, is an element of a Component, and performs functions necessary to the operation of the Component as a whole. Examples: filter assembly, amplifier assembly (af, rf, if, video, etc.), gyro assembly, oscillator assembly (rf or af), pulsing networks, etc. The following type items are assemblies only when an internal part of a component. Examples: filters, amplifiers, modulators, power supplies, junction boxes, etc.

1.5.9 PART. A part is defined as an article which is an element of a sub-assembly, or an assembly, and is of such construction that it is not practically or economically amenable to further disassembly for maintenance purposes. Examples: resistor, coupling bushing, fixed capacitor, transformer, electron tube, relay, potentiometer, switch, connector, socket, mask, etc.

Section 2

APPLICABLE DOCUMENTS

None.

Section 3

REQUIRED DEVELOPMENT PROCEDURE

3.1 PHASE I - STUDY AND PLANNING

3.1.1 REVIEW OF REQUIREMENTS. A review shall be made of system and equipment requirements to establish an accurate picture of all the parameters which may affect its performance. Special attention shall be given to operational environments of the equipment, qualifications and duties of the operating personnel, maintenance procedures and storage and handling conditions involved in the transportation, installation and operation in actual service. This review may require discussions with operational personnel and systems engineering, installation and maintenance groups. It may also require a study of comparable equipment, and visits to activities having comparable installations.

3.1.2 ESTABLISHMENT OF PROPOSED DESIGN. Decisions shall be made on methods of problem solution. Combinations of electrical, electronic, mechanical, hydraulic, and pneumatic systems may be used. Optimum levels of signals shall be established for converting from one system to another. Manual versus automatic control methods, speed of operation, programming and other such factors shall be evaluated for reliable operation with respect to the required multiplicity of component parts and circuits. An intense effort shall be made to simplify the equipment in every way practical. Modified performance requirements shall be recommended if an analysis indicates that there is no practical way to meet the reliability if specified performance is fully complied with, or if slight changes would result in better reliability, easier maintenance or less costly equipment.

3.1.3 ESTIMATION OF RELIABILITY. The areas of Use Reliability shall be taken into account in the planning of features of the design to minimize the reduction of Operational Reliability due to these areas. The contractor should make an estimate of the degradation of the Inherent Equipment Reliability to be contributed by the factors involved in the use of the equipment. This analysis shall be included in the report required by Paragraph 3.1.4.

3.1.3.1 Operational Reliability. The product of the Use Reliability and Inherent Equipment Reliability will establish the required Operational Reliability - R_1. It should be noted that some of the areas under R_2 and R_3 are independent of each other. Other areas can influence the numerical values of each other. The numerical value of R_1 will always be less than that of R_2 or R_3, unless either R_2 or R_3 is 100%, in which case R_1 will be equal to the other. At all other times, however, R_1 will be less than R_2 or R_3.

3.1.3.2 Use Reliability. Unless reliability data is available for reference from activities having installations of similar equipment under similar conditions, it will be necessary to make a "best guess" estimation of, at least, the items indicated under Use Reliability - R_2 (See Figure 1). Such a "best guess" estimate shall consider carefully the effect of each item on the probability that the support given to the equipment will be as planned. Careful consideration of each of these items in the design of the equipment is essential, the objective being a design that is most tolerant of unplanned conditions. Improvement in Use Reliability must come from a study of each of the factors affecting Use Reliability and its effect on the others.

3.1.3.3 Inherent Equipment Reliability. A careful study shall be made of the end function of the equipment, installation and maintenance problems, also other considerations as indicated under Figure 1 to determine the number of components into which the equipment should be divided.

After a tentative design of the system or equipment has been prepared that will be capable of meeting the performance requirements including the function to be performed, operational characteristics, provision for maintenance, etc., an analysis shall be made to determine the reliability requirements for each of the components and parts in order for the system or equipment to meet the specified reliability.

If the design is one in which all of the components and parts are vital to the operation so that the failure of any one will cause equipment to malfunction, the following procedure may be employed. This procedure can be followed first to determine components reliability requirements and then the components can be analyzed to determine the reliability requirements of the individual parts.

3.1.3.4 Component Analysis. An analysis of the proposed design for a system or equipment shall be made that will indicate the allowable failure rate of components. If all the components have equal responsibility for successful operation of the system or equipment, the inherent failure contribution can be divided among the components. If some components are inherently capable of greater reliability than others due to fewer parts or parts that are more reliable, the allowable failure rate allocation can be modified accordingly. The component reliability allocation is an essential part of the system or equipment design. The allowable failure rates for components can be adjusted in accordance with data obtained in regard to failure rates of parts contemplated to be used, so long as the total failures per hour are within the permissible limits. The analysis is based on the assumption that the failure rate is in its period of being nearly constant and that the relation of R_3 (reliability), or r (failure rate) and m (mean-time-to-failure) are given by the formula -

$$R_3 = e^{-\frac{t}{m}} = e^{-rt}$$

Assume, for example, a component is required to have mean-time-to-failure of 1000 hours. This 1000 hours mean-time-to-failure (m) may be stated as a component failure rate per hour (r).

$r = \frac{1}{m}$ or $\frac{1}{1000}$ in this case, thus r = .001 or .1% per hour or 1000 per million hours.

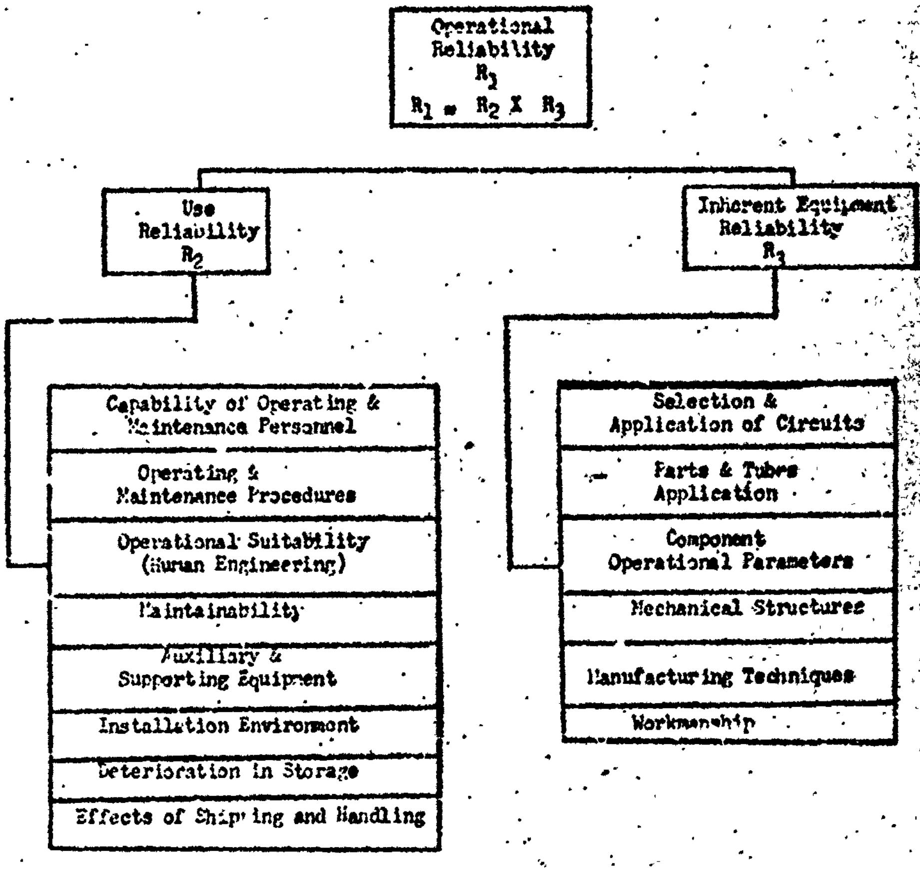
Operational Reliability R_1
$R_1 = R_2 \times R_3$
Use Reliability R_2
Inherent Equipment Reliability R_3
Capability of Operating & Maintenance Personnel
Operating & Maintenance Procedures
Operational Suitability (Human Engineering)
Maintainability
Auxiliary & Supporting Equipment
Installation Environment
Deterioration in Storage
Effects of Shipping and Handling
Selection & Application of Circuits
Parts & Tubes Application
Component Operational Parameters
Mechanical Structures
Manufacturing Techniques
Workmanship

Figure I

A similar procedure, in turn, will indicate the allowable failure rates for parts used in the various components to meet the specified reliability required for that component in the system or equipment.

To determine the allowable parts failure rate, the parts used should be classified by type or category and the quantity of each determined:

n_1 units of part type or category 1.

n_2 2

.

.

.

n_p units of part type or category p

The actual number of parts of each type which go into the component should be listed:

$$r \text{ (component)} = n_1r_1 + n_2r_2 + n_3r_3 + \ldots n_pr_p$$

where

r_1, r_2, r_3 are part failure rates and $n_1, n_2 \ldots n_p$ are the quantities of each.

The sum of the $(n_1r_1 + n_2r_2 + n_3r_3 \ldots n_pr_p)$ failures of all parts must not exceed the allowable for the component. The sum of the failures of all components must not exceed that allowable for the equipment.

Failure rate information on parts should be obtained from the manufacturers of parts, government, and other available sources. In cases where the information is not available, it will be necessary to determine the capability of parts manufacturers to develop parts and make the necessary tests to provide the information in regard to failure rates to be expected under specific test conditions. When necessary to obtain failure rate information through life test, the life test should be continued for a sufficient length of time for significant quantities of parts to attain a fairly constant failure rate. Failure rate information obtained on parts in comparable equipment, as has been experienced in actual use, should be considered. If the required failure rates are compatible with actual experienced failure rates, good circuit and equipment design should result in high probability that the specification will be met.

Categories of parts should be listed for specific failure rate analysis. These should include but not be limited to the following:

Tubes	Potentiometers
Magnetrons	Motors
Resistors	Switches
Capacitors	Transformers
Crystals, diodes	Micro-switches
Gyros	Connectors, sockets
Clutches	Gears, drive bands
Synchros	Miscellaneous*
Transistors	

Multisection units such as dual potentiometers, multisection capacitors, etc., shall be considered as sub-assemblies; and the failure rate should be determined by analysis of each section as a separate part in its specific circuit.

The total parts failure must not exceed that number allocated to the component. It is a design responsibility to derate the parts and design the circuits so that the failure rate required can be realized in actual use. It is also necessary to take into account circuit interactions as they may be affected by changes in values of parameters of parts. All changes in part characteristics that could cause the equipment or system to fail must be evaluated. Changes in characteristics of parts can appreciably affect reliability, especially when complex systems are to be highly reliable.

If the required component reliability is not probable of attainment with available parts, the contractor will determine what must be done to obtain parts that will meet the requirement. If parts having the required reliability are not obtainable, either the complexity of the equipment in terms of number of parts in series must be reduced or redundant parts or redundant components will be necessary. Parts having higher reliability than the need indicated by the calculation shall be used (if available) wherever such use will compensate for lack of other high reliability parts.

The objective of redundancy methods is to design equipment to operate satisfactorily in spite of failure of certain critical parts. Redundancy techniques shall be considered when it becomes evident, as a result of the study and analysis of the tentative design that the desired reliability cannot otherwise be met. Redundancy may be very useful in obtaining the required reliability when using miniature or sub-miniature techniques to minimize size and weight. The resulting design is amenable to the same reliability analysis as the basic system without redundancy bearing in mind that the redundant parts are in parallel rather than in series.

3.1.4 REPORT, PHASE I. Upon completion of the Study and Planning Phase of the development, the contractor shall prepare and submit a

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*This class includes any new part category which is introduced by new design and other electrical, mechanical, or electronic parts, such as indicators, lights, meters, fuses, soldered joints, workmanship, etc. Approximately 20 per cent of the failures due to all the categories of parts listed above should be allowed for these miscellaneous items.

report to the government agency concerned, which shall show what provisions are being made to insure that the equipment will be suitable for operational use, that provisions for its maintenance will be adequate in the contemplated environment, that it will perform the function in accordance with the specification, and the estimated probability of the equipment meeting the specified operational reliability. The report shall include:

(a) Calculations and data that has been used to estimate the Use Reliability.

(b) Description of Ease of Maintenance features to be included to meet the maintainability requirement.

(c) Calculated reliability requirement for all parts and components by categories or types required to meet the necessary Inherent Reliability. Include all data available regarding failure rate of parts contemplated to be used.

(d) The reason for anticipated parts and component failure rates that are lower than failure rate data based on experience with existing equipments.

(e) Recommendation of the contractor in regard to modifications of the requirements that may appear to be essential in order that planned schedules and allowable costs can be met.

(f) Recommendations of the contractor regarding changes in requirements needed to effect simplication in equipment, its relation to the reliability requirement, weight, space, and cost.

On the basis of this analysis and report the military agency may decide to proceed with the development or to change certain requirements in order to meet the required reliability. The purpose of this Phase I analysis and report is to provide the information needed to assess the risk related to the total specification requirements. Before proceeding into Phase II there should be agreement between the military agencies and the contractor that the final specification and requirement including reliability are achievable and have a high probability of being met in production.

3.2 PHASE II - DESIGN AND CONSTRUCTION OF PROTOTYPE

3.2.1 REVIEW OF DESIGN STUDY. Based on the requirements determined during the Phase I study for size, weight, functional performance, environment, suitability for operation, maintenance provisions to meet specified repair and check-out time, and means to provide part environments to obtain the necessary part reliability, the contractor shall establish the number and characteristics of the component and the design features to be used in each component.

3.2.2 SELECTION AND APPLICATION OF CIRCUITS. Every effort shall be made to select standard circuits and parts which have proven to be reliable and for which data regarding failure rates is available.

If suitable proven circuits cannot be found, others may be used whose performance is based on parameters of the parts which are controlled by specification. If the performance of the only circuits which will function in the required manner is based upon parameters which are uncontrolled, then specific approval for use of such circuits and parts shall be obtained from the government procurement agency and recommendations regarding the control of the required parameter shall be made. Critical circuitry shall be eliminated by design to allow large tolerance margins in circuit operation.

A large number of equipment failures can result from a drift in the value of critical part characteristics. To minimize the effect of drift with time, circuits must be designed that will operate satisfactorily beyond the initial normal distribution (-) of the part characteristics. Inverse feedback and similar compensating types of circuit design shall be applied wherever they are needed so that large changes in part characteristic may be tolerated before the normal circuit function is affected.

3.2.3 SELECTION OF PARTS. Every effort shall be made to select parts and materials from military preferred and standard parts lists as specified in the contract. When it has been determined that required failure rate information on parts and materials is not suitably described by existing military specifications, the contractor shall prepare suitable procurement information. The contractor shall request approval from the government agency concerned to use such parts and submit data accurately demonstrating the performance, describing the parts, the circuit application, and application environments.

3.2.4 SELECTION OF ASSEMBLY DESIGN TECHNIQUES.

3.2.4.1 Maintenance. The type of construction adopted must permit quick fault location, speed of repair, adaptability to future equipment modernization, and must simplify problems of logistic support.

(1) The number and type of replaceable sub-assemblies shall be determined by the requirements for maintenance time and skill of maintenance personnel at operating levels. Where the cost of supporting spares and storage space for them is a critical criteria, the following must be considered:

   a. The number of times the sub-assembly is used in the equipment.
   b. The number of times the sub-assembly is used in other equipments supplied with spare parts from the same location.

(2) Allowable maintenance time will determine requirements for fault indicating provisions that must be incorporated in the design. The complexity of the fault indicating provisions may be modified by the decision as to the number of the replaceable sub-assemblies used.

(3) The decision in regard to the number of replaceable sub-assemblies to be used must be determined by the complexity of fault indicating provisions with its possible effect on reliability.

Arrangements for marginal testing techniques are to be considered where applicable to the type of equipment being designed. Marginal testing should be employed in connection with digital equipment to increase the reliability of a system during a mission.

3.2.4.2 General Environmental Considerations. Certain considerations of heat dissipation, mounting of parts for protection from effects of vibration and shock, and protection of parts from effects of moisture will materially affect final assembly design technique. Suitable means should also be considered for protection against sand, dust, altitude, and high rates of change of altitude when applicable.

3.2.4.3 Thermal. In the design of electronic equipment for optimum cooling, the heat produced by the parts shall be directed along specific paths to a heat-sink. Parts which generate heat shall be isolated from parts which have a failure rate that is affected by heat. Isolation may be accomplished in one or more of the following ways:

(1) The parts may be physically separated.

(2) The parts may be isolated by means of thermal barriers.

(3) Where cooling fluid (liquid or gas) is utilized, the parts which produce heat may be placed "downstream" in the flow of the fluid, so that the cooler fluid is in the vicinity of the parts which are sensitive to heat.

Where heat conduction techniques are used, heat flow paths of low resistance shall be provided to carry heat from the heat-producing parts to the heat-sink. These paths shall be as short as possible and of suitably large cross-sectional area. Where heat convection is used, it shall be in such a direction as to aid the natural convection currents. Particular attention should be given to the effects of high altitude when pertinent. Heat dissipation techniques which are effective at low altitudes may not be effective at high altitudes. The construction shall be capable of withstanding the stresses imposed by thermal shocks and cycling to which the equipment may be exposed.

3.2.4.4 Shock and Vibration. In the mounting of parts for protection from the effects of vibration and shock, the type of mounting to be used is dependent upon the duration, amplitude, and frequency of vibration and shock encountered.

Under conditions of continuous or intermittent vibration and impact shocks of limited amplitude, satisfactory isolation may be provided for by mounting equipments, components or parts on shock absorbing mounts. Sound waves may result in part failures dependent on the amplitude and frequency of the pressure waves unless the parts are adequately protected.

Under conditions where the equipment is subjected to short exposure, to intermittent vibration of variable or indeterminate frequencies and impact shocks of high amplitude, it may be best to mount the parts rigidly to the frame of the vehicle in order to avoid resonance effects in the mounting structures that would increase the amplitude of vibration to which the parts are subjected. Parts should be secured by clips, brackets, or suitable bonding to their mounting structures.

3.2.4.5 Humidity. In the protection of parts from the effects of moisture, the following basic techniques shall be considered:

(1) Mounting parts in suitable containers which are hermetically sealed. Leads or terminals must be suitably designed to prevent moisture entrance.

(2) Encapsulating or coating parts with suitable plastics which are capable of acting as effective barriers to entrance of moisture within the parts. Leads can make this technique ineffective unless suitable precautions are taken.

(3) Use of materials which are water repellant in nature and thus minimize deleterious effects of moisture.

(4) Provide an environment for the equipment from which excess moisture has been removed.

3.2.5 APPLICATION OF PARTS. Parts shall be applied with due regard to tolerance, stability, and environmental conditions as covered by applicable specifications and other pertinent application information. In this process of application, particular attention shall be given to the effects on equipment performance of the tolerance distribution of the parts at the beginning and at the end of the equipment life and as affected by environmental conditions. Parts shall be judiciously applied in circuits such that an additional tolerance change to the original part tolerance can be tolerated without detrimental change in circuit performance. The magnitude of this tolerance margin will be dependent on the type of part, the circuit in which it is used, and the severity of environmental conditions to which the part is exposed.

3.2.5.1 Part Operational Parameters. Established ratings of wattage, maximum working voltage, maximum operating temperature, etc., are all based on failure rate figures for operation for specified times. If this failure rate figure is not as low as desired, the part may often be derated for a higher reliability. Derating of the part for a lower failure rate may be on the basis of reduced wattage, reduced working voltage, reduced operating temperature but should only be done after consultation with, and agreement by, the parts manufacturer. The actual mounting of the parts in the particular design shall be carefully considered to assure that the ratings on vibration, shock, temperature, moisture, etc., are not exceeded.

3.2.6 MECHANICAL STRUCTURES. The selection of suitable mechanical structures is an integral part of selection of assembly design techniques. The prime requirements for a good mechanical structure are that it be rugged enough to prevent damage to itself or to parts mounted within or on it when the component is subjected to its normal operational use, normal handling and specified condition of shipping and storage. It should be of such a type that replacement or repair of components or modular sub-assemblies can be made within specified down time. Care shall be taken to assure that resonances, due to shock or to vibration, will not cause failures or excessive reduction in life.

3.2.7 MANUFACTURING TECHNIQUES. Manufacturing techniques and design features shall be selected which eliminate or reduce the human errors in the construction of the equipment, and shall be compatible with the potential quantity and rate of production. The following techniques should be considered in the design: printed circuit boards to eliminate hand assembly, the repetitive use of standard mechanical brackets, chassis, frames, etc., to reduce the variety of parts which must be fabricated, and the use of techniques for protection of parts and wiring from damage causes by handling, shipping and storage.

3.2.8 CONSTRUCTION OF PROTOTYPE AND EVALUATION TESTING. Method of construction of the prototype shall be based on the incorporation of information discussed in preceding paragraphs and suitable for immediate use in production. A complete series of evaluation tests shall be conducted to assure that the equipment, with any modifications required to correct deficiences found during test, will meet the operational and performance requirements of the contract with the specified degree of reliability and maintainability.

3.2.9 REPORT, PHASE II. Upon completion of the design, construction and evaluation of the prototype of the equipment, the contractor shall prepare and submit a report to the government agency concerned, which contains the following:

(1) An explanation of the procedures used to determine that parts have been suitably selected and applied. This should be illustrated by two or three critical examples showing parts ratings with circuit requirements for each particular application.

(2) A description of circuit techniques employed to eliminate or minimize deleterious effects on equipment performance due to parts aging. Give two or three specific critical examples.

(3) The calculation of the predicted reliability based upon the design and data on the type of parts used in the construction of the prototype.

(4) Consideration given to redundancy techniques, if required.

(5) A general description of assembly design techniques selected.

(6) A general description of mechanical structures selected.

(7) A general description of manufacturing techniques.

(8) An analysis of the evaluation tests that have been made to prove the equipment will have the required degree of reliability and maintainability under the conditions of operation and handling as specified in the contract.

(9) Information on the features of the equipment that the contractor considers weak from reliability standpoint and the contractor's recommendations for improvement.

(10) Information on conditions that will improve or decrease the reliability of the equipment in operation, with special consideration of storage, handling and maintenance requirements.

(11) Any other comments or recommentations the manufacturer desires to make on simplification of design, reliability of operation and maintainability of the equipment, or on operational techniques and maintenance, which may influence reliability.

THE FINDINGS AND RECOMMENDATIONS OF

TASK GROUP NO. 8

CONTENTS

1.0 SUMMARY

This Task Force found it necessary to go far beyond the development of mathematical criteria and expressions for component reliability to accomplish the true intent of its mission.

Major changes in military component specifications, methods of testing, approval and inspection practices, and in procurement and specification development policies are found necessary.

Substantial changes in manpower and budgetary allowances are found mandatory.

A mathematical and statistically valid basis for developing and stating in arithmetic terms the criteria for, and methods of expression of, Acceptable Failure Rate for electronic components is presented.

2.0 MEMBERS OF AGREE TASK FORCE NO. 5

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4.0 INTRODUCTION

4.1 The assigned mission of this Task Force as modified was "Establish criteria and methods for specifying that a component has a predetermined level of probability of delivering a specified performance under designated environmental conditions for a specified period of time."

4.2 The Task Force found it necessary to arrive at a definition of a reliable component for the purposes of its work, as follows: "A component is reliable if it has a pre-determined level of probability of delivering a specified performance under designated environmental conditions for a specified period of time."

There are many kinds and levels of reliability, both of components and equipment, dependent upon the end use and application. It is considered that the definition of a reliable component stated above is the best that can be developed for the generalized fields of application intended in the scope of this activity.

The committee also found it necessary to determine the basis for a statement of failure rate and agreed that failure rates of electron tubes and components should be based upon their specification ratings and expressed in terms of percent failure per unit of time for each critical mode of failure, including sufficient information as to failure rate variation with environment to permit an equipment design engineer to properly use the tube or component.

4.3 LIMITATIONS ON THE ACCOMPLISHMENT OF THE TASK BY THIS GROUP

4.3.1 It was clearly recognized from the outset that the findings and recommendations of this group would have to be based upon the direct experience, knowledge and immediate fact finding of its members. No extensive test programs, as have been found necessary and to be discussed herein, were possible within the limits of this assignment.

4.3.2 The Task Group clearly recognized that its recommendations must be of such nature as to preserve the continuity of the presently existing specifications and systems of inspection operated by the military departments, even though the findings of the Task Force indicate radical departures from these practices, if utter chaos is to be avoided. The present systems evolved on the basis of the best information, manpower and financial allotments made. The recommendations to be made herein will be faced with the same factors for implementation.

4.3.3 The findings and recommendations to be made by this Task Force were considered from the outset to be circumscribed by factors of economic and logistic feasibility within a practical military system and have been weighted with these factors in mind.

4.4 In order to properly accomplish its task, our group found it necessary to go far beyond the mathematical or statistical approach and to examine basic environmental requirements, present military practices, and many other factors. In this, its final report, the Task Group feels it necessary to report the results of these subsidiary investigations in a brief manner to present the background for its conclusions and recommendations.

5.0 THE PRESENT STATUS OF MILITARY COMPONENT RELIABILITY

5.1 PRESENT MILITARY COMPONENT SPECIFICATIONS

5.1.1 RELATIONSHIP TO PRESENT AND FORESEEABLE NEEDS

Examination of the broad spectrum of military component specifications reveals that there is a complete lack of specifications covering a substantial percentage* of components used in military electronic equipment programs. It appears that the specification development activity as now staffed and budgeted is not capable of keeping pace with the equipment development program needs.

5.2 RELATIONSHIP OF REQUIREMENTS WITHIN VARIOUS SPECIFICATIONS

5.2.1 Examination of the existing military specifications for various classes of electronic components shows that there is no consistency of the performance test or quality assurance requirements of the specifications with regard to one another. This results in the chaotic situation that a piece of electronic equipment required to be produced under a contract for a certain performance or reliability level, which contract mandatorily referenced existing military component specifications and used the components procured under them, would contain components with a wide divergence of performance capability and quality level.

The development of MIL-STD-202 was a recognition of this lack of consistency and an attempt to overcome it. Insofar as MIL-STD-202 tests would be valid for the testing of components in relation to end use, some consistency would be provided.

* Various percentages have been stated. Factual studies of eleven particular equipments made by the Bureau of Ships show JAN and MIL specification usage between 50.1% and 86.4%, with substantial portions of the balance which could have been covered by existing specifications.

The Air Research and Development Command presented to the committee a study of specification compatibility covering 152 single Service and joint Service specifications on components which broke down the requirements for major environmental performance for ready comparison. This study shows very wide divergence in the performance requirements and a general lack of consistency, which in part reflects the various levels of available component capability.

There are wide differences in the progress of quality and reliability levels in various component specifications. Somewhat more work seems to have been done in the electron tube field, and more direct implementation of requirements for quality control and reliability are contained in the more modern tube specifications.

5.2.2 Examination of the sampling table, number of samples tested per requirement, number of failures permitted, etc. in the various military specifications indicates that they do not contain a statistically valid procedure for any statement of reliability in us . The numbers of samples chosen, the numbers of failures permitted, the sampling schemes used in many cases, are purely arbitrary, and it is not possible from the results obtained to give any assurance of any level of reliability. The sampling schemes used in general are based on the AQL concept, which is shown in the mathematical section of this report to require further augmentation if the true requirements for reliability are to be met.

5.2.3 The test conditions called for in the various military component specifications were examined with regard to the conditions of known environments to which military electronic apparatus is subjected. There is a general lack of known relationships between the presently used test conditions and the absolutely known environments for the equipment. There is much less correlation between the test conditions and the actual environments for the components since the components may operate in substantially different environment within the equipment from that to which the equipment is subjected. The test conditions called for in present military specifications were the outgrowth of available test apparatus and test methods and have not been determined in relation to the actual environmental conditions known. Exhibit 1 contains the operational environments for military electronic equipment obtained from the three Armed Services. The comparison of this data with component specifications quickly reveals the conditions stated herein.

5.2.4 Accelerated tests are used in numerous military component specifications. To be of value in the establishment of reliability criteria, the acceleration factors of the test with respect to use conditions must be known. In only a very few instances is there any such known relationship to justify the acceleration factors used.

5.2.5 The testing performed under present military component specifications determines the effe s on individual parameters of the components by exposure suc ively to single environments. This practice does not represent service conditions since almost surely the degradation and failure of components is the result of the action of combination and multiple environments operating simultaneously. The degradation rates of various materials and components as the result of combination environments are dep t upon the accelerating effects of one environment upon another, and are largely unknow .

5.3 THE SYSTEM OF DEVELOPMENT AND USE OF MILITARY COMPONENT SPECIFICATIONS

The individual component divisions of the various military services contain many highly skilled and technically competent individuals. However, there is serious question regarding the technical validity of the specifications which are developed because of the manner in which these individuals must work. The necessity for rationalizing many divergent viewpoint. for reaching agreement between three Services with different needs, and the requirement for broad industry agreement, result in some cases in a specification which is a compromise of compromises, and which may not have absolute technical validity in relation to the purpose and intent of the specification.

5.3.1 The speed of development of military component specifications is entirely inadequate for the pace at which new apparatus is being developed to meet present and foreseeable military needs. It is estimated that only fifty percent of present component needs are presently covered by component specifications. It is obvious that the manpower and directives of this activity need expansion and that the system of developing specifications must be improved.

5.3.2 The system of administration of both the development and application of military component specifications, although competent, is inadequate in that personnel restrictions and basic directives limit the effectiveness of the job which can be done.

5.3.3 The application of the present military component specifications by the military inspectors in component manufacturer plants in most cases does not insure any consistent level of product quality, and it cannot do so because the specifications themselves and the particular sampling schemes applied to items produced on a lot by lot basis, and variable lot quantities, cannot insure with any degree of confidence any particular level of quality in the product. Qualification approval, which is extended to a particular components manufacturer on the basis of a single sample submission, simply indicates that at one time, with one particular group of materials, one small lot of units was produced which was capable of demonstrating conformance to an arbitrarily established set of test requirements. The qualification approval itself, therefore, gives no assurance of any continued or sustained quality level in the future, except insofar as the inherent good faith and quality control of the manufacturer provides it. The subsequent military inspection of random lots cannot even with the most rigid adherence to the requirements of the specification, which seldom takes place, insure any definite known or expressible quality level.

6.0 THE REQUIREMENTS FOR RELIABLE COMPONENTS IN SYSTEMS

6.1 Voluminous data has been produced to show the relationship to system reliability of the numbers of components contained in a system and the individual failure rates of the components. Figure 1 and Figure 2 show such relationships.

6.1.1 What is incompletely understood in a determination of component failure rate is the degree to which the parameters of a component may shift from median or rated values and still be tolerable. Obviously the tolerable changes in parameters from application to application for a single component can cover a very broad range and still permit it to be useful. How to categorize such parameter changes into recognizable and controllable limit groups so as to develop usable failure rate information for particular classes of end product use is a major problem.

6.2 THE KINDS OF COMPONENT RELIABILITY

Many kinds of reliability may be required of a single electronic component dependent upon factors as follows:

6.2.1 Reliability in operational use - the definition of such reliability is inseparably related to the kind of end equipment, to the kind of mission of this equipment, to the duration of this mission, etc.

6.2.2 Whether or not a component which has been stored in a supply or repair depot, or has been in storage in a piece of complete end equipment, functions within its required parameter tolerances when called upon to do so can also be interpreted as a kind of component reliability. We are faced here with variable, and in many cases indefinite, periods of storage under a variety of storage conditions. To what extent there is degradation of the components and a mathematically assessable failure rate or contribution to failure rate for this factor is unknown.

6.2.3 For a single component, presumably any component produced under present military component specifications, a wide range of performance reliability as determined by failure rate can be experienced dependent upon the actual percentage of rated stress applied. For example, a capacitor or a tube may have under existing specifications a certain maximum rated performance capability with which, by properly designed tests, we can establish a failure rate. What is the failure rate for conditions of operation with regard to each important rating parameter if the component is operated at lesser levels; e.g., voltage, current, temperature, etc.? Simply stated, what safety factor in component reliability can be purchased by more conservative use? This is a highly important factor in reliability and the answers for most components and parameters are unknown.

6.2.4 One of the most seriously lacking pieces of information with which to establish an accurate numerical performance rating for any component is the inter relationship of rating severity and use severity, storage degradation, etc., and the obtaining of information for such inter relationships would seemingly be a gargantuan task beyond economic practicality.

6.3 THE ENVIRONMENTS ENCOUNTERED BY COMPONENTS

6.3.1 No failure rates or reliability ratings for components can be developed outside of direct relationship to operating environments and are meaningless without such relationship.

It is incumbent on the equipment designer to limit the actual component environment to as low an amplification as possible over that of the "black box" environment.

We show in Exhibit I the stated present and foreseeable environments for the operation of electronic equipment by each of the Armed Services. The actual environment in which a component operates may be more or less severe than this equipment environment, depending upon such factors as cooling, shock mounting, protection, etc. The limiting environments which will give acceptable failure rates for the components must be the basic guide to equipment design.

6.4 THE EFFECT OF MISSION LENGTH ON ACCEPTABLE FAILURE RATE

6.4.1 As stated under 6.2 above, many levels of acceptable failure rate are possible. A component may have one acceptable failure rate for short time, high intensity environment and a very different tolerable failure rate for long time, reduced severity environment. The failure rate which is put on the component must therefore be directly related to the mission length of the end equipment in which it will be used. Task Group No. 1 will provide us with the minimum mission time for each class of electronic equipment. Reworking of military component specifications must then change the test time to give proper information for a failure rate or reliability rating consistent with these mission lengths. The mathematical section of this report demonstrates how this can be done.

7.0 CONCLUSIONS

As stated in the introduction to this report, no attempt is to be made here to document in detail the findings or conclusions here to be presented. They are based upon thorough discussion and the direct experience of the Task Force members, together with the findings of the several investigations conducted as part of this task. Our conclusions are:

7.1 Our present military component specifications do not describe or give assurance with regard to the component reliability levels now known to be necessary.

7.2 The present system of qualification approval of components can be considered only as a limited proof of design capability. It is impossible to apply first area statistical procedures, such as the concept of AQL, to the manufacture of components using the requirements for qualification approval as the basis for insuring or establishing reliability at predetermined levels of maximum failure rate. We cannot use the present concept of qualification approval, with the existing military inspection system, as a basis for insuring component reliability at any level.

7.3 The present military inspection practices as applied to component parts manufacture do not and cannot police reliability levels or provide the information necessary to insure the end equipment user any stated level of reliability.

7.4 Present environmental test methods, as contained in MIL-STD-202 or MIL-E-1, were not designed as the methods for obtaining the information with which to establish failure rate information. These methods are largely the outgrowth of existing equipments and test laboratories and require modification and modernization. They do not correspond to anticipated environmental conditions.

7.5 Performance requirements of components in present military specifications do not fully reflect currently needed actual relationships to the component end use, and it is impossible to relate them to such end use, with present information, in a known and statistically valid manner.

7.6 The degradation or failure rates of most present military components and the materials of their composition are largely unknown, even for single environmental conditions, and are completely unknown for the effects of combination environments.

7.7 The present government regulations for drafting military component specifications must be amended if these specifications are to establish the requirements for reliability based on failure rate information.

7.8 The implementing of any consistent program for the development of reliable specifications, the carrying on of test programs to obtain the basic information necessary, the dissemination of this information, the control of manufacture of components meeting the requirements, must in some way be centralized and coordinated. It cannot be expected that reliability will result if the various portions of the component program are separately and independently controlled.

Fantastic amounts of engineering manpower and test facilities are being devoted by components and equipment producers and agencies to component reliability studies in complete duplication of work done elsewhere. This must stop.

7.9 In order to provide the equipment designer with the necessary tools to design reliable equipment, failure rate information must be made available in terms of percent failures per unit time for each critical mode of failure or parameter change, including sufficient information as to the variation of failure rate with environment to permit the proper use of the tube or component.

7.10 The practical accomplishment of the true overall task of this group will be a long, difficult, and tortuous job which must be carried out on a continuous, full time basis by a permanent group.

8.0 RECOMMENDATIONS

It would be dangerous and destructive to wipe out and supplant at one stroke the present military component specifications and inspections systems, however inadequate they have been found to be. Whatever system is developed, based upon the recommendations herein, must be gradually introduced with the maximum practical speed without disrupting the military procurement programs.

8.1 The present practices of most military component inspection have been found herein to be ineffective and incapable of insuring any stated level of reliability. It is recommended that the present specifications, inspection practices, and quality acceptance procedures be modified immediately to assure that the reliability inherent in the qualified product is maintained. Immediate consideration should be given to more critical inspection, and to a basis for at least semi-annual requalification or product examination for conformance with specifications. <u>All of these steps would at best, with present knowledge, be temporary measures to maintain the level of component uniformity and to insure whatever minimum level of quality was represented by the original qualification samples.</u>

8.2 New specifications must be developed for a true reliability program which contain statistically designed experiments to produce the maximum of information from the minimum number of test samples, and must contain the proper tests in single and multiple environments related to the end use of the components to specify the failure rate with relation to various severities of test. That is, levels of reliability dependent upon severity of use factor must be established in a clear and statistically valid manner. Appendix I of this report provides one approach for designing the experiments and obtaining the reliability levels and confidence factors in a limited but useful form. To implement such a program may require modification of existing regulations and directives by which military component specifications are developed.

8.3 The Armed Services should be asked to reconcile the divergent environmental requirements which they have expressed, and to state a single set of coordinated environmental conditions which can be taken as the basis for the testing of components to establish failure rates for these environments.* MIL-STD-202 and MIL-E-1 should be revised, when the above environmental coordination has been established, to provide tests and severities which truly measure the performance of components for these environments. The severities of test to be established must be based on the factors developed by AGREE Task Force No. 1 for the reliability levels of equipment necessary in the light of such parameters as mission length, type of equipment, and end use. Several severity levels will be mandatory. The subsequent design of equipment must then mandatorily be such that the end use of the components is then limited to these environments if reliability is to be achieved.

8.4 It is recommended that as part of the qualification approval or other government procurement procedure of a component that a sufficiently large number of samples be tested to establish primary failure rates for the important parameters, as required by the specification and developed in accordance with the methods of Appendix I. If the results of these tests justify, the supplier should then be investigated further as to his "in-plant" quality control, operating under a new procedure given in the next recommendation.

8.5 The system of military inspection and approval of supplier techniques should be revised. The supplier of military components should be rated as an "approved supplier" or "supplier of reliable components" based upon a new system. This system would establish an organization which would examine and approve the "in plant" inspection and quality control procedures of the supplier initially, and would make periodic re-examinations of the record keeping and results of these procedures, the supplier to remain approved only for the time duration between inspection periods and only if the record keeping and process control systems are maintained adequately.

Shipments of components from such an approved plant would then not be based on an unlimited "qualification approval" as now granted, but would be based on the continuous flow of quality control data indicating product and process in control with adequate inspection and record keeping to insure this result.

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* The committee has been advised that this work has been started by an Ad Hoc Group operating under AGEP. It should be a prime full time task.

8.6 It is recommended that the development of military component specifications, the testing of components for design capability, and the development of inspection methods, be integrated and coordinated by one controlling group at D.O.D. level. The group should be comprised of representatives from industry and from the three Services, including personnel from Research and Development, Standardization, Procurement, and Quality Assurance functions. Adequate supply of manpower and budget to establish and operate a proper and coordinated system must be provided.

8.7 The accumulation and feedback of information from usage, failure reports, or controlled experiments on components must be obtained by and directed to a centralized organization established as in 8.6 above.

This information should then be used to determine whether the specification in existence covering the component in question is adequate for the end use, and where excessive failures appear, whether the quality control information of the components supplier correlates with the information feedback. In the case of continued or flagrant failure of components to perform in the field, assuming proper specification and end use, a decision must be made as to whether the supplier should be continued on the approved list.

8.8 The further work to be done to implement the task assigned to this group, as herein recommended, should be made the responsibility of a permanent committee consisting of proper representation of military and industry personnel. This committee should have policy making power. Some areas of continuing activity for this group should be:

8.8.1 Review all existing reliability programs and projects now being performed by the Services and establish coordination and eliminate duplication.

8.8.2 Determine what further work needs to be performed.

8.8.3 Indicate what contracts should be established for performing work in the needed areas.

8.8.4 Establish procedures and methods for disseminating the information gained from this activity.

8.8.5 Establish a basis for providing documents which are companion to, but separate from, specifications, which contain use and application notes for components to insure reliability in use, including common environments and conditions other than those contained in the specifications.

PREFACE TO APPENDIX

The mathematical discussion presented in Appendix I is not intended as an absolute development of the one best method of failure rate expression. No method can be absolute. Certain assumptions must be made to arrive at arithmetic expressions which limit the range and integrity of any practical method of expression.

This Appendix is intended to illustrate the complex factors which must be considered, and to show how a useful arithmetic solution may be derived within the limitations of the practical assumptions made.

APPENDIX I

A Logical Mathematical Basis for Component Reliability and Acceptance

Even the most cursory consideration of the problems of component reliability lead inescapably to the mathematics and mechanics of statistics for expression. Much work has already been done, not only on the formal development of statistical methods, but on the application of such methods to the problems of both component and equipment reliability. No attempt will be made here to develop or expound either particular theories of statistics or their application in detail.

A short bibliography of highly important and applicable references is included at the end of this section. Some of the most straight forward exposition of statistical method and its application is given in a series of five monographs by Marcus A. Acheson, a member of this Task Force, which are included in the bibliography. Although presented in relation to electron tubes, the statistics and methods of these monographs are readily generalized for use with any type of component.

We will attempt here to show, in somewhat concentrated form, some of the mathematical problems and approaches involved in the development of expressions for component reliability in terms of failure rate as <u>numbers</u> having both usefulness and validity.

The expression of failure rate for a single component in a single test environment is relatively straight forward when we have previously defined the word "failure" explicitly to mean open or short circuit, failure to function, excessive change of certain important parameters of the component, or any prestated set of limits of degradation. Obviously, if we test "N" components in a given test environment or set of conditions for a time "T", and we find that "n" units fail to function or exceed the prestated limits of parameter change in this time, we have established a failure rate of $s = n/T$ per hour.

If we neglect or weed out the very early failures, and restrict the time of test to a period shorter than the onset of known chemical or mechanical degradation effects; e.g., "wear out failure", we can arrive at certain simple expressions of reliability.

"r" is the probable fraction of the given component failing per hour, if "S" is the total number of such components tested, or maintained in constant population in a given equipment, and "s" as above, is the number of parts failing per hour, or $r = \frac{s}{S}$.

If, for the identical set of test environments or operating conditions we establish failure rates for various components as r_1, r_2, r_3 ---- r_p and these components are applied in various quantities in an equipment respectively n_1, n_2, n_3 ---- n_p, the overall failure rate per hour can be stated $F_r = n_1r_1 + n_2r_2 + n_3r_3$ ---- n_pr_p.

and for the operating or test time "t" hours the total failures are $F_T t$, and the reliability of the equipment or group is $R = e^{-F_T t}$. (Conversely the unreliability $Q = 1 - R$.) How happy we could be if we could state our reliability problem so simply with any assurance! Unfortunately, as we shall see, we cannot do so.

Ryerson (Reference 9) has shown a chart, Figure 3, to illustrate probability of equipment surviving for 200 operational hours with various numbers of components of five different failure rate levels.

Hill, Voeghtlen, and Yueh (Reference 10) have shown, see Figure 2, the mean life expectancy of systems of various component complexity when the failure rate of the components is varied over wide limits.

When we are presented a certain number of any given component, n_1, and we have tested or observed it as outlined above, and have determined for this number of units a failure rate r_1, what do we know? What "confidence" can we have that this r_1 is characteristic of this component? Does it represent all other components of the same type, from the same lot; from preceding and following manufactured lots? Using the same single test conditions and pre-established failure criteria, how sure can we be that the r_1 we have now obtained will hold for all such units tested and is a safe figure to use in calculating equipment reliability? Suppose none of the tested units fail?

Herein is the crux of reliability -- the <u>confidence</u> which we can have that any number of tested units, under any stated test or performance conditions, will give us an answer that is representative of the true performance of that lot, component, or category. If none of the units fail can we have high "confidence" that the units are reliable? From a statistical standpoint it can be shown that we have more real data and can perhaps establish a better confidence if some ordered number of units do fail in a recognizable manner!

The establishment of this "confidence" involves the extensive application of the mathematics of probability for reduction to real numbers. The problem is complicated if we restrict the data to be obtained to a single set of parameters for any component in a single test environment. It becomes more complex, but still manageable, if we are concerned with the effects on the same parameters of successive exposures to different single environments. It is when we try to reduce to mathematical terms the effects on the multiple parameters of a component of simultaneous combination environments - such as are representative of actual service conditions - that we seemingly reach the limit of present practical application of statistical theory. New theories are being developed, particularly the technique of "response surfaces", which may be helpful in the future.

We shall quote liberally from Acheson's Monograph No. 5 to illustrate the basis for a mathematical approach to our problem.

The generally accepted use of statistical procedures for product acceptance are based largely on the economic factors of sample lot inspection versus 100% product inspection and are the outgrowth of basic work by Dodge and Romig. MIL-STD-105 is based largely on these procedures. This procedure evaluates a component in its present state for the purpose of determining whether we can introduce that component into a system without more than a permissible amount of immediate trouble -- for example, without too adverse an effect on the number of workable systems produced, or conversely on the number of systems which will require repair or rework to make them acceptable. This procedure will not provide any information on how the systems will perform after leaving the production line or maintenance shop.

We can determine the continued performance of systems only by performing second area statistical procedures which determine the reaction of initially good components under continued use. This is the only true determination of reliability, since reliability is measured only by the probability of satisfactory continuing usage.

The first area procedure examines only the present defective content, while we should be observing instead the good components for their continuing reaction. It is apparent that first area procedures which were determined strictly on an economic basis to provide a satisfactory control of a desired AQL at least cost have little direct relationship to reliability and cannot insure it no matter how widely used.

Second area procedures involve all sorts of destructive tests, life tests, stability tests, etc. to determine if the component will withstand specified usage for a certain time. In this area we have no choice but to use statistical procedures for we cannot, even if we wish, test 100% of the product -- we cannot test it to destruction either wholly or partly and use it too!

Both AQL and AOQL, as useful terms and measures in the first area, have no physical meaning or measure in the second area. For example, we could inspect a lot either by sampling or complete inspection, and determine that this lot had a very low AQL and was very satisfactory. This AQL states that a lot probably contains a very low and satisfactory percent of defectives at this particular moment. But this has no relation to, and is no measure of, whether this lot will have a high unsatisfactory rate or a low satisfactory rate of developing additional defectives as we use it. We need to express a rate, not a percent. And since a failure rate involves time as a factor, while percent defective does not, we find the physical terms must be expressed in different fundamental units, and, therefore, cannot be directly related one to the other. Nevertheless, we commonly extend the AQL label to life testing. We do this by noting the sample size and allowable failures (in an arbitrarily fixed time), on the life test, and use existing first area tables to find the corresponding AQL value. MIL-STD-105 is commonly used for this purpose. Such a value, however, when applied to life testing has no physical meaning or measure -- it is at best only a handy label to distinguish one life test from another. Typically, a statement that the exercise of an acceptance test having a sample size of 150 tubes, and an acceptance number of 3 tubes, assures that a lot of 2000 tubes has a controlled quality measured by an AQL of 0.65. But the 0.65 AQL statement for this lot has no obvious relationship as to whether these tubes will or will not work satisfactorily for 50 hours in an aircraft employing 3000 tubes. We may leave the tube user highly impressed by these authoritative measures of quality control, but if the statements were made in Sanscrit they would be no less useless to the user's need to evaluate reliability.

We need to express acceptability of a product in terms of a criterion which we can best label an Acceptable Failure Rate (AFR) rather than the criterion of Acceptable Quality Level (AQL), commonly used in first area acceptance procedures. An AFR might be derived for any particular case by noting the value of AQL that would be associated with the sample size and acceptance number to be used for life test; and dividing that value of AQL by the total specified life test time, in order to obtain an average failure rate that we could label the AFR for that test. This process might have merit in allowing one to use existing first area procedure sampling tables for second area procedures; but we find when we examine the subject in some detail that such a simply derived AFR may not adequately express our needs, and may be quite misleading when we attempt to evaluate or control reliability by its use.

The chance for successful equipment operation, or probable fraction of total equipments operating as required, when using components having exactly r failures on life test is given by the generalized expression:

$$S_r = \frac{\int_0^\infty p(0, NTmf)\, p(r, ntf)\, df}{\int_0^\infty p(r, ntf)\, df} \qquad (1)$$

where:

- T = hours of failure free operation required.
- N = number of components used in equipment.
- t = hours of component operation on life test.
- n = number of components tested on life test.
- r = number of components which failed on life test.
- m = severity of use factor (where m = 1 for the applicable life test).
- f = component failure rate.

The expression P(0,NTmf) is the probability of enjoying zero failures in an equipment which uses a certain number of components, N, for a certain time, T, at a certain severity of usage level, m, when the failure rate of the components, f, is taken as an independent parameter.

Since we can never know the absolutely true failure rate, f, from any practical size of test sample or field use sample, we must employ a probability distribution to calculate from the information we have the most probable value of f between f = 0 and f = ∞. This probability distribution is contained in the expression p(r,ntf) in the equation above.

If we make the assumption that the observed failures contributing to the value of f occur individually and collectively at random, we may use Poisson distribution functions for sufficient accuracy at the reliability levels and uses which are of interest here.

When Equation (1) is evaluated by use of Poisson* distributions, we derive an expression usable in arithmetic terms:

$$S_r = \left(\frac{nt}{nt + NTm} \right)^{r + 1} \tag{2}$$

For simplification, and to permit later calculation, we can combine terms of (2) in a ratio, which we will call the test ratio:

$$q = \frac{nt}{NTm} \tag{3}$$

and this permits writing the equation for S_r in terms of q and r alone:

$$S_r = \left(\frac{q}{q + 1} \right)^{r + 1} \tag{4}$$

Equation (4) expresses the value of probability of successful equipment operation in terms of observation of <u>exactly</u> r failures per sample, no more or less.

This is seldom our situation when we are operating with specifications, particularly the present JAN or MIL specifications which require life tests of n components, for a period of t hours, with no more than c components allowable as failures. That is, we now require c or less failures per sample and we agree to accept lots having not only c failures, but any lesser number from zero to c.

Equation (4) can be used to calculate exactly the equipment reliability from an <u>exactly observed</u> number of component failures, but if it is desired to relate equipment reliability to component specifications certain assumptions and modifications must be made.

Three assumptions might be made -- most pessimistic, that all received components just barely meet c failures per lot, -- most optimistic, that all received components have zero failures per lot, -- or third, that various lots have passed the tests with observed failures ranging from r = 0 to r = c. The assumption must be made in the third case that any one value of c is just as likely to occur in the range of 0 to c as any other value, and although experience teaches that there are unlikely to be equal proportions of lots at all levels, the third assumption is as good as can be made with the information at hand from a specification.

* We will use throughout the Poisson distribution rather than the more exact binomial theorem expression, as the accuracy so obtained is generally sufficient.

With this assumption we can now modify Equation (1) to predict equipment reliability in terms of component specifications:

$$S_c = \frac{\int_0^{\infty} p(0, NTmf)_s (c, ntf)\,df}{\int_0^{\infty} s(c, ntf)\,df} \qquad (5)$$

where:

S_c = chance of successful equipment operation, or probable fraction of total equipments operating as required, when using components having c or less failures on life test.

c = acceptance number on specified life test.

Evaluation of Equation (5) by use of Poisson distribution gives:

$$S_c = \frac{nt}{NTm}\left[\frac{1-\left(\frac{nt}{nt+NTm}\right)^{c+1}}{c+1}\right] \qquad (6)$$

which may also be written in terms of q and c, as previously for Equation (1), thus:

$$S_c = \frac{q}{c+1}\left[1-\left(\frac{q}{q+1}\right)\right]^{c+1} \qquad (7)$$

Figure 4 shows the relationship of S_c to q and c graphically.

The test ratio q, which is used in the equations above, is a quantity which measures the relative amount of component testing performed, in terms of numbers of components, and hours of operation adjusted for a severity of use factor, in relation to the component - hour requirements of an end equipment. When q is small, we have done relatively little testing and have relatively little information about component quality for the intended application for which q was computed. When q is large we have done a relatively large amount of testing and have obtained a relatively large amount of information about component quality. Since q depends on both the parameters of an acceptance test and the parameters of the intended usage, the assurance of successful equipment operation, S_c, becomes larger and larger as we increase the value of q and keep constant the acceptance number, c, of allowable test failures.

Within the limits of economic and equipment practicality we cannot continuously increase our sample size, or the value of q above, to get greater and greater amounts of information, yet we must obtain this information if we are to have absolute assurance of reliability. This dilemma poses certain alternatives:

A. We can lower the severity of use factor, m, by more conservative use of the components. This may pose problems of equipment size or weight, or other undesirable factors.

B. We can be satisfied with lesser values of S_c, the assurance of success function. This has ramifications in the importance and cost of missions, but may be somewhat offset by preventive maintenance.

C. We can increase the severity of life testing by the use of increased acceleration factors, so as to get more information from a smaller number of samples in shorter time. Pabst (Reference 7) has shown a method of statistical test design to obtain maximum information from minimum samples. We already use accelerated tests on components, but as shown elsewhere in this report, we do not know very much about the acceleration factors for most parameters, or the inter relationship of the multitude of environmental and performance factors. Accelerated tests are common in other fields of engineering, and we must in time learn the ratios and extent of acceleration of various factors in electronic component testing as related to actual usage.

D. We can apply our statistical techniques to many past lots of components to predict the performance of the present lot. This can be done, however, only when the production is sufficiently continuous to produce reasonable uniformity from lot to lot, and is "in control". This is the technique of "process - average" quality control which is infinitely preferable to any single lot or random lot data.

E. We may employ the field usage of the components themselves to set up a feed back loop for continuous product control and acceptance of product. This procedure, however, is extremely difficult in military practice, and the rate of information feed back will probably be too slow to control components produced in limited quantities.

Whichever of the above alternatives is chosen, it will affect in the end only the value of the composite parameter q, and of the value c. The general relationships above will in any case express the testing and acceptance procedure which must be used as they are fixed by the reliability requirements of the user of the equipment.

As we attempt to reduce the amount of testing to be done, we could do so with easier mind if we could know definitely the confidence which could be placed in any given level of performance desired. Some further manipulation of the equations above will help us to derive a figure of "confidence".

From the shape and nature of the curves in Figure 4, we are led by the apparently constant ratio of c/q to the expression of S_c as:

$$S_c = K_c \left[\frac{1 - \varepsilon^{-c/q}}{c/q} \right] \qquad (6)$$

where K_c is a factor which adjusts a theoretical expression for ideal reliability, S_{ic}, to an exact value, S_c.

We can derive K_c as:

$$K_c = \frac{c}{c+1}\left[\frac{1-\left(\frac{q}{q+1}\right)^{c+1}}{1-\epsilon^{-c/q}}\right] \qquad (9)$$

The value of K_c is near unity for most values of c and q, except when c or q, or both, are small.

The portion of Equation (8) within the brackets is the equipment reliability prediction under ideal test conditions, where we have employed an infinite size test of $q = \infty$. The parameter K_c adjusts this idealistic value of S_c to lower resultant values based on practical values of q and c for tests which do not generate 100% confidence in our results. The parameter K_c is therefore a confidence factor. We can choose values of q and c to give us any desired degree of confidence in the test result.

The equation variations above have expressed reliability predictions in terms of specifications, calculated by the use of parameters c and S_c. We can set up similar expressions to relate reliability predictions to observed data from tests, using the original parameters r and S_r, as follows:

$$S_r = K_r S_{ri} = \left[\frac{q}{q+1}\right]^{r+1} \qquad (10)$$

where S_{ri} expresses the idealized value of reliability from infinite q test size,

$$S_{ri} = \epsilon^{-r/q} \qquad (11)$$

$$K_r = \epsilon^{-r/q}\left[\frac{q}{q+1}\right]^{r+1} \qquad (12)$$

and K is the confidence factor we may have in our practically limited observations.

Note the identity of form of Equation (11) with the expression $R = \epsilon^{-ft}$, used in the early part of this section, to state reliability. What a long way we have come to realize the invalidity of such expressions in practical cases, and the realistic requirement for the confidence factor K! The use of such unmodified reliability factors can lead only to over optimistic predictions and disaster.

The forms of expression for equipment reliability prediction, for S_{ci}, and for S_{ri}, can be put into other useful forms. To do this, we need to recognize and define several sorts of failure rates.

First, a lot of components, operated under a single set of defined conditions, undoubtedly has an actual, inherent, failure rate, and we have used the symbol "f" to symbolize this rate. The rate may be quite variable with time of life or component age, or may be quite constant in many practical cases where we deal with constant failure rate mechanisms. In any case, the failure rate, f, symbolizes the actual instantaneous failure rate. For any actual lot of components, we can never know this true failure rate, but can only estimate it from observation. The accuracy of estimate, as we have observed, is poor when we collect but little information. Thus, when we try to evaluate an instantaneous failure rate by observation, where the time period of observation is very short or approaches zero, we collect exceedingly little information, and our confidence in our calculation approaches zero. In practice, we must collect information over considerable time periods, even when we observe considerable quantities of components, in order to have any reasonable confidence in the accuracy of the numbers we calculate. When we so observe over a considerable unit period of time, we cannot ascribe the observed individual failures to any time period shorter than the unit time period, and retain the desired confidence in the result.

During a unit time period, t, we may symbolize the total failures as r from a lot initially numbering n components. The estimated failure rate which we may compute from these values is:

$$f_e = \frac{r}{nt} \qquad (13)$$

This is some sort of average failure rate over the entire unit time period, but calculated by dividing by n, the initial sample size. Actually, the sample size varies during the period, ending with n - r components. We cannot have enough information at a desired confidence level to tell how it might truly vary for the lot, rather than the sample, throughout the period. We can, however, make a reasonable assumption, which is, that in the absence of information to the contrary, the true failure rate is constant at least throughout this unit time period, and that, accordingly, the surviving population follows a decreasing exponential life curve during the unit time period. If we define the estimated assumed-constant failure rate as f_{ec}, then we may write where f_{ec} is the estimated assumed-constant failure rate for the unit time period.

$$f_{ec} = \frac{1}{t} \log_\epsilon \left(\frac{n}{n-r} \right) \qquad (14)$$

By manipulating Equations (13) and (14), we may find a relationship between f_e and f_{ec}, which is:

$$\frac{f_{ec}}{f_e} = \frac{-\log_\epsilon (1-\phi)}{\phi} \qquad (15)$$

where ϕ is the fraction of the original sample which fails during the period, or:

$$\phi = f_e t = \frac{r}{n} \qquad (16)$$

Values of f_{ec}/f_e calculated from Equation (15) are shown in Table 1.

TABLE 1

ϕ	f_{ec}/f_e	ϕ	f_{ec}/f_e
0	1.000	0.4	1.277
0.01	1.005	0.5	1.386
0.02	1.010	0.6	1.527
0.05	1.026	0.7	1.720
0.1	1.054	0.8	2.012
0.2	1.116	0.9	2.558
0.3	1.139	1.0	∞

Thus, if we observe a sample over a unit time period, and only a small fraction fail, we may say that the simple estimation of f_e from Equation (14) is accurate enough for practical computations, since f_{ec}/f_e is close to unity. If a large fraction fail, we may need to adjust our failure rate upward from the simple estimate of Equation (14) by use of Table 1 or calculate and use f_{ec} from Equation (15) rather than use the value f_e. In general, when dealing with the reliability levels usually desired for electronic equipment, we need to make no such adjustment, and can simplify our mathematical treatment. This simplification is followed throughout the balance of this treatment, not only for values of the estimated failure rate f_e, but for other failure rates, such as [illegible], that we examine later. In any unusual case, all such rates should be adjusted by means of Table 1, when necessary, for sake of accuracy of calculation. Usually when we need to make this adjustment, we would also need to use expressions derived by use of binomial functions, rather than Poisson functions, as has been indicated earlier in this section.

When we use Equation (13), we may combine it with Equation (3) and find:

$$\frac{r}{g} = f_e N T m \tag{17}$$

and we may further combine this with Equation (11) and find:

$$S_{ri} = \epsilon^{-f_e N T m} \tag{18}$$

Since the composite parameter, $f_e NTm$, is the estimated number of failures we would expect to find in the equipment when using components having an estimated failure rate f_e, we might note the estimated total equipment failures during time T to be:

$$B_e = f_e N T m \tag{19}$$

Then:

$$S_{ri} = \epsilon^{-B_e} \tag{20}$$

This expression, with various symbols, and in various forms, has been published as an equipment reliability prediction. It is, however, <u>not correct or complete in itself, but must be multiplied by the confidence factor, [illegible], from Equation (12)</u>.

If we consult a life test specification, which specifies a maximum number of allowable failures (the acceptance number c) for certain sample sizes and operating times, then we may calculate a rated maximum-allowable failure rate from these figures. The calculations may become somewhat involved in cases where the sample number of components is required to be varied during life, or where a failure during a certain period will be arbitrarily counted as being at some arbitrary time, or where one sort of failure is given more weight than another, or for various other circumstances; but these adjustments are details. To maintain simplicity of treatment, we calculate only an average failure rate based on total allowable failures. This we symbolize as f_m, for rated maximum-allowable failure rate. Then:

$$f_m = \frac{c}{n t} \tag{21}$$

for the simple case, unadjusted for complication as discussed above. We may derive from this relationship that:

$$c/q = f_m N t m \qquad (22)$$

where f_m is the rated maximum allowable failure rate.

If we combine Equation (22) with the expression for ideal reliability, we obtain:

$$S_{ci} = \left[\frac{1 - \epsilon^{-f_m N T m}}{f_m N T m} \right] \qquad (23)$$

which expresses the probability of successful equipment operation, when the test is presumed to be 100 percent adequate, or $K_c = 1.0$. The expression of Equation (22) contains only terms which relate to usage, and to rated maximum-allowable failure rate (f_m) as taken from a specification or data sheet.

The composite parameter, $f_m NTm$, has a simple meaning. It is the total number of failures we would expect to find in the equipment, if we were to use components all having failure rates exactly equal to the rated maximum-allowable failure rate. We may conveniently give this composite parameter in a single symbol, thus:

$$B_m = f_m N T m \qquad (24)$$

where B_m is the number of failures we expect to find in the equipment using N components for time T, at severity of usage factor m, when f_m is the component failure rate. Then we may rewrite Equation (23) as:

$$S_{ci} = \left[\frac{1 - \epsilon^{-B_m}}{B_m} \right] \qquad (25)$$

This function is computed in Table 2.

TABLE 2

B	s_{ci}	B	s_{ci}
0	1.00000	0.1	0.95163
0.0001	0.99995	0.2	0.90634
0.0002	0.99990	0.5	0.78694
0.0005	0.99975	1.0	0.63212
0.001	0.99950	2	0.43233
0.002	0.99900	5	0.19865
0.005	0.99750	10	0.10000
0.01	0.99502	20	0.05000
0.02	0.99007	50	0.02000
0.05	0.97542	100	0.01000

The values of s_{ci} as taken from Table 2, or computed from Equation (25), are the maximum equipment reliabilities we might expect if our tests were ideal. All the values above must be multiplied by the factor K_c, from Equation (12) to account for the imperfect confidence we may have in practical test specifications.

As we examine the considerations above, that predicted equipment reliability depends both on the confidence factor K_c, and on the ideal reliability factor s_{ci}, we note that tests using low values of c produce relatively low K_c but relatively high s_{ci}; likewise, tests using high values of c produce relatively high K_c but relatively low s_{ci}. There is an optimum value of c for every possible value of q we might encounter that will produce a most effective test result. If we choose c too low, the indicated ideal failure rate may be good, but if K_c is low for this case, then we have employed a relatively inadequate test, and the low confidence in our information lowers predicted equipment reliability. Here we have brought less confidence in the apparently good result than we can logically justify.

If we choose c too high, the confidence we have in our information may be very high, but perhaps unjustifiably high if s_{ci} is calculated to be low. Here we have bought a more expensive test and more confidence than we may justify for the relatively low quality of components under consideration.

The optimum value of c is that which produces equal values of K_c and s_{ci} for each case under consideration. When we calculate this value of c to make $K_c = s_{ci}$, for various values of q, we find that c is usually a fractional number. Since c in practice must be an integral number, we pick the integral value of c which most nearly makes $K_c = s_{ci}$ for various ranges of q. The result is shown in Table 3.

TABLE 3

When q is larger than	but smaller than	then optimum value of c is
0	0.178	0
0.178	2.704	1
2.704	∞	2

There are no cases where we find it logical to devise tests requiring more than two failures as an acceptance number. All such tests provide more confidence in the information produced than is justified, since we are already sufficiently certain that predicted reliability is limited as calculated by the use of $c = 2$ and the value of q under consideration. There is, for example, no logic in having a 99-44/100 percent confidence that predicted equipment reliability is only 50 percent. Likewise we should not use less than $c = 2$ as an acceptance number, when $c = 2$ is indicated, since that would be equivalent to the poor logic of having only a 50 percent confidence that our components are 99-44/100 percent reliable.

If we devise tests having values of c other than as indicated in Table 3, we produce either inadequate or excess information in comparison with than indicated on a logical basis. We are either undertesting a good product or overtesting a poor product.

We may readily calculate for intermediate values of q the corresponding values of s_c for each range in Table 3. These results may best be displayed in three figures. Usually we will wish to choose a value of s_c to meet a desired usage. Therefore, these curves are drawn with s_c as an independent parameter, and once its value is chosen, values of c and q are determined uniquely.

Figure 5 displays all cases where the optimum acceptance number $c = 0$. On this curve, values of s_c range from $s_c = 0$ to $s_c = 0.05$. Figure 5 will cover all cases which we might label low reliability cases, and it is labelled as Reliability Range L. The end-of-range value of $s_c = 0.05$ does not quite agree with Table 3 - we have chosen a rounded value of s_c instead of an exact value.

Figure 6 displays all cases where the optimum acceptance number $c = 1$. On this curve, values of s_c range from $s_c = 0.05$ to $s_c = 0.5$, (rounded values). Figure 6 will cover all cases which we might label medium reliability cases, and it is labelled as Reliability Range M.

Figure 7 displays all cases where the optimum acceptance number $c = 2$. On this curve, values of s_c range from $s_c = 0.5$ (rounded value) to $s_c = 1$. Figure 7 will cover cases which we might label high reliability cases, and it is labelled as Reliability Range H.

Since reasonably exact values of q are difficult to read from Figure 7, we also show a part of Range H, labelled Range H1, in Figure 8, where s_c ranges from $s_c = 0.5$ to $s_c = 0.95$.

Figure 9 shows part of Range H, labelled Range H2, where s_c ranges from $s_c = 0.95$ to $s_c = 0.995$. If even higher values of s_c ranges are desired, we may multiply the right hand q scale of Figure 9 by any power of 10, and simultaneously insert a number of 9 digits equal to this power of 10, before the decimal point on the lower (s_c) scale of Figure 9. Thus, Range H5 would show s_c ranging from $s_c = 0.99995$ to $s_c = 0.999995$, and q ranging from $q = 30000$ to $q = 500000$.

These five figures replace Figure 4 which displays most of its information in ranges that are far from optimum for test purposes.

Rarely will one require the use of Ranges M or L, since Reliability Range H will usually be found desirable even for noncritical usages. We will nearly always work with an optimum acceptance number $c = 2$.

The choice of an unvarying acceptance number appears to be an oversimplification of some sort, since it may first appear that we test everything by the same test. This is not the case, however, as can best be shown by the following examples.

Suppose we desire a test to control reliability of tube usage in household radio receivers, using $N = 5$ tubes at a severity-of-usage factor $m = 0.2$, and that during each $T = 100$ hours operation (about one month), we desire a radio reliability of $s_c = 0.921$. From Figure 8 we find that the required test acceptance number $c = 2$, and the test ratio $q = 25$. From Equation (3) we find the value of the product <u>nt</u> must be $nt = 2500$ tube hours. We might test 2500 tubes for one hour, or 250 tubes for 10 hours, or perhaps 5 tubes for 500 hours, allowing but two failures. For reasons not examined in this material, the latter choice of 5 tubes for 500 hours may be most practical, - and it is approximately the test applied to many tubes intended for household radio usage.

Suppose we desire a test to control reliability of tube usage in a business computer using $N = 1250$ tubes at a severity-of-usage factor $m = 0.2$, and that during each $T = 100$ hours operation (about one month), we desire a computer reliability of $s_c = 0.921$. From Figure 8 we find that the required test acceptance number $c = 2$, and the test ratio $q = 25$. From Equation (3) we find the value of the product <u>nt</u> must be $nt = 625{,}000$ tube-hours. We might test 625,000 tubes for one hour, or 62,500 tubes for 10 hours, or 1250 tubes for 500 hours, or perhaps 25 tubes for 25,000 hours. (The latter time is about three years. In the interest of promptness in controlling the product, this would be ridiculous.) Suppose we choose a test of 1250 tubes for 500 hours, allowing but two failures.

In the latter case, it is apparent that we would need to examine the use of the five alternatives to expensive testing, since the test quantities indicated would result in prohibitive test costs if undertaken to assay or control single lots.

In most of the previous material, we have taken the point of view that each user might calculate an appropriate test from knowledge of his particular economic and reliability requirements, and he might transmit the values associated with such a test to a producer or a specification standardization group to be put to use. Since there are usually a multitude of users for any single component (each user having widely varying requirements of quantity of components, time of use, and severity of use factor) it is apparent that a producer might be faced with an unreconcilable range of test requirements, ranging perhaps over a 1000 to 1 range or more, all for the same component. No producer could cope with such a situation.

The practical situation is that a producer who produces a certain reliable component with certain materials and techniques, would find he should test his reliable product by a test having the optimum acceptance number $c = 2$. He would fix the sample quantity n (and, accordingly, for each separate user, a separate test-ratio q) at the highest value consistent with the manufacturing techniques and materials employed. Actually he would fix both the sample size n and the test time t, so that we would have a value of <u>nt</u> specified for this product.

By the exercise of good judgment, and with the aid of statistical tools to provide figures on which to base good judgment, a producer or a specification standardization group may set an nt value consistent with the product under consideration.

George Levenbach of Bell Telephone Laboratories, a consultant to Task Group No. 5, has provided us with Figure 10 to illustrate the testing it would be necessary to do to obtain various confidence levels, as the failure rate of the components varies.

By use of the c and nt values encountered on a specification, various users may calculate the suitability for their use of the product tested by the parameters c and nt. Many users may find the product too good for their requirements, and they may pay a higher price for this good product than they might feel justified. If so, the continued presentation on their part of the need for a lower quality product at a lower price, may induce a producer to offer a cheaper second product tested by a lower nt value, and which product may be manufactured by techniques and materials consistent with the lower nt value. Or perhaps a user who finds the product too good for his use may wish to use the product less conservatively, that is, at a higher severity-of-use factor (m) and thereby enjoy higher performance.

Many users may calculate that the product is too poor to meet their reliability requirements. They may continue to present their needs for a higher reliability product, perhaps in terms of a higher nt value than that currently available. A producer may be able to find improvements in technique or material that will justify a higher nt value for a second product of higher quality.

But if technique or material improvement cannot be found, then the arbitrary setting of a high nt value in a specification will not produce higher reliability, contrary to the belief of some advocates that one may produce reliability by specification alone. The result of too high an nt value is that a lesser fraction of the product of unchanged quality is passed as a matter of probability by the stricter test. But a product of unchanged quality continues to flow to the user -- the user receives a lesser fraction of the same old stuff, and a greater fraction flows into the scrap can. The cost of the higher rejection fraction is directly a producer's cost, but eventually the consumer pays the bill if the producer stays in business. A consumer who dictates quality into a product by tightening of a specification alone has not only raised his own prices for a product of unchanged quality, but he has also paved the way for his own disaster by believing in a product improvement that does not exist.

The situation above is a common one, and one impossible to control or evaluate when product quality is judged on a lot-by-lot basis. The examination of continuing production of a product to determine a process average, including the effect of rejected as well as accepted lots on process average, is the only way to assay and control the situation. The need for continuity of production and quality evaluation has previously been examined as one of the alternatives to exorbitant test costs. The general methods by which one might operate a specification when controlling by process average has also been noted briefly. We now emphasize that such methods are necessary, not only from an economic basis, but also as a means of preventing a user from injuring himself by attempts to raise quality by writing more stringent specifications alone.

Strict lot specifications or lot inspection alone cannot produce reliability, but they may produce mis-understanding, high costs, and possible disaster to a product user.

In material in this appendix, we have evolved second area acceptance procedures, involving sample sizes and acceptance numbers of a radically different sort than those developed and used for first area acceptance procedures.

We still need a label for the various second area acceptance tests we may use, and this label should have a relationship to a failure rate, rather than to some percent defective value such as an AQL. There are several ways of setting up such a test label in terms of failure rate, but no matter which one we use, we find it somewhat arbitrary for two reasons.

First, as was noted in developing Equation 7, we must make an assumption concerning the distribution of lots that may be received consistent with a given test specification. We made an assumption lying between the worst and best performance that could be expected when exercising a given specification in order to develop Equation (7). When the acceptance number is $c = 2$, we find the assumption can be in error by a factor not exceeding 2 in its effect on reliability. Usually the assumption will be much closer to the facts, but there is nothing that can possibly appear in a specification to tell us how good the assumption may be except that actual average quality must lie between the limits of 50 and 200 percent of the assumption we make. Thus, when we set a failure rate as a label for a test, we may be off by a factor of two, but usually much less.

Second, should we try the same unvarying lot of components in varying usages, we will get somewhat varying estimated failure rates by observation. The true failure rate will be observed only when we use the components in an equipment using an infinity of components. Even in the limited life test, we will observe a slightly different estimated failure rate than the true failure rate of the lot, when we estimate failure rate by Equation (13) or Equation (14).

A good compromise failure rate label, not exact, since no value can be exact, is to define an Acceptable Failure Rate (AFR), or f_a, in accordance with Equation (26).

$$f_a = \frac{c + 1}{2nt} \qquad (26)$$

For example, a test with acceptance number $c = 2$, sample quantity $n = 5$, and test time $t = 500$ hours, would result in $f_a = 0.0006$. The test, however, will also pass, with increasingly small fraction of rejection, lots having true failure rates of $f = 0.00006$ or $f = 0.000006$ or on down to $f = 0$ (perfect lots). The test will also pass, with considerable fractions of rejection, lots having true failure rates of $f = 0.0012$ or with increasing fraction of rejection, $f = 0.006$ or $f = 0.06$, or worse yet. The chance of passing such bad quality is very small, but these chances as they affect equipment reliability predictions are automatically calculated when we use Equation (7) or Figure 4 to determine s_c.

Many other attempts to develop and simplify the expression of failure rate in usable form have been made. One such presentation which may be useful, although not statistically accurate, is contained in the Report of the RETMA Task Group on Preparation of a Reliability Definition, and is entitled "Determination of Permissible Component Part Failure Rates". This report developes a method of expressing reliability when the ratios of failure of various components to one another are known, but the absolute individual failure rates are unknown. Pending a time when sufficient test data is available to provide statistically valid failure rates for individual components, this method suggested by the RETMA EA(R) Committee may be useful.

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EXHIBIT 1

ARMED FORCES DATA ON ENVIRONMENTAL CONDITIONS APPLICABLE TO ELECTRONIC EQUIPMENT

(This environmental data applies only to external ambients and does not apply to internal conditions within equipment or on components. Internal temperature rise, mechanical magnifications and compactness factors will determine component ambient conditions)

(This data is not fully comprehensive and is for discussion only)

	Army	Navy	Air Force
1. TEMPERATURE	Storage: -67°C to + 71°C Operation: -55°C to + 55°C	**Ship & Shore Equipment:** Storage: -55°C to + 71°C Operation: -67°C to + 62°C **Airborne Equipment (Excluding Missiles & Rocket Powered Vehicles):** 1956: -55°C to + 125°C Year "A": -55°C to + 200°C Year "B": -65°C to + 500°C There is present need for 125°C withstand capability for all components if equipment ambient, internal temperature rise, and life extension factors due to temperature derating are taken into account. It is estimated that a 20°C reduction in temperature doubles the life of a component, other factors being equal.	Storage: -65°C to + 71°C Operation: -55°C to 500°C Thermal Shock: -55°C to + 500°C in 5 minutes In present equipment 125°C withstand capability will meet requirements if cooling is taken into account.
2. HUMIDITY	To saturation with condensation.	100% relative humidity with condensation.	5% to 100%, including condensation in the form of both water and frost.
3. RAIN	2" per hour with 20 mph wind.	30" fall in 24 hour period. 24" per hour with 40 mph wind.	Rainfall as encountered in any locale.

	Army	Navy	Air Force
4. ALTITUDE	50,000 feet (3.45" Hg) equipment non-operating.	Shipboard & Shore Applications: Maximum pressure 15.4 lbs. per square inch. Minimum pressure 12.9 per square inch. Airborne Equipment Applications: 1956: 50,000 feet Year "A": 70,000 feet Year "B": 125,000 feet	Operation: Sea level to 150,000 feet (29.92 to .04415" Hg). Shock: Sea level to 150,000 feet in 15 minutes.
5. SHOCK	15G for 11 ± 1 milli-second in all 3 planes. (Ballistic): 2000 foot pounds.	Shipboard & Shore Applications: 15G for 11 milliseconds in all 3 planes. (Ballistic): 300G for 1 millisecond. Airborne Equipment Application: 1956. 30G at 5 ms Year "A": 50G at 5 ms Year "B": 100G at 10 ms	Acceleration: 50G, 11 ± 1 milli-second. Constant Acceleration: 30G for 10 seconds.
6. VIBRATION	No mechanical resonance below 55 cps. Transportation bounce random excitation, rms shock 5G.	Shipboard & Shore Applications: No mechanical resonance thru 55 cycles in all 3 planes. Airborne Equipment: 1956: 500 cps Year "A": 2000 cps (15G) Year "B": 3000 cps (30G) Vibration (air induced): Year "A": 8000 cycles Year "B": 10,000 cycles	Structurally transmitted: Low frequency 5 to 55 cps, double amplitude of .06" or 10G. High frequency 55 to 3000 cps, 20G. Acoustical (white noise and line spectrum): Frequency 35 to 10,000 cps Energy level 190 db (reference level 2×10^{-4} dynes/cm^2)
7. RADIATION	Solar radiation 105 watts per square foot (51% infra red, 44% visible, 5% ultra violet).	Solar radiation 90 watts per square foot (51% infra red, 4.5% ultra violet).	Maximum radiant energy as found under natural conditions.

No limits have been established for nuclear radiation.

Army	Navy	Air Force
8. DUST		
Not considered a problem in the design of electronic equipment or in the selection of parts.	$6 \times 10^{-?}$ grams/cm^{-3}, .0001 to .01 mm dia., blowing at 40 mph at height of 5', 72°F temperature.	Sand and dust as encountered in desert areas.
9. SALT SPRAY		
Not considered a problem in design of electronic equipment or selection of parts.	Omitted for this discussion.	Atmosphere as encountered in coastal areas.
10. FUNGUS		
Not considered a major problem in the design of electronic equipment or in the selection of parts.	Omitted.	Fungus growth as encountered in tropical areas.
11. LIFE		
Omitted.	Ship & Shore Equipment Application: 10,000 hours minimum (reliable) Airborne Equipment Application: 1956: 2000 hours Year "A": 2000 hours Year "B": 3000 hours	Operating life 500 to 1000 hours. Shelf life 20,000 to 50,000 hours.

FIGURE #1

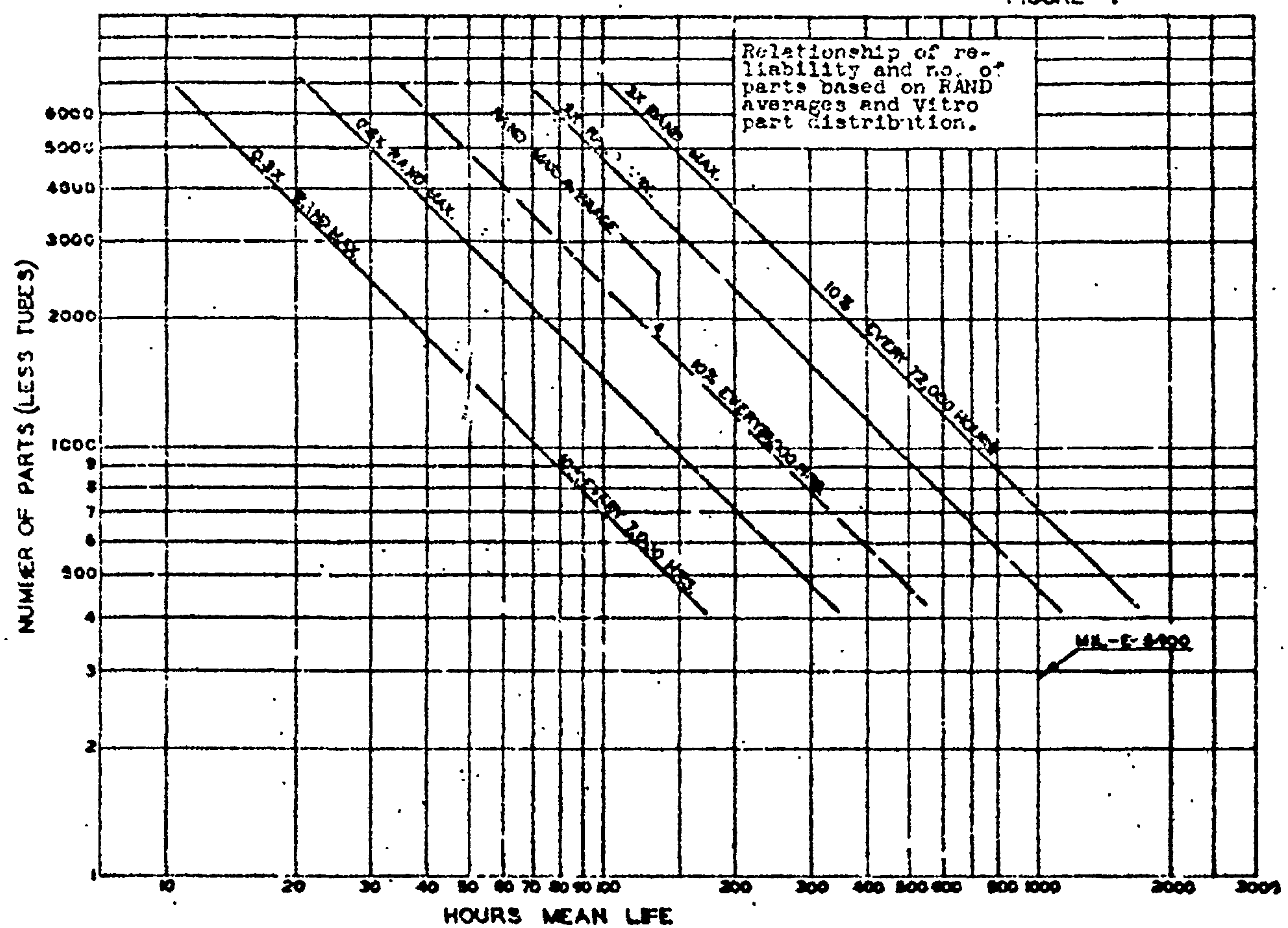
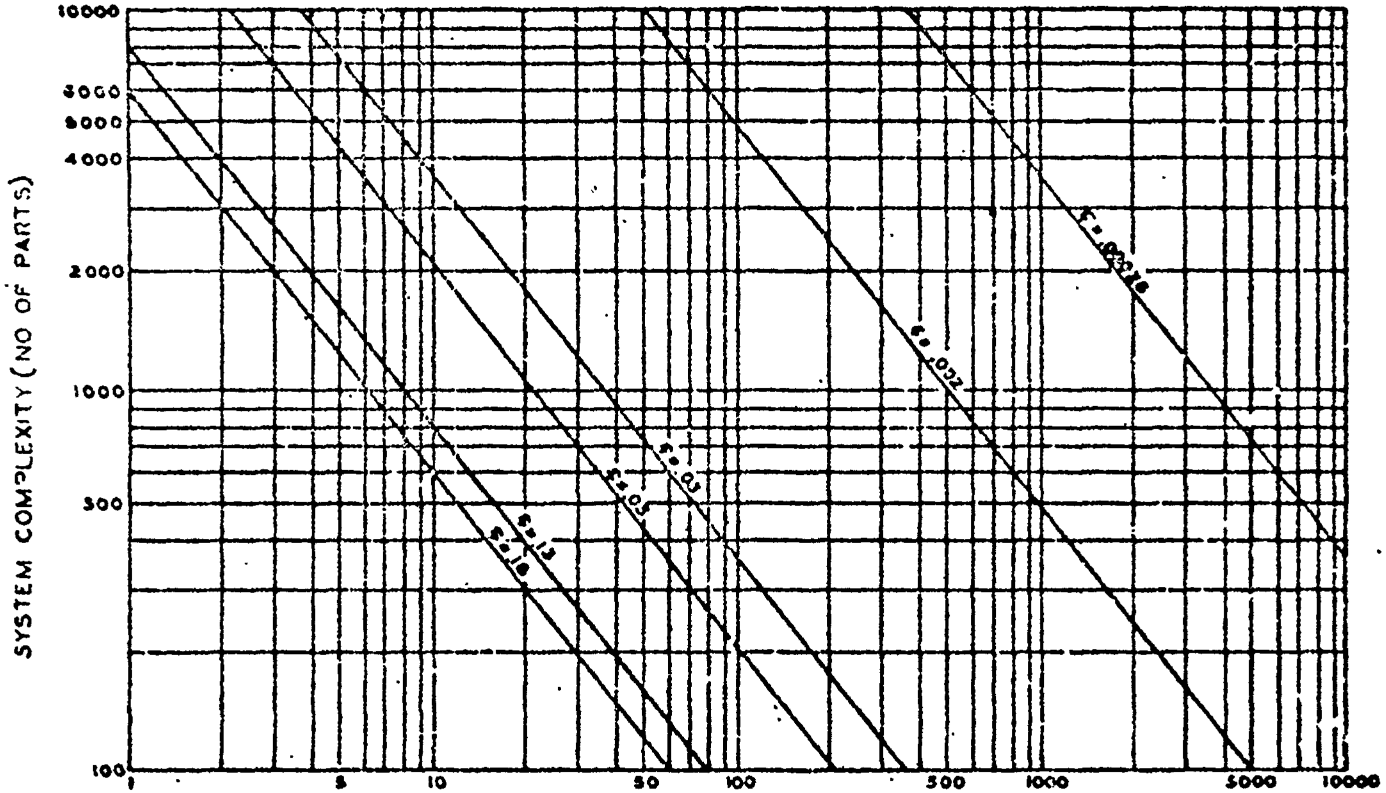

Relationship of reliability and no. of parts based on RAND averages and Vitro part distribution.
NUMBER OF PARTS (LESS TUBES)
HOURS MEAN LIFE
3X RAND MAX.
RAND MAX. AVERAGE
0.3X RAND MAX.
10% EVERY 12,000 HOURS
10% EVERY 2000 HRS.
MIL-E-5400
6000
5000
4000
3000
2000
1000
500
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
800
1000
2000
3000

FIG. NO.2

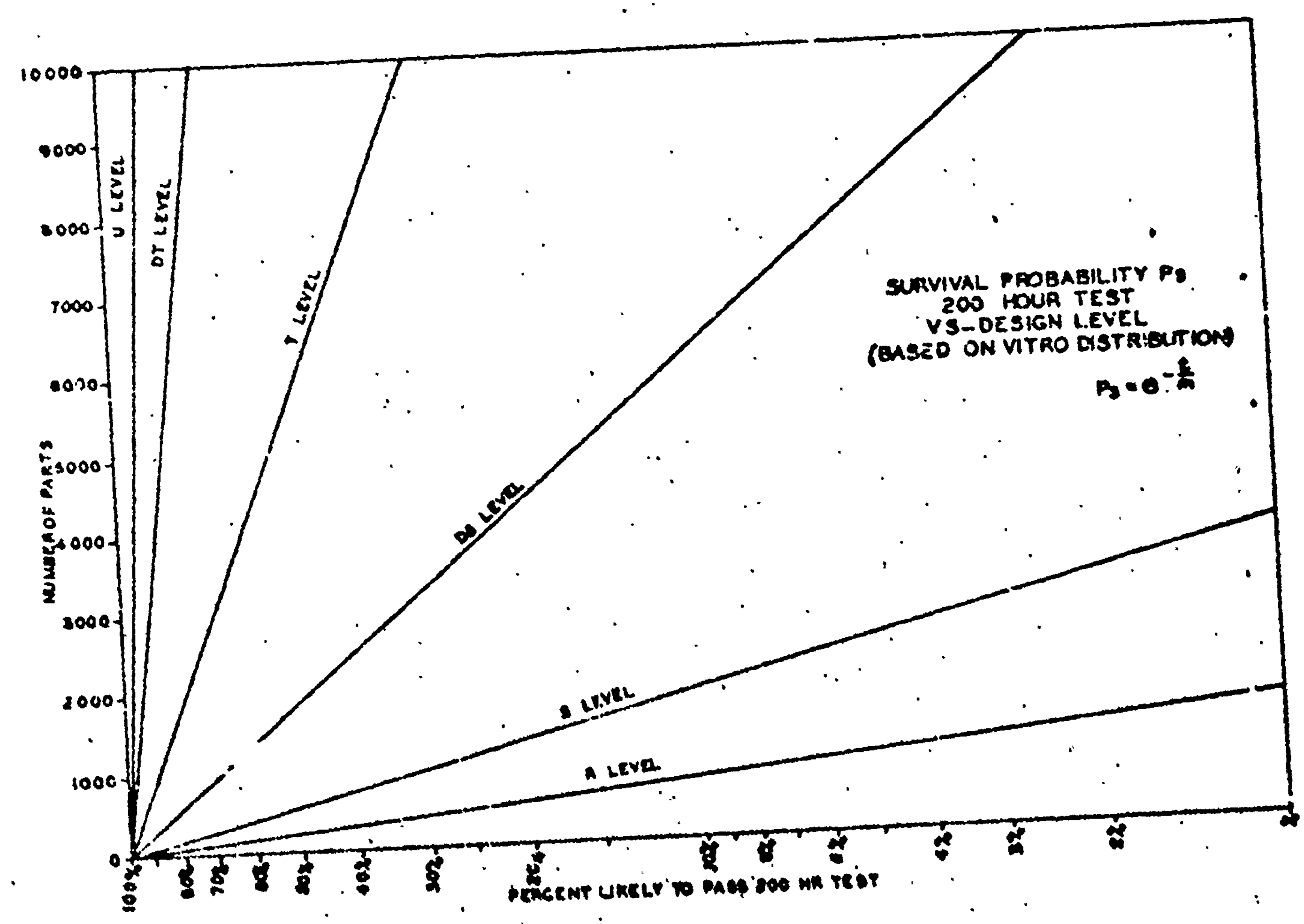


HOURS OF MEAN LIFE (m)

LEVELS OF RELIABILITY OF DIFFERENT SYSTEMS

(f = AVERAGE PART FAILURE RATE PER 1000 HOURS).

FIGURE 3


SURVIVAL PROBABILITY Ps
200 HOUR TEST
VS-DESIGN LEVEL
(BASED ON VITRO DISTRIBUTION)
U LEVEL
DT LEVEL
T LEVEL
DB LEVEL
S LEVEL
R LEVEL
NUMBER OF PARTS
PERCENT LIKELY TO PASS 200 HR TEST
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
100%
90%
70%
60%
50%
40%
30%

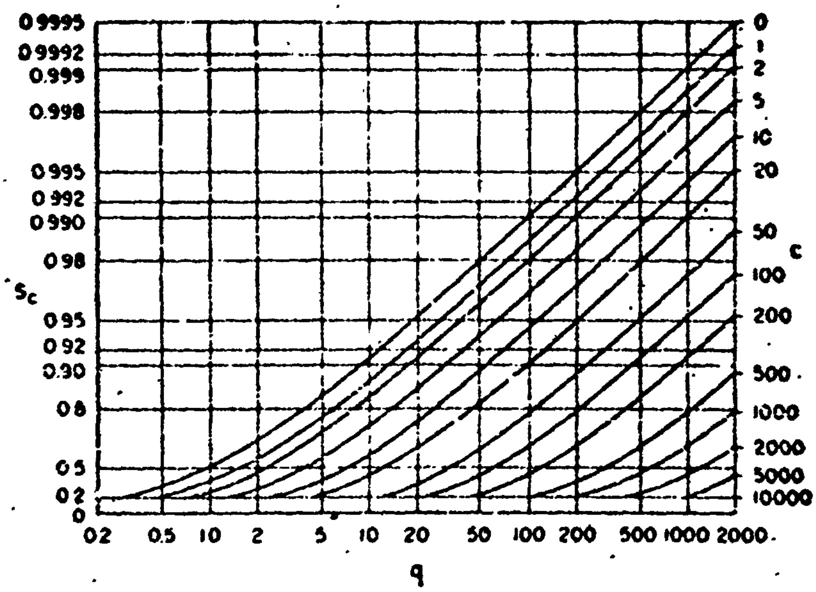


Figure 4

VALUES OF S_c vs. q and C

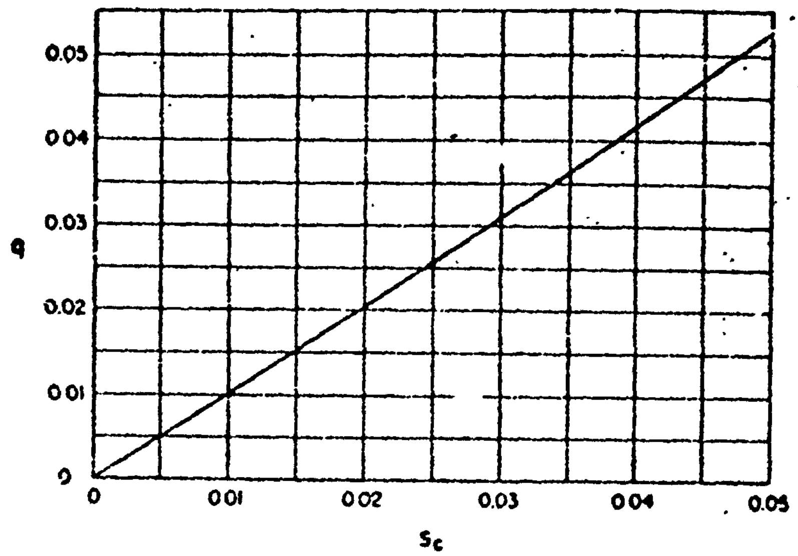


Figure 5

RELIABILITY RANGE L (c = 0)

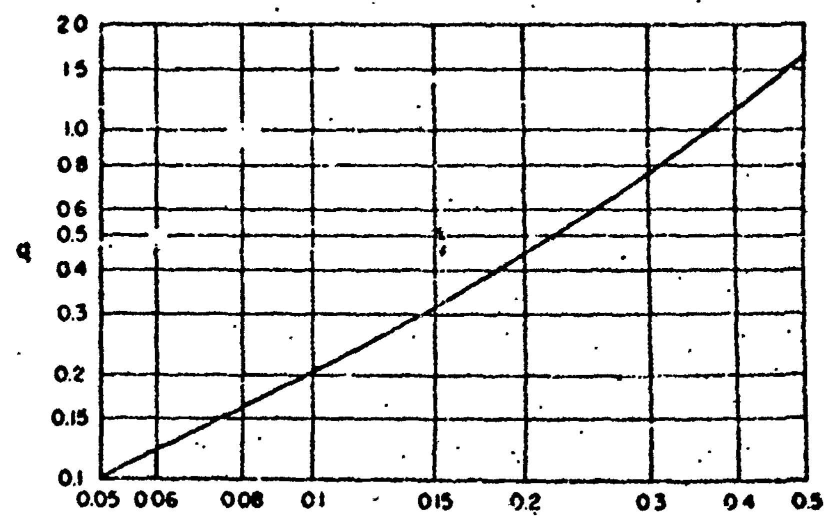


Figure 6

RELIABILITY RANGE M (c = 1)

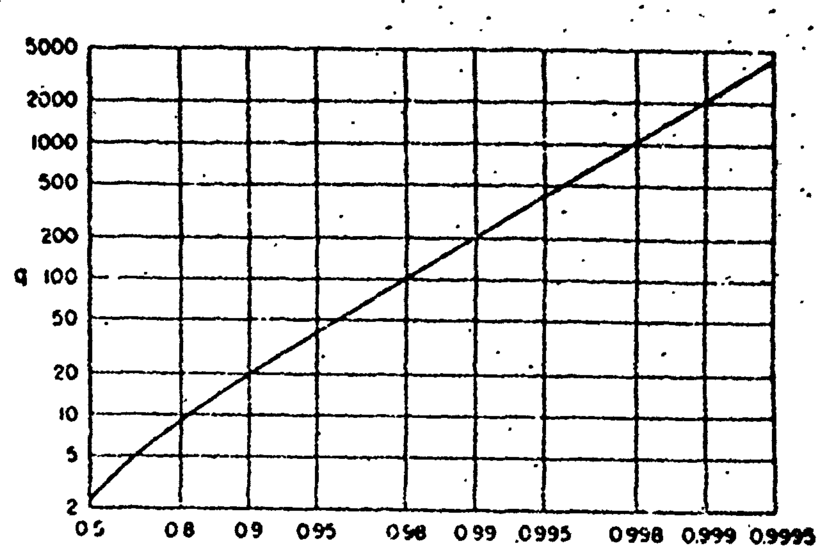


Figure 7

RELIABILITY RANGE H (c = 2)

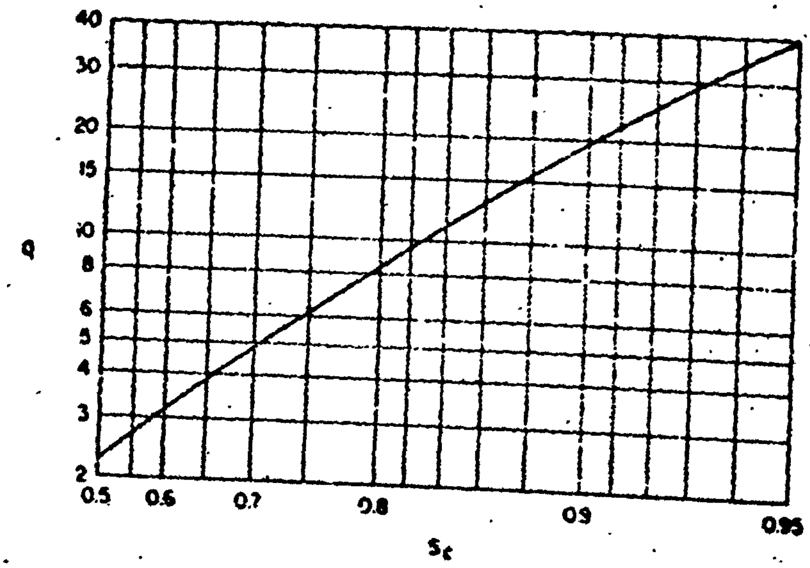


Figure 8

RELIABILITY RANGE H_1 ($c = 2$)

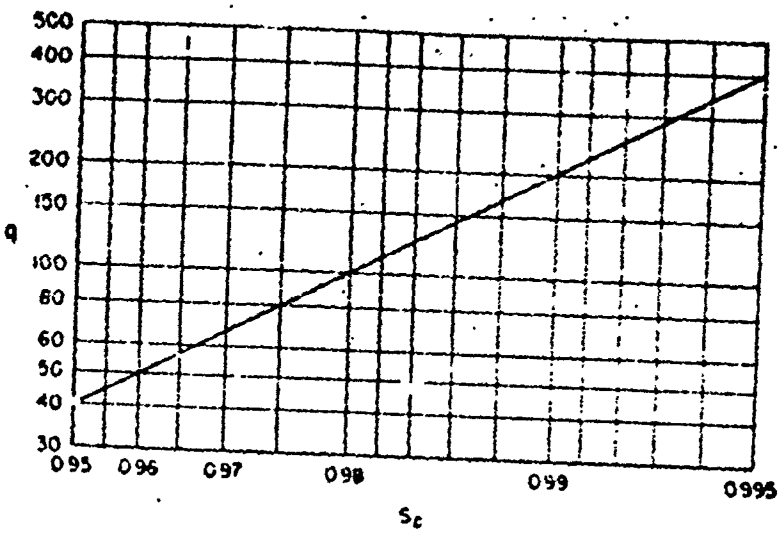


Figure 9

RELIABILITY RANGE H_2 ($c = 2$)

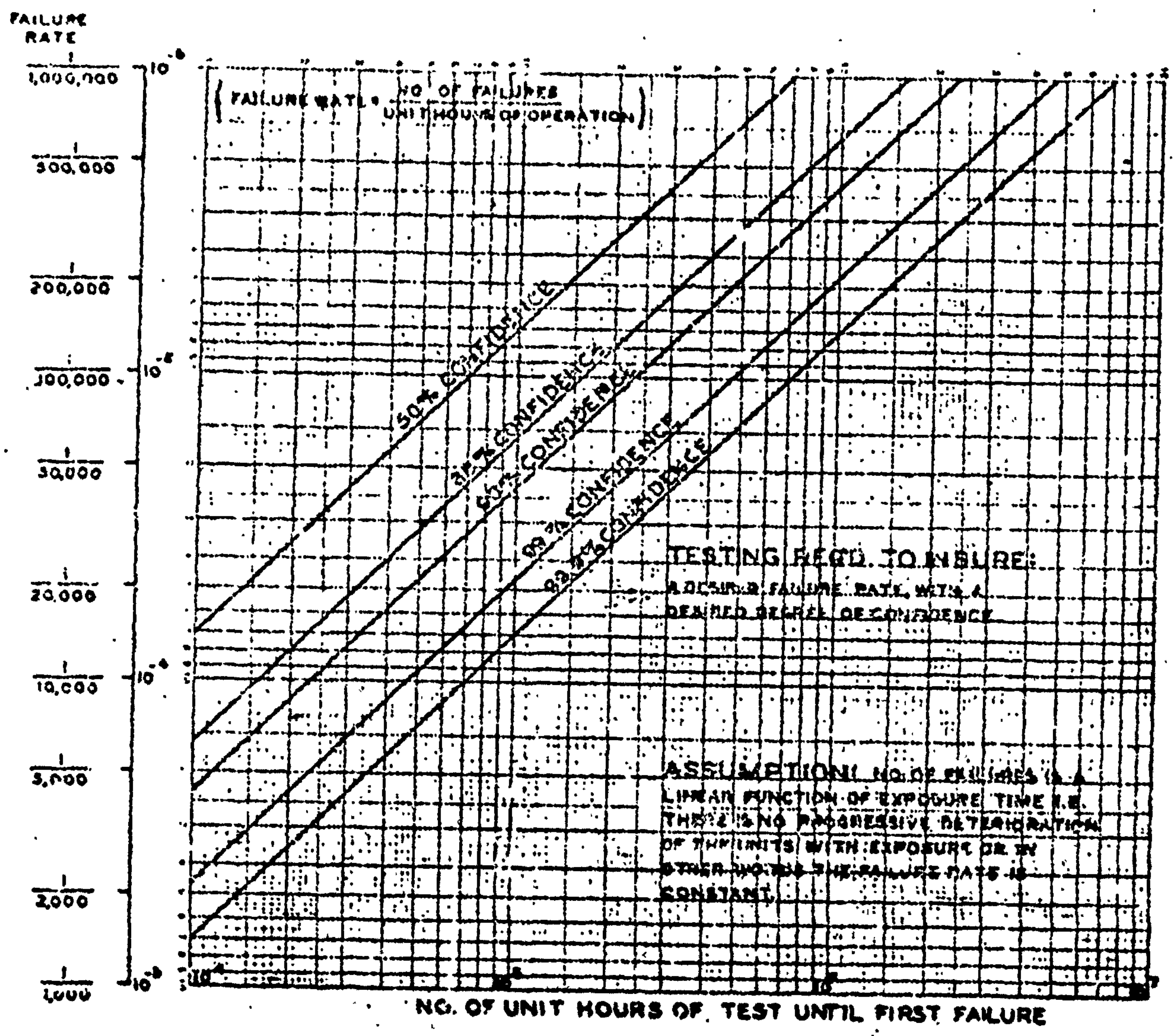

FAILURE RATE
1/1,000,000
1/300,000
1/200,000
1/100,000
1/30,000
1/20,000
1/10,000
1/5,000
1/2,000
1/1,000
(FAILURE RATE = NO. OF FAILURES / UNIT HOURS OF OPERATION)
50% CONFIDENCE
99% CONFIDENCE
TESTING REQ'D. TO INSURE:
A DESIRED FAILURE RATE WITH A DESIRED DEGREE OF CONFIDENCE
ASSUMPTION: NO. OF FAILURES IS A LINEAR FUNCTION OF EXPOSURE TIME I.E. THERE IS NO PROGRESSIVE DETERIORATION OF THE UNITS WITH EXPOSURE OR IN OTHER WORDS THE FAILURE RATE IS CONSTANT.
NO. OF UNIT HOURS OF TEST UNTIL FIRST FAILURE

FIG. 10

FINAL REPORT

TASK GROUP NO. 6

1 April 1957

The members of the Task Group agree that concerted action must be taken to improve the reliability of electronic equipment.

The Task Group believes that existing laws and procurement regulations are adequate and sufficiently flexible to enable the contracting officer to obtain fully qualified producers for the more important electronic items. This is particularly true if all technical services and bureaus uniformly interpret and implement ODM and DOD guidance for establishment and maintenance of the mobilization base for reliable electronic equipment.

This Committee, therefore, does not recommend at this time any basic change in the regulations. It does, however, strongly recommend standardization in the interpretation of each clause in the ASPR regulations between all of the procuring services.

The Task Group is convinced that reliable electronic equipment can not be procured unless the contracting officer can incorporate in his proposal a comprehensive set of technical specifications which, if met, will produce the degree of reliability required. Such technical specifications do not now exist but Task Committees 1 to 5 of AGREE are responsible for developing the framework around which it is hoped such specifications can be written. Given these specifications, the contracting officer has the procurement tools which are necessary to ensure improved reliability. These tools are:

a. Use of cost type or redeterminable contracts during the initial production run.

b. Ability to contract for a pilot run to provide for extensive tests prior to full production.

c. Careful selection of highly qualified contractors for the establishment of the mobilization base, using a qualification procedure to accurately evaluate the supplier's present and potential capabilities.

d. Restriction of competition to planned suppliers once the base has been established. This should apply to subsequent spare part procurement as well as the original end equipment.

e. Provision, if necessary, for operational tests prior to acceptance.

f. Provision in the production contract for a program of continued product improvement based on controlled testing and field experience.

The Task Group recognizes the need for continuing and increased emphasis on programs to design, develop, production engineer and mass produce new an improved electronic component parts and materials, and the writing of specifications which will permit the end equipment manufacturer to purchase these parts. Inherent reliability in these parts and materials will have a material effect on improving the reliability of the end equipment. To summarize, the Task Group recommends:

a. Continuing action to improve technical specifications.

b. Uniform interpretation and implementation of procurement laws and regulations.

c. The use of a comprehensive qualification procedure to ensure that contracts are let with qualified contractors.

d. Use of contracting procedures for end equipment and spare parts that will provide optimum conditions for insurance of reliability to the degree required.

e. Increased emphasis on the use of improved electronic components and materials.

f. A program for product improvement as a phase of the production plan.

FINAL REPORT OF

TASK GROUP 7

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
Washington 25, D. C.

Supply and Logistics
SS-7

30 April 1957

MEMORANDUM FOR THE EXECUTIVE DIRECTOR, ADVISORY GROUP ON RELIABILITY OF ELECTRONIC EQUIPMENT

SUBJECT: Final Report - Task Group 7

The following personnel constituted subject Task Group:

R. A. Norris, Chairman	OASD(S&L), Washington, D. C.
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M. C. Dunn, Bureau of Ships	Washington, D. C.
C. L. Nickerson, Signal Corp	Philadelphia, Pa.
R. H. Thomas, General Electric Co.	Utica, N. Y.
E. M. McDermott, General Electric Co.	Syracuse, N. Y.
J. P. O'Hanlon, RCA	Camden, N. J.
G. C. Cunningham, Raytheon Mfg. Co.	Waltham, Mass.
W. R. MacKinnon, Hughes Aircraft Co.	ElSegundo, California
R. S. Dunn, Collins Radio Co.	Cedar Rapids, Iowa
R. C. Cunderman, Western Electric Co.	Winston Salem, N. C.

This Task Group was activated in July 1956. Two formal meetings were held in Washington, D. C., one on July 24, 1956 and the second on November 27, 1956. The following areas were considered by the Task Group and deemed the more important:

1. Relationships between the designer of electronic equipment and the packaging engineer in order that designs of electronic equipment could be properly preserved, packaged and packed and that in the case of newly designed equipment, there would be a close working relationship between these two interests during the design stage.

Investigations indicated that while in the past, there was some lack of communication between the designer of the equipment and the packaging engineer, through management, currently there is the interchange of information, so that relations are good and there is no longer a serious problem in this area.

Task Group recommends that working relations between the equipment designer and package designer be continued and improved.

2. Industry representatives pointed out there is little information available on cushioning to dampen dynamic forces. This problem is also of concern to the military departments.

Currently the Centralizing Activity for Shock and Vibration, under the sponsorship of the Assistant Secretary of Defense (R&E) is coordinating efforts toward the development of data on shock and vibration encountered in handling and transportation. Further a new type recorder of shock and vibration is being developed under the sponsorship of the Naval Research laboratory, since currently available recorders are limited to the recording of peak shocks. When this new recorder is available it is believed more realistic shock and vibration values will be available, thereby providing the package designer with more practical criteria from which better shock dampening techniques can be developed.

These newly developed shock recorders are planned to measure and record all shocks within 2 to 150 G limits, and will further record the duration of shock in seconds. These new recorders are planned to operate for a period of 30 days, unattended.

Specific dynamic values for cushioning materials should be developed in order that the data pertaining to the efficiency of types may be used in determining selection for particular installations.

The Air Force, in conjunction with industry, is currently working to establish dynamic values for cushioning materials. It is planned to issue this data as a handbook. It is anticipated this handbook will be issued approximately 1 July 1958.

The Task Group recommends continued emphasis to improvement in container design. On the completion of the studies indicated above, there be a new concerted effort to reflect the results in container design for electronic equipment.

3. The Armed Services are experiencing damage to electronic equipment resulting from excessive rough handling in transit and faulty and inadequate blocking and bracing of packs of electronic equipment within the transportation media.

The Task Group recommends that a review of all application rules, regulations, and tarriffs involving blocking and bracing be made with the objective of improvement in, and enforcement of, those requirements.

4. The development of specific test procedures to more clearly simulate transportation and handling environments was recommended by the Task Group. Project Number 70-90 has been established by the Standardization Division, OASD(S&L) with the Bureau of Ships as preparing activity responsible for the development of the basic draft of a specification for the testing of packed electronic equipment. The Signal Corps will represent the Department of the Army and the Wright Air Development Center, the Air Force. This specification will be coordinated with interested military and industry groups. It is anticipated this specification be coordinated and available during July 1958.

The Task Group recommends this specification be completed as rapidly as possible.

5. An evaluation of damage to electronic equipment due to improper packing resulted in a divergence of opinion with the military departments and by the industry members of this Task Group. The Bureau of Ships representative pointed out the Navy is currently experiencing substantial damage to electronic equipment, resulting from improper packaging and packing. The Army and Air Force after checks and research reported the damage to electronic equipment other than due to blocking and bracing in transportation media, (not including the shipping containers therefor) was insignificant. Industry representatives further pointed out only minor reported damage to electronic equipment. The industry representatives

indicated careful design and testing of boxed equipment, prior to the submission of shipping container designs for new equipment for approval by the Government.

It was the consensus of the Task Group that with the work currently underway, improvement can be made to the packaging and packing of electronic equipment which will improve reliability. However, the industry representatives did point out that by close collaboration with the container designer, some equipments were being built more rugged than in the past. This was particularly true of shipboard electronic equipment and Signal Corps field communications equipment where the environment of use made more rugged design a necessity for operational reasons.

6. Task Group recommends that in view of changing conditions and the many new and unique development in this rapidly changing field, it is of the utmost importance that close collaboration be maintained between the equipment designer, the container designer and the Government.

R.A. Norris
RAYMOND A. NORRIS
Chairman, Task Group 7

THE EFFECTS OF STORAGE UPON THE RELIABILITY OF ELECTRONIC EQUIPMENT

Final Report

TASK GROUP 8

1 February 1957

MEMBERS OF TASK GROUP - 8, AGREE

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B. F. Knell	Navy - Bureau of Ordnance
S. Schwartz	Navy - Bureau of Ships
Lt. Col. S. J. Grady	Air Force - Air Materiel Command
R. D. Bright	Air Force - Air Materiel Command

ACKNOWLEDGEMENTS

The members of Task Group-8 express their thanks to the various branches of the Armed Services and to the many industrial organizations that have supplied pertinent data and information, and to the personnel who contributed so generously in time and effort to aid in expediting the completion of the Group's assignment. Many of these people, through their assistance in the gathering and analyzing of the data, and in the reviewing of the results, contributed greatly both to the conclusions reached and to the recommendations submitted.

In particular, the Group expresses its appreciation to the following organizations and individuals:

Headquarters, Air Materiel Command

Airman First Class Gerald J. Rosenkrantz

Navy - Bureau of Ships

Navy - Bureau of Ordnance

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Mr. Gerardo L. Lombardi
Mrs. Kathy Teske
Mr Ralph Whitmore

The members of the Group are indebted to Mr. Richard H. DeWitt, of the Office of the Assistant Secretary of Defense (Engineering) for his guidance of the Group at its early meetings and for his continuing help and advice throughout the year. Appreciation is also expressed to his secretary, Mrs. Emily H. Keller, for making the arrangements for the Task Group-8 meetings and for her assistance to the members in regard to accommodations and transportation.

CONTENTS

ABSTRACT

This report presents the results of the investigations conducted by Task Group - 8, AGREE, during 1956.

On the basis of the data analyzed, there is a 90 per cent probability that the expected failure rate due to storage of Armed Forces electronic equipment is not greater than 0.040 per cent and not less than 0.035 per cent. In other words, the reliability, at the 90 per cent confidence level, of these electronic equipments in terms of the effects on reliability of storage only, is from 99.960 per cent to 99.965 per cent.

These results indicate that the problem of failures due to storage is not serious when compared to the problems of failures due to other causes, such as inadequate component and equipment design, poorly controlled manufacturing and assembly processes, contractor and acceptance inspection inconsistencies and invalid failure reports resulting from inspection and testing errors in storage and in the field.

1. INTRODUCTION

1.1 Purpose of the Program

The purpose of the program assigned to Task Group-8 by AGREE is "to investigate the effects of storage of electronic equipment upon reliability and recommend improvements where desirable."

The effects of packaging, transportation and handling are not considered as effects of storage in this report. These problems were investigated separately by another AGREE Task Group.

1.2 Approach to the Problem

It was agreed that the results obtained by the Group would depend on the adequacy and validity of the data available from the various branches of the Armed Forces and from industry. On this basis, the Group set up the following approach to the problem.

1.2.1 To consider equipment failure as the measure of reliability and to consider component or piece-part failure only for analysis of the causes of equipment failure.

1.2.2 To study those equipments required to operate continuously or intermittently for extended periods of time and also those equipments required to operate only once for a limited period of time.

1.2.3 To investigate all available sources of data.

1.2.4 To review and evaluate the data obtained from these sources.

1.2.5 To draw conclusions in terms of the effects of storage on the reliability of electronic equipment.

1.2.6 To report the investigation results to AGREE.

1.2.7 To recommend certain actions by the Department of Defense.

1.3 Definitions Adopted

The evaluation of data and the determination of reliability estimates are [illegible] on basic definitions of reliability and reliability requirements for various types of military electronic equipments. Task Group-8, for the purpose of its investigation, has adopted the following definitions.

1.3.1 Failure - The failure of an equipment to meet specified operational requirements or test procedures.

1.3.2 Reliability - The probability that an equipment will meet the specified [illegible] requirements and test procedures [illegible] that an equipment [illegible] at the time of storage [illegible] or use (briefly, the [illegible] that an equipment works when turned on).

2. SUMMARY OF THE PROGRAM

2.1 Sources of Data

Contacts were made with numerous concerns in the fields of development, manufacture, and use of electronic equipments throughout the United States. Although many groups are planning future studies of the effects of storage on electronic equipment reliability, none has data available for analysis at this time. In general, since World War II, manufacturers have not had electronic equipments in storage for extended periods of time, because the demand has exceeded the supply in most cases. Therefore, the study by Task Group-8 is restricted to data from the following sources.

2.1.1 Army Signal Corps Depots

2.1.2 Army Signal Corps Engineering Laboratories

2.1.3 Army Signal Equipment Support Agency

2.1.4 Navy - Bureau of Ordnance

2.1.5 Navy - Bureau of Ships

2.1.6 Air Force - Air Materiel Command

2.1.7 Western Electric Company - Field Engineering

2.1.8 Sandia Corporation - Quality Assurance

2.2 Analyses of Data

The reports submitted from the various sources were not expressed in compatible terms and could not be converted into valid statements of comparative failure rates or reliability with any degree of consistency. For this reason information has been converted into estimates of maximum expected failure rates due to storage by tempering statistics with experience and engineering judgment.

2.2.1 Data from Signal Corps Depots

2.2.1.1 The Signal Corps employs a so-called recertification program. Domestic-packed equipment is unpacked and tested at three-year intervals; export-packed equipment, at five-year intervals. No record is kept of the test results, or even of the number of equipments accepted or rejected. Since the Signal Corps data are in terms of tons of electronic equipment examined during surveillance programs, the per cent sampled and the per cent defective reported can give only a general indication of the effect of storage on reliability.

It is estimated that over fifty per cent of the equipments involved in this study had been in storage for a period of from three to five years at the time of surveillance inspection.

The reports submitted included quantities tested, quantities rejected, and estimates of the percentage of rejections caused by, or as a result of, storage.

Obviously, unless an engineering study of the causes of rejection is made, the actual failure rate in storage cannot be stated and subsequently analyzed to determine which failures actually were due to storage conditions and not to other causes. The data are not such that an engineering study would be practical at this time.

2.2.1.2 The Signal Corps depots reported on a total of 6,761 tons of stored electronic equipment that were inspected during the surveillance programs at the four reporting depots. The inspections were performed during various periods between 1 July 1954 and 1 June 1956. (See individual depot reports in Appendix A.)

2.2.1.3 The figures in tons of equipments have been converted to numbers of equipments after a study of the variation in equipment type, weight, and complexity at each storage location. This conversion procedure was arbitrary and based on estimates made after discussions with Army Signal Corps personnel, not on actual report figures.

2.2.1.4 The total Signal Corps Surveillance inspections reported represent examination of approximately 375,665 equipments, of which 7,344 (1.95 per cent) were rejected for defectiveness described as 'deterioration in storage.' Obviously, something less than this 1.95 per cent of the total sample inspected can be considered as representing rejections for actual failures to function.

The maintenance of complete records of failures and failure causes would provide a more valid basis for evaluation and determination of the actual effects of storage on the reliability of these equipments.

2.2.1.5 As a result of comparison with other source data, it is believed that the average actual failure rate of Signal Corps equipments due to storage is approximately 0.1 per cent; and, on this basis, there would be a 90 per cent (or 0.9) probability that the expected failure rate due to storage would not exceed 0.108 per cent.

2.2.2 Data from Signal Corps Unsatisfactory Equipment Reports (UER's)

2.2.2.1 For the period 1 July 1955 through 31 December 1955, examination of 730 UER's disclosed that failures due to storage were not reported as such but were included in the category of miscellaneous Failures, which covered 92 reports, or 14 per cent of the defective equipment.

2.2.2.2 Of 408 Unsatisfactory Equipment Reports processed in the quarter ending 31 March 1956, nine, or 2.2 per cent, identified storage as the cause of failure. Investigation of these nine revealed the following:

a. Three reports covered transformers made by the same firm; one covered a metallic rectifier used in the same piece of equipment. This equipment had been in storage (type of storage unknown) in Okinawa for seven months. Its previous storage history is unknown.

b. Three reports covered dry batteries. One group of these batteries was obviously over-age; the age of the other two groups was not stated, but, there is reason to believe these groups also were over-age.

c. One was rubber-covered multiconductor cable stored in Germany for an unknown period. Indications are that it probably had been there for over ten years.

d. One was an un-refinished metal cabinet showing definite signs of previous use and abuse.

The metallic rectifier of "a" above and the batteries of "b" are known short shelf-life items; the cable of "c" was obviously over-age and the cabinet of "d" was clearly the result of use and abuse, not storage. This leaves only three of the original nine reports which may be blamed on storage, though there is no actual proof that storage was responsible; the three transformers of "a" may have been from a defective lot.

This reveals that of the 408 Unsatisfactory Equipment Reports analyzed, a maximum of 0.735 per cent of the failures reported may be blamed on storage.

Since no sample size can be determined, no estimate of failure rate can be made.

2.2.3 Data from Navy - Bureau of Ordnance

Records on cyclic inspections of Fire Control Instruments over a period of five years (equipment in Type One controlled storage, 30 per cent RH and 80°F, for three to five years) show that of 3,545 equipments operated, no failures due to storage were reported. Operational failures were attributed to other causes.

On the basis of these data, there is a 90 per cent (or 0.9) probability that the expected failure rate (due to storage) under these storage conditions will not be greater than 0.065 per cent. (For details of Navy--Bureau of Ordnance Cyclic Inspection of Fire Control Instruments see Appendix B.)

2.2.4 Data from Navy - Bureau of Ships

2.2.4.1 A study of 22,000 equipment failures showed that 52, or 0.24 per cent, were attributed to storage. A total of 60 component failures on these equipments were reported. Of these, 19 were electron tube failures, 28 were capacitor failures, and 13 were listed as miscellaneous failures.

2.2.4.2 Another study of 33,000 equipment failures showed that four, or 0.012 per cent, were attributed to storage. These equipments had a total of six component failures, of which four were electron tube failures, one a resistor failure, and one a filter failure.

2.2.4.3 An engineering investigation of the above component failures would be necessary to determine if they were actually caused by storage conditions; therefore the range (0.012 per cent to 0.24 per cent) of the per cent of failures attributed to storage cannot be used as a valid datum for drawing conclusions. Since the number of equipments operating satisfactorily during the period of testing is unknown, no statistical reliability estimates can be made. (See Appendix C for Navy - Bureau of Ships data summary.)

2.2.4.4 An investigation into the "Inactive Fleet Records" disclosed that no valid data are available concerning the operability of electronic equipment at the time of inactivation or at the time of reactivation. Complete and accurate records of this operation would have been of great value in the study of the effects of storage on the reliability of electronic equipment.

2.2.5 Data from Air Force - Air Materiel Command

2.2.5.1 Analysis of 100,000 USAF failure reports, covering both airborne and ground electronic equipment, revealed that 454, or 0.45 per cent of these failures were attributed to storage. These data were published in AMC publication 530-08 (30 July 1956), pp 1[illegible]-56, but no information on the number of equipments not failing during the period covered by the report is available. Hence, no failure rate due to storage is known

2.2.5.2 For statistical purposes, however, the Group made an arbitrary assumption of an over-all failure rate of five per cent. This is an estimate based on discussions with Air Force personnel. Even when this high over-all failure rate is assumed, the failure rate due to storage is only 0.0225 per cent and there is a 90 per cent (or 0.9) probability that the expected failure rate due to storage will not be greater than 0.024 per cent. (See Appendix D for source of above data.)

2.2.6 Data from Western Electric Company Field Engineering

2.2.6.1 A total of 46,000 Field Engineering Air Force Equipment Failure Reports were analyzed. Of these failures, 250, or 0.5 per cent, were attributed to storage. However, many of these equipment failures were the result of electron tube and other component failures that may have been due to design or manufacturing causes, so the actual failure rate of equipments due to storage was probably much lower. Since no record is available of the number of units operating satisfactorily during the test period in which the above failures occurred, no statistical reliability estimates are possible.

2.2.6.2 Storage of the above equipments was in warehouses within the United States, and since the maximum period of storage was estimated to be ninety days, it is not likely that storage conditions would have had time to affect the function of a significant number of equipments. (See Appendix E for supporting information.)

2.2.7 Data from Sandia Corporation Quality Assurance

2.2.7.1 An analysis of storage inspections reported by the Armed Forces in two general storage areas (A and B) on Sandia Corporation designed electronic equipments during a four-year period (1 January 1952 through 31 December 1955) results [illegible] estimated failure rates shown on the chart on p 1[illegible]. These Sandia Corporation data indicate an average of a little over one failure reported as due to storage per thousand equipments in storage during the stated four-year period; and a 90 per cent (0r 0.9) probability that the expected failure rate due to storage would not be greater than 0.136 per cent. However, the analysis indicates that many of these failures apparently were due to inherent equipment or component weaknesses that can be traced to design or manufacturing causes. (See Appendix F for supporting information.)

2.2.7.2 An analysis was made of 34,562 storage inspection reports received from the Armed Forces covering inspections of 5,246 units of Sandia Corporation designed electronic equipments during the interval 1951 through 1954. The data were processed for:

a. Time in storage before failure.

b. Correlation between time in storage and number and types of failure.

c. Number of inspections before failure.

d. Correlation between number of inspections and types of failure.

Items a. and b. are shown on CHART A.

Items c. and d. are shown on CHART B.

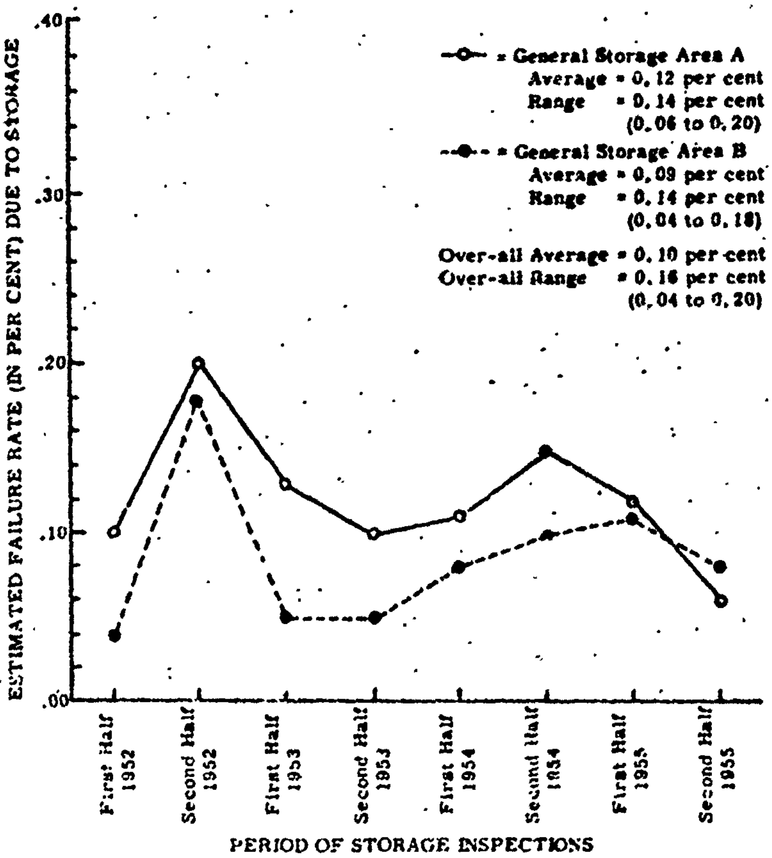
2.2.7.3 The only electronic equipment failures in storage, as shown on CHARTS A and B, that could possibly be attributed to storage are those indicated as due to unknown causes. If this assumption is made, the failure rate due to storage was 0.15 per cent, and there is a 90 per cent (or 0.9) probability that the expected failure rate due to storage is not greater than 0.135 per cent. (See Appendix F for supporting information.)

2.3 Results

2.3.1 Summing up the information analyzed in which failure rates were known or estimated, the total number of equipments tested in storage was 2,449,772 and the total number of equipment failures attributed to storage was 920, or 0.038 per cent of the total tested.

On this basis, there is a 90 per cent (or 0.9) probability that the expected failure rate due to storage of electronic equipment stored by the Armed

SANDIA CORPORATION-DESIGNED ELECTRONIC EQUIPMENTS
FAILURE RATES DUE TO STORAGE
(Based on Storage Inspections by Armed Forces)



SANDIA CORPORATION DESIGNED ELECTRONIC EQUIPMENTS
FAILURE RATES VS TIME IN STORAGE
(Based on Storage Inspections by Armed Forces)

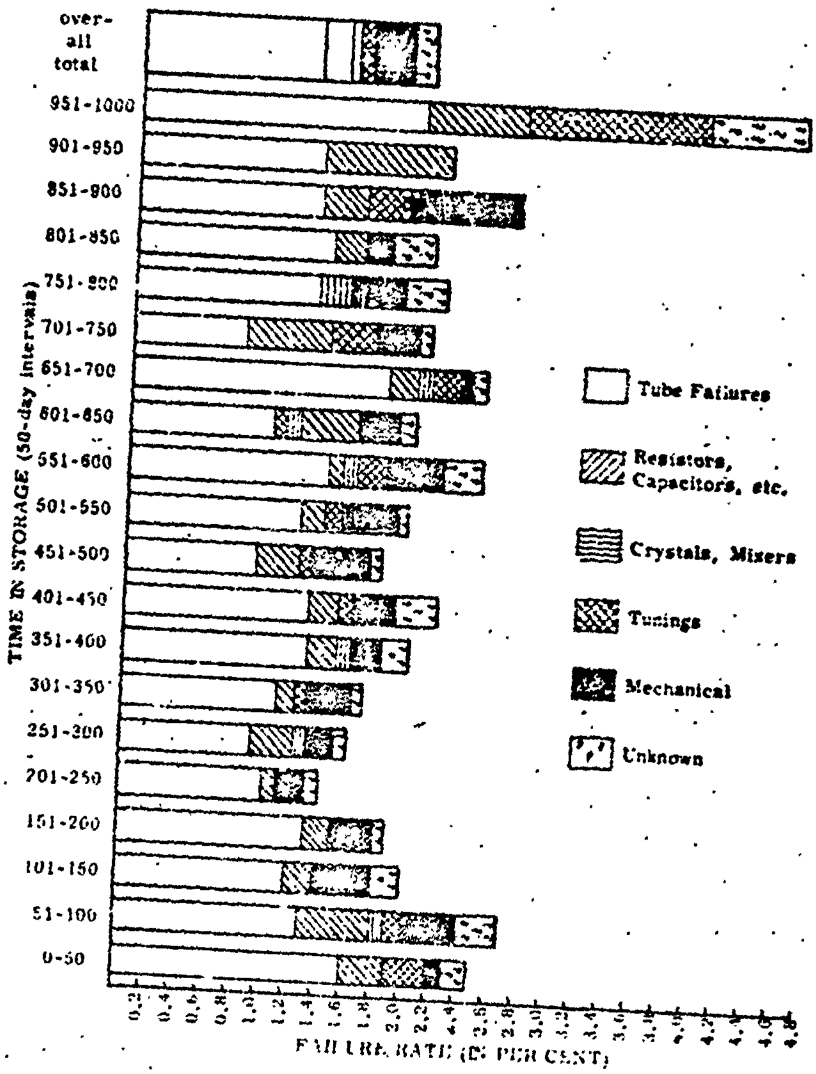


CHART A

Forces is not greater than 0.040 per cent and not less than 0.035 per cent. In other words, the reliability, at the 90 per cent confidence level, of electronic equipments in terms of the effects on reliability of <u>storage only</u>, is from 99.960 per cent to 99.965 per cent.

2.3.2 In many cases, failure rate figures were not available, and the difference between <u>failure rate</u> and the <u>per cent of failures</u> that are due to storage must be kept in mind at all times. These are defined as follows:

a. Failure rate (in per cent) due to storage

$$\text{due to storage} = 100 \times \frac{\text{Total failures due to storage}}{\text{Total equipments inspected in storage}}$$

b. Per cent of failures due to storage

$$\text{storage} = 100 \times \frac{\text{Total failures due to storage}}{\text{Total failures due to all causes}}$$

SANDIA CORPORATION-DESIGNED ELECTRONIC EQUIPMENTS
FAILURE RATES VS INSPECTION FREQUENCY
(Based on Storage Inspections by Armed Forces)

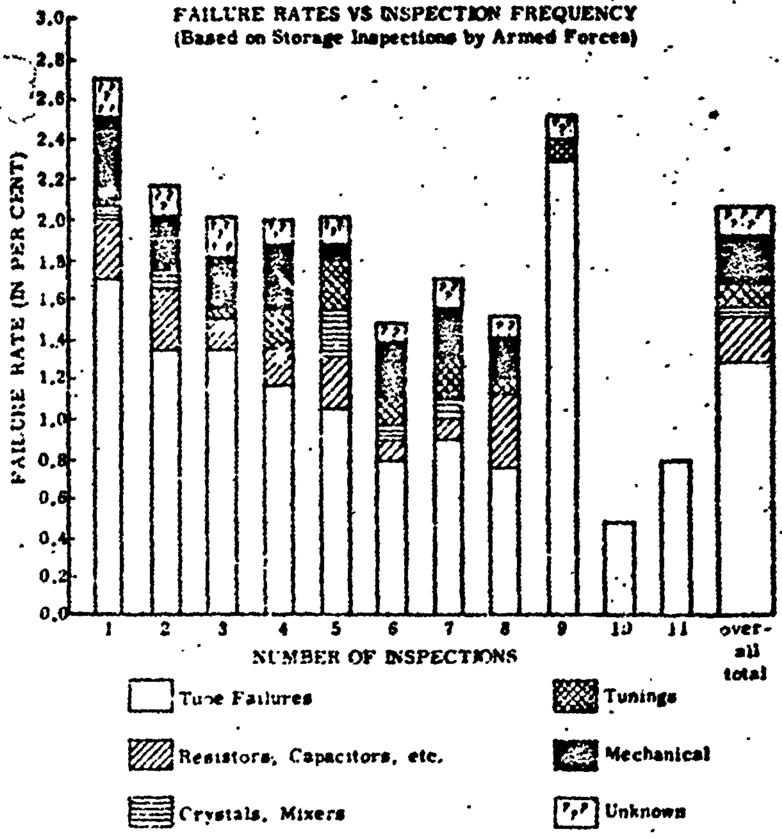


CHART B

3. CONCLUSIONS

3.1 The results of the investigations by Task Group 6 indicate that the problem of failures due to storage is not serious when compared to the problems of failures due to other causes, such as inadequate component and equipment design, poorly controlled manufacturing and assembly processes, contractor and acceptance inspection inconsistencies, and invalid failure reports resulting from inspection and testing errors in storage and in the field.

3.2 The life histories of individual units of electronic equipments have not, in general, been recorded, so that the condition or operability of the equipment at the time it is put in storage is usually unknown. Later evaluations cannot then be correlated with previous data. In other words, the more that is known about any equipment when it is put in storage, the more can be learned about the effect of storage on its reliability.

3.3 The Group found that there are considerable data in the files of the Armed Services that can be useful to the AGREE program in general.

3.4 It is believed that competent engineering and statistical assistance is needed in the programming for machine analysis of these data, which, for the most part, are on EAM cards or magnetic tape. Considerable information is available, but it must be converted to a standard form that lends itself to statistical and engineering analyses and the subsequent reporting of results.

3.5 The cost of gathering and recording this mass of data should not be wasted by allowing the information to remain in an archived state, of use for historical purposes only. Through a program of planned reduction and analysis, with periodic publication of results as a means to decision making, the cost already incurred can, in some measure, be justified.

3.6 The inspection and maintenance operations in the field do assure that the operability of equipment is maintained [illegible], but unless the records of these operations are valid in content, are reported promptly and consistently, and are used as a basis for corrective action at the design and manufacturing stages, they have only partially fulfilled their purpose.

3.7 On the basis of a portion of the data examined it is probable that the variation in accuracy and precision of the test equipment used in the field and in storage tests is such that a considerable percentage (at least [illegible] per cent) of the rejection and acceptance decisions made are invalid. These erroneous decisions may to some extent balance out, with the errors of rejection being offset statistically by the errors of acceptance, but it is unsound to draw definite conclusions from such an assumption. It can be stated with assurance, however, that the errors occur often enough to cast doubt on the results of the functional tests made on electronic equipments in storage and in the field.

This conclusion is supported by the report of Task Subcommittee B-2 of the Tube Application Planning Group EA(R) 1 of RETMA (Radio-Electronics-Television Manufacturers Association) published 2 October [illegible]. The present situation is pointed out in this report and a recommendation is made for the design of simplified standard test equipment that can be (a) calibrated in the field using available basic standards, and (b) maintained in a state of accuracy that will minimize rejection and acceptance errors resulting from inadequately controlled and maintained test equipment.

The Group has concluded that, [illegible] the design of adequate test equipment has been treated as a secondary requ[illegible] [illegible] that is considered after, not during, the period of design and manufacture of the electronic equipments themselves. Obviously, this is fallacious planning and execution which results in the delivery of equipments that cannot be adequately tested for reliability of function until some later--perhaps too late--date. At present, much of the test equipment in use is less reliable than the equipment tested; thus, the results of the testing can hardly be considered valid for analysis in terms of the reliability of the equipments.

3.8 The Group believes that there is a basic lack of management understanding of the need for the valid and specific data that are required for reliability studies and estimates. To date, most discussions at the management level have been general and philosophic, showing a lack of the leadership necessary to direct the line organizations toward a program of improving the qualifications of inspection and evaluation personnel and equipping them with more adequate testers and testing and reporting procedures.

4. RECOMMENDATIONS

Task Group-8 presents the following recommendations:

4.1 That the apparently widespread philosophy that adequate and valid testing and reporting are not military functions of primary importance, even during peacetime, be reviewed. It is believed that all levels should be indoctrinated with the philosophy that when an emergency arises, previous evaluations of data from inspections and tests will result in the reduction of the probability of failure of a mission.

4.2 That test and inspection requirements be reviewed and amended to provide the data necessary for reliability studies.

4.3 That reporting procedures be revised to supply this data in a form for consistent reduction and analysis.

4.4 That the Department of Defense investigate the advisability of implementing the Proposed Programs for Obtaining Data on the Reliability of Electronic Equipment, as outlined in Appendix I.

4.5 That sufficient authority be vested in quality control organizations in all branches of the service and in industry to assure their fulfillment of the responsibilities outlined in 4.2 and 4.3 above.

4.6 That a planned program of reducing and analyzing the data now on file be put into effect at an early date in order to capitalize on the available information to the extent that sources of defectiveness may be discovered and corrective action taken.

4.7 That a centralized working group within the Department of Defense be established, on a continuing basis, to coordinate and evaluate the reliability data from all sources and to report the results of these evaluations at regular intervals so that prompt action can be taken when necessary.

4.8 That, if the results obtained by the other eight AGREE Task Groups confirm the need for more reliable data in order to determine the actual reliability of the various electronic equipments and to isolate the factors that contribute to unreliability, AGREE consider a controlled experiment involving the storage and testing of a statistically significant sample of typical electronic equipments. This experiment would be planned and executed under the supervision of trained engineers and statisticians and would be conducted independently of other storage and testing projects. Valid data on the effects of storage on reliability that might confirm or modify the conclusions drawn by the Group in this report could be obtained concurrently from such a program.

NOTE: Task Group-8 wishes to state that the above recommendations are not made primarily for the purpose of obtaining additional information on the effects of storage on the reliability of electronic equipment. They are submitted with the hope that they may be considered by AGREE with respect to the over-all problem of obtaining higher reliability of electronic equipment purchased by the Armed Services.

APPENDIX A

5.1 SIGNAL CORPS SUPPORTING INFORMATION

Following are copies of the correspondence that was used as a basis for the analysis of Signal Corps failures due to storage. In addition, discussions were held with Signal Corps personnel to clarify and augment this information.

This appendix also includes proposed programs for obtaining data on the effect of storage on the reliability of electronic equipment.

HEADQUARTERS
SIGNAL CORPS ENGINEERING LABORATORIES
Fort Monmouth, New Jersey

SIGEL-Pmm 3 Commanding General

3 APR 1956

SUBJECT: Reliability of Electronic Equipment

TO: Commanding General
Signal Corps Supply Agency
225 South Eighteenth Street
Philadelphia 3, Pennsylvania
ATTN: SIGSU-H3

1. The Office of the Assistant Secretary of Defense has requested, through the Advisory Group of Reliability of Electronic Equipment that these Laboratories supply the information outlined below:

a. Are equipments (not piece parts) tested periodically? If so, how often? If so, are they required to meet the requirements of the applicable Signal Corps Repair Standard at each testing?

b. Are they tested before shipment? If so, are they tested only at the time of repair, if repaired, and before shipment?

c. If either a. or b. above are standard practice, does your office have records of test results on individual equipments, obtained at different times?

d. If the records mentioned in c above are not available, do you have test results obtained at time of repair, and test results on other similar equipments obtained after a period of storage?

e. Any other information available on the effect of storage on electronic equipment.

2. If any of the above mentioned data is available, will supplying it be a minor or a major problem? If major, to what extent and at what estimate cost?

3. The purpose of the above questions is to attempt to determine the extent to which electronic equipment deteriorates during storage, and to attempt to devise a method, or methods, to combat such deterioration.

4. It is requested that a reply be received by this office not later than 12 April 1956 as it has been directed that this and other information be given the above mentioned group at a conference to be held 17 April 1956.

5. It is also requested that Mr. Harris of these Laboratories, Eatontown 3-1000, Extension 51525, be contacted by telephone if further details relative to this request are required.

FOR THE COMMANDER:

/s/ Robert B. Tomlinson
ROBERT B. TOMLINSON
Colonel, Signal Corps
Chief, Proc-Maint Engineering Div

SIGSU-H3b (3 Apr 56) 1st Ind Mr. Belcher/MRB/631
SUBJECT: Reliability of Electronic Equipment

The Army Signal Supply Agency, 225 S. 18th St., Phila. 3, Pa., 11 April 56.

TO: Commanding General, Headquarters, Signal Corps Engineering Laboratories, Ft. Monmouth, N.J. ATTN: Ch. Proc-Maint Engineering Div, SIGEL-PMM-3

1. With reference to paragraph 1 of basic letter, the following information is furnished:

a. Equipments are tested when procured and every three or five years thereafter while in storage, depending on the packing method used. Inspection is required every three years when the equipment is domestic packed and every five years when export packed. The requirements of the applicable Repair Standard must be met at each testing, unless a Depot Deviation Request is approved.

b. Equipments are not tested prior to shipment, except when the three or five-year limit (or "certification date") has been exceeded due to the workload at the depot. In these cases, the equipment is tested prior to shipment. All equipments are tested at the time of repair and as outlined in paragraph 1a above.

c. There is no requirement that test results be recorded at the depots; however, test data sheets are maintained by some depots and are available from them.

d. The only records available are those kept at the option of the depot, as mentioned in paragraph 1c above.

e. Copies of Depot Packaging Instructions will be forwarded as soon as possible.

2. In accordance with telephone conversation between Mr. Drayton of this Agency and Mr. Harris of your Laboratories, the test information available at the depots will be requested directly. However, it is requested that the results of this study be coordinated with this agency.

FOR THE COMMANDER:

/s/ Douglas O. Toft
DOUGLAS O. TOFT
Colonel, Signal Corps
Deputy for Quality Assurance

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF SIGNAL OFFICER
Washington 25, D. C.

SIGPD-6A 25 May 1956

SUBJECT: Effects of Storage on Reliability of Electronic Equipment

TO: All Sig Corps Branch Depots

1. DOD Task Group on effects of storage on reliability of electronics equipment has not been able to find actual records from any service to assist them in their endeavor.

2. It is now contemplated to design a reporting system to gather information on a continuing basis which would reflect effects of storage on such equipment.

3. The cost of gathering such information will have to be weighed against the end result, i.e. are effects of storage so insignificant that the cost would not be justified.

4. In order to evaluate this problem, it is requested that the following information be furnished for period FY-55 and 9 month FY-56:

a. Total tons processed thru surveillance program.

b. Estimated quantity sample tested.

c. % of b rejected.

d. % of c caused by or as a result of storage.

5. It is realized that some of the above information is not available. However, your best estimate of the situation is requested.

6. Request information be furnished by 15 June 1956 in order to be available to Task Group before next meeting on 18 June 1956.

FOR THE CHIEF SIGNAL OFFICER:

/s/ B. Risque
FRANK H. DRAKE
Colonel, Signal Corps
Chief, Distribution Branch

B. RISQUE
Lt. Colonel, Signal Corps
Chief, Depot Management Section
Distribution Branch

The following reports received from the Signal Depots indicated:

SIGFT-1 (25 May 56) 1st Ind.
SUBJECT: Effects of Storage on Reliability of Electronic Equipment

Sacramento Signal Depot, Sacramento 1, California, 11 June 1956

TO: Chief, Procurement and Distribution Division, Signal Corps,
Main Navy Building, Washington 25, D.C., ATTENTION: SIGPD-6A.

1. This depot has maintained accurate records of its surveillance program as of 1 August 1955. These records were initially maintained in terms of locations surveyed rather than in terms of tons processed. Records of tons processed are available only from November 1955.

2. There is on hand approximately 76,600 tons of stored material in 147,000 locations. During the period 1 November to 30 March, a total of 2,930 tons was surveyed, or 3.8% of the total tons on hand, however, in this same period, 23,589 locations were surveyed or 15.7% of existing locations. This condition existed because of the heavy emphasis placed on the surveillance of loose issue items rather than bulk stock items, consequently the location/tons ratio appears abnormally high.

3. Since basic letter requests information to be furnished in terms of tons processed, the conversion from locations surveyed to tons processed, based on records available, is as follows:

a. Total tons processed through surveillance program period 1 August 1955 to 30 March 1956, 4,700 tons.

b. All locations containing sufficient quantities to warrant sampling, were inspected by sampling procedures. Approximately 85% of all items surveyed were sample inspected.

c. 22% required packing, labeling, and/or repackaging. 2.1% required minor repair or salvage disposal action. 11% required segregation of mixed stock or reidentification.

d. The entire quantity of 2.1% requiring minor repair or salvage disposal action was caused directly by deterioration due to length of storage.

FOR THE COMMANDER:

F. J. COFFEY
Lt. Colonel, Signal Corps
Deputy Commander

SIGTD-13 (400.163) (25 May 56) 1st Ind.
SUBJECT: Effects of Storage on Reliability of Electronic Equipment

Headquarters, Tobyhanna Signal Depot, Tobyhanna, Pennsylvania

TO: Chief, Procurement and Distribution Division, Signal Corps, Main Navy Building, Washington 25, D.C.
ATTN: SIGPD-6A

1. In reply to your request, the following information is submitted concerning the surveillance program for the period July 1954 to March 1956, inclusive:

a. Total Tons processed - 23,235.

b. Material sample tested - 1930.1 tons.

c. 5% of the sample material or approximately 96.5 tons rejected.

d. 50% of the rejected material or approximately 48 tons was defective as a result of storage.

2. The tonnage figure is based on information contained in Cost and Analysis Report. Reports Control Symbol SIGGS-537. The quantity sample tested and percentage figures were derived by combining information from sampling records, P&D Form 835 and experience.

ROBERT G. ANGSTER
Colonel, Signal Corps
Commanding

SIGDD-10 (25 May 56) 1st Ind
SUBJECT: Effects of Storage on Reliability of Electronic Equipment

Decatur Signal Depot, Decatur, Illinois, 12 June 1956

TO: Chief, Procurement and Distribution Division, Signal Corps, Main Navy Building, Washington 25, D.C., ATTN: SIGPD-6A

In compliance with paragraph 4, letter from Chief, Distribution Branch, Subject: "Effects of Storage on Reliability of Electronic Equipment", dated 25 May 1956, the following information is submitted:

	FY-1955	FY-1956(0 Mo)
a. Total tons processed through surveillance program.	1298.2	2529.6
b. Estimated quantity sample tested (Tons).	103.9	121.2
c. % of b. rejected approx.	5% approx.	5%
d. % of c. caused by or as a result of storage	less than 1%	less than 1/2%

FOR THE COMMANDER:

NICHOLAS S. MUNSON
Major, Signal Corps
Executive Officer

SIGDL-80 (25 May 56) 1st Ind 7 June 56

SUBJECT: Effects of Storage on Reliability of Electonic Equipment

Lexington Signal Depot, Lexington, Kentucky

TO: Chief Signal Officer, Procurement & Distribution Division, Department of the Army, Main Navy Building, Washington 25, D.C., ATTN: SIGPD-6A

1. Reference is made to basic communication.

2. This depot is currently engaged in processing work loads of such volume and priority as to preclude the assignment of present personnel to the planned Maintenance-in-Storage Surveillance Program. Category "E" and "F" dues out, MDAP and Modification Work Order Projects are being given top Priority handling. Screening of stock in connection with the MWO Program is the only planned Surveillance-in-Storage being accomplished at present.

3. In connection with this program, approximately six hundred and eleven (611) tons of electronic and associated equipments have been modified and tested since March 1955. The equipments involved included such items as:

AM-65/GRC	4,282 each
RT-66/GRC	3,554 each
[illegible]	[illegible] each
RT-68/GRC	1,617 each
PP-109/GRC -	271 each
PP-112/GRC -	531 each
PP-282/GRC -	5,588 each
AN/GRA-6 -	270 each
C-375/VRC -	13,056 each
R-109/GRC -	234 each
AN/TPS-1D -	99 each
AN/VIA-1 -	2,670 each

The bulk of these equipments was initially received at this depot during 1951-1952 from vendors and has been retained in permanent warehouse storage stocks.

4. The modification and test results of these equipments have revealed an occasional tube breakage, sticky relay or loose solder joint which are attributed to the in-manufacturing process.

5. The Mountings MC-297, 298, 299, 300, and MT-327/GR have been found in discrepancy in that the inner insulation of the individual conductors has become brittle and flaky, causing electrical shorts. This condition, however, has been recognized as a latent manufacturer's defect rather than a cause of storage.

6. Certain other categories of stocks such as dry batteries, electrolytic capacitors, and selenium rectifiers have been observed with respect to their established shelf life at the time of shipment. Other than requiring test and/or reforming by virtue of their shelf life dates having expired, no storage deficiencies have been noted

7. It is recognized that the equipments reported herein cover only a portion of our stocks; however, it is believed that the over-all condition of other stocks is reflected, and since no deterioration or ill effects as a result of storage is apparent on these equipments it is believed that the above may be construed as a representative sample of equipments in stock at this depot.

8. This depot has budgeted for monies to perform the surveillance of one-third of its stocks during FY-57. Little additional costs would be involved in maintaining records as requested during the accomplishment of this program.

FOR THE COMMANDER:

JOHN P. JOHNSON
Lt. Colonel, SIGC
Deputy Commanding Officer

APPENDIX B

5.2 NAVY - BUREAU OF ORDNANCE SUPPORTING INFORMATION

CYCLIC INSPECTION OF FIRE CONTROL INSTRUMENTS

I. **INTRODUCTION**

A. This report covers both Class "J" and "Z" controlled instruments, stored in Building No. 50, Bellevue Annex. The quantities and categories of Fire Control instruments and material are listed in their respective chapters, as per instructions in O. P. 1105.

B. Building No. 50 is a type one (1) storage, with controlled relative humidity of approximately thirty per cent (30%) and temperature of [illegible]. Instruments are stowed on wooden pallets and on special designed brackets in metal racks. The purpose of this method of stowage is to provide convenient and rapid means of periodic manual exercising of mechanical components of instruments, without the necessity of removing the instruments from the pallets or the metal racks. In this type of storage, all desiccants are removed from the interior of instruments and equipments to allow for energizing the electrical components and manually exercising the mechanical parts without causing damage to the mechanism of the instruments, while conducting the cyclic inspection.

C. At present there are 3545 instruments stored in Building No. 50, initially preserved per O. P. 1105, for type one (1) storage, and carried as: "Ready for Issue." Semi-annual cyclic inspection is of major importance in order to maintain these instruments in a "Ready for Issue" status.

II. **PROCEDURES**

A. Instruments having mechanical components are manually exercised monthly in order to prevent them from becoming stiff, which could cause damage to delicate mechanisms.

B. In the course of conducting cyclic inspection of fire control instruments, special attention is given to the proper function of both electrical and mechanical components. Tests are performed by experienced personnel, using numerous electrical testing devices, including: Dummy Directors, Transmitting and Indicating Units, Meggers, Ohm, Volt and Ammeters, which are used to detect malfunctioning of electrical components of the instrument, and also for "trouble shooting."

C. Minor repairs and adjustments are made during this inspection, as conditions warrant. All covers are removed from 5% of the instruments to permit a thorough and complete inspection of gaskets to detect any indication of deterioration or damage. All openings, such as terminal tubes, are sealed with "Ca-Plugs" (G45-S-392-1250 thru 1380). At this time a complete inspection is made to determine the condition of the preservatives, taking into consideration the physical characteristics of individual instruments and the various types of preservatives required for proper preservation.

D. Where instruments have been initially preserved as per O. P. 1105, for Type 1 Storage, for a period of three (3) years or longer, particular attention is given to the condition of the preservatives relative to oxidation and drying out of lubricants. This inspection also includes the use of Glo-Lamp (Model #94, Switzer Bros., Inc., Cleveland 3, Ohio) to determine the condition of moisture and fungus treatment of wiring and electrical elements. In the event there is any indication of corrosion or fungus forming on the component parts, this condition is corrected by the removal of the corrosion or fungus by proper cleaning methods and the application of fresh preservatives.

E. Upon inspecting material received from other naval activities in a "Ready for Issue" status, the inspection has shown some to be unfit for issue to service, due to poor application of preser..tives, or in some cases no preservation, cracked or discolored windows, defective gaskets, missing parts and incorrect wiring. On a number of occasions, instruments were received with considerable shop dirt and other foreign matter in them such as metal shavings, loose screws, nuts, etc., lying in the bottom of the instrument case, the presence of which could cause damage to delicate mechanisms. The above are only a few of the defects noted on inspection of fire control instruments received at this activity. In 1952, a quantity of Indicators, Gun Elevation Mk 23, and Gun Train Mk 25, were received in a boxed condition, having been in long term storage since 1945. These instruments were found to be mechanically inoperative, due to frozen shafts and gearing, caused by hardening of the service lubricant first applied by the manufacturer. All of these instruments required overhaul prior to issue. If these instruments had been mechanically and electrically exercised at regular periods, this condition could have been prevented. Where possible, personnel of the Technical Division, Supply Department, have corrected such conditions on a large quantity of fire control instruments received from other activities in order to place them in a "Ready for Issue" status.

F. In 1952, twenty-five (25) Gun Directors Mk 51-3 (Ready for Issue) were received from another activity. An inspection revealed that some had considerable fungi on wiring and terminal strips, located in the pedestal stand. Several had badly rusted center columns. All required initial preservation and overhaul prior to issue. This condition was caused by failure to seal off the [illegible] tube opening at the base of the director pedestal. Some items a.. [illegible] ived with incorrect preservation data on inspection tags, as to Chapter, Plan or Method, as per O.P. 1105 instructions.

G. When fire control instruments are first received in Building No. 50, the instruments are opened and a thorough and complete inspection is made to determine their serviceability and condition. This includes a check for indications of contamination, fungus or corrosion, and the condition of preservatives. Mechanical and electrical components are tested to determine that they are functioning properly and for determining any defects noted in the general condition of the instrument. A complete instrument condition record card (Fire Control Instrument Inspection, PRNC-NGF-1178) is maintained for the purpose of conducting an adequate cyclic inspection program.

III. INSPECTIONS (on instruments initially preserved in accordance with O. P. 1105).

A. <u>O. P. 1105, Chapter 6, Type 1 Storage</u>

Quantity: 723 - initially preserved in accordance with above chapter.

<u>Instruments</u>

Ind. Regulator, Gun Elev.	Receiver Regulator, Cross-Level
" " Gun Train	" " Elevation
" " Fuze Setting	" " Fuze Setting
" " Gyro Setting	" " Gun Elevation
Power Drive, Elevation	" " Gun Train
Power Drive, Train	" " Train
Reducer Error	" " Director Train
Sight Slewing	

Frequency of cyclic inspection: Semi-annual. Quantity cyclic inspected - 5%; quantity energized and operated - 100%.

Instruments that are opened for inspection are observed closely for deterioration on critical parts such as gears, shafts, bearings and other highly finished surfaces. Electrical components are inspected for fungus and contamination. Preservatives are inspected for oxidation, dying-out and pH factors, particularly where nonferrous metals bear on ferrous metals. These instruments are divided into two classes: (1) electric hydraulic and (2) electrical mechanical. Hydraulic preservatives are checked for acid content. Any discrepancy noted during the inspection is corrected immediately by the inspecting personnel, if within their capacity.

B. O.P. 1105, Chapter 10, Type 1 Storage

Quantity: 51 - initially preserved in accordance with above chapter.

Instruments

Compensator	Motor Amplidyne
Controller	Motor Generator Amplifier
Control Panel	Relay Cabinet
Firing Panel	Motor Control Unit
Motor Alternator	Amplifier

Frequency of cyclic inspection: Annual. Quantity cyclic inspected and electrically energized - 100%.

The physical characteristics of the above material requires that all covers be removed prior to conducting an electrical test for determining serviceability. At this time a thorough inspection is made for detecting any indication of corrosion, fungus or other contamination. In the event any of these conditions exist, and it is within the capacity of the inspecting personnel, the condition is corrected by proper cleaning and the application of preservatives.

C. O.P. 1105, Chapter 53, Type 1 Storage

Quantity: 35 initially preserved in accordance with above chapter.

Instruments

Computer Mk 6 & Mods	Searchlight, Trunnion Tilt Corrector

Frequency of cyclic inspection: Semi-annual. Quantity cyclic inspected - 5%; quantity manually operated - 100%.

Since the Computer Mk 6 is a mechanical type of instrument, without electrical components, it is mechanically exercised monthly, due to the fact that the instrument contains a mechanical clock mechanism, which requires rewinding and running to prevent the spring from becoming set. All input knobs are exercised to prevent hardening and setting of preservatives and lubricants. Instruments are inspected for corrosion on critical parts such as gears, shafts, bearings, and other highly finished surfaces. Particular attention is given to oxidation and preservative pH factor.

D. O.P. 1105, Chapter 54, Type 1 Storage

Quantity 26 - initially preserved in accordance with above chapter.

Instruments

Element, Stabl: Vertical, Stable Unit, Stabilizing

Frequency of cyclic inspection: semi-annual. Quantity cyclic inspected - 5%; quantity manually exercised and energized - 100%.

These instruments are manually exercised to insure a complete function of mechanical components, thus preventing stiffness in operation. Electrical components, energized and exercised, consist of synchros, gimbal rotation motors, etc. There are no facilities available in Building No. 30 for energizing and running of gyros. A thorough inspection is made at this time to ascertain the condition of preservatives, particularly relative to "souring" of lubricants, where applied to non-ferrous and ferrous metals, bearing on each other, such as gears, worms, etc. Close attention is given to indications of corrosion or formation of fungus on electrical components, or any other type of contamination. If there are any indications of the existence of these conditions, and it is within the capacity of the inspecting personnel, they are corrected.

E. O.P. 1105, Chapter 55, Type 1 Storage

Quantity: 2656 - initially preserved in accordance with above chapter.

Instruments

Indicator, Battle Order
" Bearing
" Bearing & Range
" Director Elevation
" Director Train
" Elevation
" Fuze Setting
" Gun Elevation
" Gun Train
" Multiple Turret Train
" Range
" Repeater Target Angle
" Searchlight Elevation
" Searchlight Train
" Sight Setter
" Target Course
" Torpedo Course
" Train
" Turret Train Transmitter
Receiver, Change of Range
" Range
" Searchlight Order Relay
" Sight Angle
" Slight Deflection
" Spot
" Target Bearing

Transmitter, Battle Order
" Gun Elevation Order
" Gun Train Order Relay
" Range
" Range Spot
" Searchlight Control
" Searchlight Elevation
" Searchlight Train
" Sight Angle & Deflection
" Star Shell Spot
" Target Designation
" Target Designation Rec.
" Train
" Train Designation & Relay
" Wind
Selector Drive
Correctors
Designator, Train

Frequency of cyclic inspection: Semi-annual. Quantity cyclic inspected - 5%; quantity energized and operated - 100%.

Instruments, listed under this chapter, are divided into two classes: (1) Electric Mechanical and (2) Electrical. Approximately 75% are in the Electric Mechanical Class. All electrical components are energized and mechanical parts exercised to ascertain that all electrical and mechanical components function properly. A thorough inspection is made to detect indications of cloudy and defective windows, defective gaskets, or any other discrepancies that may have occurred between periods of cyclic inspections.

The instruments opened are inspected to determine condition of preservatives relative to indications of oxidation and acidity effecting lubricants. In the event of corrosion or fungus on mechanical or electrical elements of these instruments, they are cleaned and re-preserved according to current directives.

F. O.P. 1105, Chapter 56, Type 1 Storage

Quantity: 54 - initially preserved in accordance with above chapter.

Instruments

Director, Gun Mk. 51 & Mods.
Director, Gun Mk. 57 & Mods.
Director, Torpedo Mk. 27 & Mods.

Frequency of cyclic inspection: Semi-annual. Quantity cyclic inspected - 5%; quantity energized and operated - 100%.

Torpedo Directors, having a complex electro-mechanical computing and follow up mechanism, require skilled and experienced personnel to operate and to detect faulty operation in the electrical and mechanical components. Particular attention is given to the condition of preservatives and to "hardening" and drying-out of lubricants, which could cause malfunction of the highly critical mechanisms. If corrosion or contamination is detected on critical metal surfaces, it is removed by using proper cleaning materials and the application of a light coat of preservative. Electrical transmitting units of Gun Directors are energized and tested. All mechanical components are manually exercised. Mechanical and electrical components are thoroughly inspected for corrosion, fungus, or contamination. In the event any "breaking down" of preservatives is detected, this condition is corrected by inspection personnel.

IV. SUMMARY

A. Cyclic inspection, as described herein, is accomplished by one Packaging and Preservation Inspector of the Technical Division, Supply Department and two electricians.

B. The nature of the inspector's duties not only require a thorough knowledge of various types of preservatives, applicable to fire control instruments, but also the correct methods of conducting a physical inspection for determining the condition of instruments relative to indications of corrosion, fungus, or other types of contamination.

C. Since there is a large quantity of various types of fire control instruments stored at this activity, a detailed knowledge of the purpose and functions of mechanical and electrical components of these instruments is essential, also a comprehensive knowledge of interpreting, electrical and mechanical diagrams and prints, in order that the proper testing equipment may be utilized, and the results of these tests, as indicated by instrument readings, be readily understood. Any incorrect readings or operational failures are corrected by making the necessary adjustments and repairs, if within the capacity of the inspector

D. All fire control equipment stored in Building No. 50 is given a physical inspection at the time of receipt to determine its condition and serviceability. In addition, at the time of issue to service, each fire control instrument is again inspected to determine if it is still in a "Ready for Issue" status.

E The past five (5) years of performing cyclic inspections have revealed that preservatives used in fire control instruments hold up very well in Type 1 Storage. Preservative failure is negligible, due to the cyclic inspection and maintenance programs, conducted at this activity, where five per cent (5%) of instruments are opened for inspection and re-preserved as conditions of the instruments warrant. Particular attention is given to selecting the five per cent from quantities that have been initially preserved for the longest period of time, but not previously inspected. Approximately twenty-five per cent (25%) of the instruments opened for inspection were preserved prior to 1950. This inspection program has been an implementing factor in eliminating the necessity for sending the instruments to the shops for re-preservation, thereby resulting in saving of considerable funds. A majority of mechanical and electrical defects are corrected at the time of inspection, thus reducing the necessity for shop overhaul or repair.

F. Inspections of material received from other naval activities, where instruments were apparently in long term storage, revealed considerable defects, due to inadequate preservation and contaminated condition of instruments. Defects to various components and faulty operations were detected upon testing the equipment for serviceability.

G. In order to facilitate the electrical energizing and exercising of fire control instruments, special electrical connection adaptors were designed and constructed by one of the Technical Division, Supply Department, personnel and an electrician. By means of these adaptors fire control instruments are electrically connected for operation in a fraction of the time required under the conventional method of connecting individually each electrical lead. Since there are large quantities of fire control instruments to be electrically energized, a considerable saving in man-hours is accomplished.

H. From past experience, obtained during five years of performing cyclic inspection of fire control instruments at this activity, it is recommended that fire control instruments be stored in Type 1 Storage, and that an adequate cyclic inspection and regular maintenance programs be initiated using as a guide instructions contained in O. P. 3487.

APPENDIX C

5.3 NAVY - BUREAU OF SHIPS SUPPORTING INFORMATION

Included in this appendix are the following items:

I. Notes on Bureau of Ships Electronic Equipment Failure Tabulation

II. Sample Failure Tabulation

III. Failure Report Form DD-787

IV. Supplementary Codes for Type of Failure

I. Notes on Bureau of Ships
Electronic Equipment Failure Tabulation

Equipment Contractor by Equipment Model by Part Reference Designation

1. This listing is arranged in ascending alpha-numeric sequence by equipment model. Within each equipment model category, the data is arranged in ascending alpha-numeric sequence by Part Reference Designation.

2. Each line of data represents one DD-787 Electronic Failure Report.

3. The data for each column comes from the boxes in DD-787 as noted on the specimen sheet.

4. The Total Failure column contains a total by Part Reference Designation, a total by Equipment Model, and a total for all equipment models. The latter total is followed by a "plus" sign.

5. The complete list of codes used for "Type of Failure" (DD-787, Box No. 30) is attached hereto.

II. (SAMPLE)

Electronic Equipment Failure Tabulation

19 Sept. 1955 — Equipment Contractor by Equipment Model by Part Reference Designation — Page 0726

Equip Instal. in.	Equip. Model	Equip. Cont. Code	Equip. Serial No.	Part Ref. Design.	Tube Type	Stand. Navy Stock No.	Mfr. Code	Type of Fail.	C A U	S Y M	P R M	P T L	Hrs. in Serv.	Time Meter Log	Date of Failure Mo Day Yr	Total Failures
	AN-[illegible]-1	CW	11642	V- 103	6AK5	16T 56191	CRC	4	1	3		Y	500		6-21-55	1
	AN-ARC-1	CW	26228	V- 104	832A	16T 68321		750	1						9-24-54	
DLR 317	AN-ARC-1	CW	2434	V-104	832A	16T 68321		6	1	1	Y				4-21-55	
	AN-ARC-1	CW	54	V- 104	832	16T 68320	CMU	4	1		Y				[illegible]	
	AN-ARC-1	CW	24319	V-.104	832A	16T 68321	CRC	99	1	3	Y				2-14-55	
DL 531	AN-ARC-1	CW	4888	V- 104	832A	16T 68321		4	1	1	N		3500U		2-26-55	
	AN-ARC-1	CW	23687	104	832A	16T 68321		750	1						9-27-54	
	AN-ARC-1	CW	34695	V- 104	832A	16T 68321	CRC	4	1	3	Y				12-20-54	
DD 538	AN-ARC-1	CW	10717	V- 104	832A	16T 68321	CRC	4	1	1	N				3-1-55	
CVA 33	AN-ARC-1	CW	327	V- 104	832A	16T 68321	JKR	4	1	3	N				4-10-55	
CA 123	AN-ARC-1	CW	49013	V- 104	832A	16T 68321	CMU	6	1	1	N				3-28-55	
5	9	11	10	23	21	22	26	30	31	29	32	28	25	6	←— 6 —→	10

111. Failure Report Form (DD-787 17 Aug 54)

REPORT THE FAILURE OF ONLY ONE PART OR TUBE ON THIS FORM

1. Report No.	2. Reporting Activity	3. Repaired or Reported by (Name)	4. Date of Failure
5. Equipment Installed in (Type & No.)	6. Time Meter Reading or Installation Log Time	7. Was Mission Aborted ☐ Yes ☐ No	8. Operational Condition

EQUIPMENT	9. Assy. Designation and Mod No.	10. Serial No.	11. Contractor	12. Contract or Order No.
COMPONENT MAJOR UNIT	13. Model Designation and Mod No.	14. Serial No.	15. Contractor	16. Contract or Order No.
ASSEMBLY OR SUBASSEMBLY	17. Assembly and Mod No.	18. Serial No.	19. Contractor	20. Contract or Order No.

PART DATA	21. Part Name or Tube Type	22. Stock No. (Failed Item)	23. Part Ref. Design. (V-101, R-101 etc.)	24. Repairtime (Man Hrs.)
	25. Hours in Service	26. Manufacturer of Failed Part	27. Serial No.	28. Was Replacement Part Available Locally? ☐ Yes ☐ No

29. First Indication of Trouble

1 ☐ Inoperative
2 ☐ Intermittent
3 ☐ Low Performance
4 ☐ Noisy
5 ☐ Off Frequency
6 ☐ Out of adjustment
7 ☐ Overheating
8 ☐ Unstable
9 ☐ Other

30. Check type(s) of Tube or Part Failure

007 ☐	Arcing	001 ☐	Gassy	790 ☐	Out of Adjust.
710 ☐	Bearing Failure	300 ☐	Grounded	006 ☐	Shorted
780 ☐	Bent	380 ☐	Leakage	770 ☐	Slip Ring or Commutator Failure
040 ☐	Binding	730 ☐	Loose	018 ☐	Tested OK did not work
070 ☐	Broken	004 ☐	Low GM or Emission	020 ☐	Worn Excessively
720 ☐	Brush Failure	750 ☐	Missing	☐	See Inside Flap for additional codes
090 ☐	Burned Out	008 ☐	Noisy		
130 ☐	Changed Value	450 ☐	Open		
170 ☐	Corroded	099 ☐	Other		

31. Cause of Failure

2 ☐ Faulty Packaging
5 ☐ Mishandling
6 ☐ Inspection or Test
1 ☐ Normal Operation
3 ☐ Storage
7 ☐ Associated Failure explained
4 ☐ Other

32. Was the Part replaced During Preventive Maint.. Yes No

33. REMARKS (Continue on reverse side if necessary)

Electronic Failure Report A15907

IV. Supplementary Codes for Type of Failure

001 - Gassy
002 - Airlead
003 - Open filament
004 - Low emission
005 - Shorted, intermittent
006 - Shorted, permanent
007 - Arcing
008 - Noisy
009 - Microphonic
010 - Poor focus
011 - Screen defects
012 - Loose elements
013 - Loose base
014 - Broken base
015 - Broken glass
016 - Glass strain
017 - Result of other component failure
018 - Tested OK, did not work
020 - Worn excessively
021 - Overloaded
022 - No oscillation
031 - Alignment, improper
040 - Mechanical binding
050 - Blistered
060 - Brittle
070 - Broken
080 - Burned out
090 - Brushes, improper tension
099 - Other
100 - Brushes, hard
110 - Brushes, soft
120 - Chafed
130 - Change of value
140 - Charred
150 - Chattering
160 - Contacts, connection defective
170 - Corroded
180 - Clogged
190 - Cracked
200 - Dented
210 - Detent action - poor
220 - Defective spring, toggle, arm, gear mesh, bearing
225 - Manufacturer's defects
230 - Dirty
235 - Dry
240 - Flaking
250 - Frayed
260 - Friction - excessive
270 - Frozen
280 - Fungus effect
290 - Grooved
300 - Grounded
310 - Handling, improper
320 - High voltage breakdown
330 - Excessive hum
340 - Installed improperly
350 - Insulation breakdown
360 - Intermittent breakdown
370 - Jammed
380 - Leakage
400 - Loss of residual magnetism
410 - Lack of lubrication
420 - Moisture - saturation
430 - Oil - saturation
440 - Old age
450 - Open
460 - Open primary
470 - Open secondary
480 - Overheated
500 - Over - lubrication
520 - Pitted
530 - Polarity reversed
540 - Punctured
560 - Poor regulation
570 - Rusty
580 - Shock
600 - Shorted to case
610 - Shorted to frame
615 - Shorted to ground
620 - Shorted primary
630 - Shorted secondary
640 - Slippage
645 - Spurious
650 - Sticky
660 - Stripped
670 - Unbalanced
680 - Unstable
690 - Vibration - excessive
700 - Weak - electrically
710 - Bearing failure
720 - Brush failure
730 - Loose
750 - Missing
770 - Slip ring or commutator failure
780 - Bent
790 - Out of adjustment

APPENDIX D

5.4 AIR FORCE SUPPORTING INFORMATION

A copy of the source data document, AMC 630-08, is on file in the office of the Assistant Secretary of Defense (Engineering), Pentagon, Washington, D.C.

Due to its bulk (166 pages) and to the fact that this report would become classified if the above document were included, it is not published in this Appendix.

APPENDIX E

5.5 WESTERN ELECTRIC COMPANY FIELD ENGINEERING SUPPORTING INFORMATION

A copy of an EAM abstract from the "Detailed Report of Air Force Equipment Failures" published by Western Electric Company, Inc., Field Engineering Force, Winston-Salem, North Carolina is on file in the office of the Task Group-8 chairman at Sandia Corporation.

Its inclusion here would have required this report to be classified.

APPENDIX F

5.6 SANDIA CORPORATION SUPPORTING INFORMATION

The source data that were analyzed and reported in Section 2.2.7 of this report are on file in the Quality Assurance Department of Sandia Corporation. They consist of:

1. Basic records of Armed Forces inspections in EAM card form and defect record ledgers.

2. EAM Tab runs and calculations from an EAM electronic calculator.

3. Copies of statistical computations for estimating reliability in terms of failure rates due to storage.

The above data and calculations are so extensive in content (over 1000 pages of Tab runs in addition to thousands of EAM cards and defect reports) that they are not included in this appendix. Furthermore, when assembled together these data become classified restricted data.

APPENDIX G

5.7 CRITICAL COMMENTS ON PRELIMINARY REPORT OF TASK GROUP-8

Following are excerpts from a memorandum written to H. P. Kelsey by Harold F. Dodge, Quality Results Engineer, Bell Telephone Laboratories, 463 West Street, New York 14, N. Y., dated September 27, 1956.

"This acknowledges your letter of September 5th and attached preliminary report prepared by your Task Group-8 of AGREE. You ask for critical comments. The following paragraphs give a few general observations:

1. Some of the difficulties associated with your Recommendations 4.1 to 4.7, inclusive, are

(a) Probable inability of most military units to supply all the data desired,

(b) Selectiveness of data, loss of data,

(c) Absence of auxiliary data and information not called for on the form but which may be of primary importance,

(d) Probable inadequacy of military personnel relative to the need for engineering skill in conducting tests and examinations.

2. It is extremely difficult to acquire 'good data' from multiple sources, especially if those sources are of a non-engineering character. The kind of information wanted here with respect to reliability probably requires engineering investigations, as distinct from investigations by service groups.

3. If it can be shown that the per cent of failures due to storage is relatively small, then storage cannot be considered a serious problem compared to other factors and extensive study would not be warranted.

4. While the over-all per cent of failures due to storage might be small, a modest engineering investigation <u>might</u> also discover a few primary facts about such failures that would be worth knowing.

5. If an engineering investigation or survey is to be made, there is probably need for a meeting of top brass in different fields to get agreement to conducting such a survey.

These are informal comments, and I trust that they may be helpful in some degree."

APPENDIX 8

5.8 NOTES ON SHORT SHELF-LIFE ITEMS

Short shelf-life is a serious problem in connection with dry batteries, selenium rectifiers and electrolytic capacitors. In addition, the following parts present less serious problems

a. Face - Shear Lead-Attached Crystals:

These comprise approximately 5 per cent of the quartz crystals in use. Severe aging in as little as one year may be expected among those produced by certain manufacturers; those produced by other manufacturers also age, but more slowly. Other types of quartz crystals present no appreciable aging problem.

b. Transistors:

There is no serious problem in connection with transistors except for the products of certain manufacturers. This is apparently due to the methods of manufacture and of handling employed.

c. Crystal Diodes:

The comments on transistors apply to crystal diodes, but to a lesser extent.

d. There is also a long range problem in connection with changing values of carbon resistors and Hi-K capacitors, however, this problem does not become serious until these items have been in storage for five years or more.

(Other than refrigerated storage for dry batteries, short shelf-life items receive no special storage. An increase in temperature, however, increases the rate of deterioration of the above items.)

APPENDIX I

5.9 PROPOSED PROGRAMS FOR OBTAINING DATA ON THE RELIABILITY OF ELECTRONIC EQUIPMENT

I Short-Range Program

All depots and similar organizations should be required to start keeping a record immediately of all equipments tested on recertification and other testing and inspection programs. This record should include:

Nomenclature or type number of equipment.
Number tested.
Number accepted.
Number failing to pass tests before repair and type of failure on each (e. g., shorted capacitor, open audio transformer, open R-F coil, etc.).
Serial number of each equipment that fails.
Each equipment tested and returned to stock, regardless of whether as a result of recertification or of repair, be stamped. Tested and Passed (REP, TM, etc.).
Test requirements (date).

This record would not be conclusive, as it would not be definitely known whether the equipment had previously passed the same tests, but future tests could be correlated with the initial tests.

II. Long-Range Program

This program should be the same as the short-range program, except that at the end of three or five years, the stamp on the equipment would insure that any defect found occurred during that period, and the data gathered would become of increasing value for analyses of the causes and frequency of failures, after re-testing results were recorded.

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METHODS AND PROCEDURES TO

ASSURE RELIABLE EQUIPMENT PERFORMANCE

PREPARED BY

TASK GROUP-9

JANUARY 8, 1957

FOREWORD

Over the past decade, military electronics systems have become increasingly complex. Since high performance in the field remains essential, the maintenance of this equipment has become a serious problem.

While considerable attention is being devoted to design for inherent reliability, it is also necessary to devise a maintenance program which will insure the full benefits of a system's inherent reliability are realized in the field. In order to achieve this goal, it is necessary to explore all possible methods of improving the maintenance programs employed.

Over the past year, Task Group 9 has devoted its efforts to study of the maintenance problem through investigations, discussions, and by inviting experts in the field to group meetings for presentations. To summarize this effort, this report has been prepared which contains recommendations to the Department of Defense on many aspects of the maintenance problem supported by details and references in all phases of our work. Our recommendations of necessity had to be broad in concept since the maintenance problem differs for each military department and for each electronic system. Consequently, it was not possible to make recommendations such as specific training courses or maintenance procedures for specific systems.

The material contained in this report is an integration of many preliminary reports and attempts have been made to eliminate excessive detail. However, details of all preliminary reports can be found in minutes of the group's meetings.

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TASK GROUP 9

MEMBERS

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L. Vidlak	Air Materiel Command

PROGRAM FOR AGREE

DEPARTMENT OF DEFENSE DIRECTIVE 5129.8

The Advisory Group will monitor, stimulate interest in, and advise on reliability matters within its field of interest. The field of interest of the Advisory Group on Reliability of Electronic Equipment will include reliability matters in electronic equipment design, development, procurement, production, maintenance, installation, operation, and training.

Recommendations and comments of the Advisory Group will be submitted for consideration and initiation of appropriate action to the Director, Office of Electronics and Guided Missiles, Office of the Assistant Secretary of Defense (Engineering).

Task Group #1. Develop minimum acceptability figures for reliability of the various types of military electronic equipment. These figures possibly may be expressed as "time between failures" or some other t. .ily quantitative measurement. The basis upon which the figures are determined shall include the factors of operational mission requirements, maintenance, complexity, and such other factors as may be significant.

Task Group #2. Develop basic requirements for tests to be accomplished on development models which will prove that the design is capable of meeting the minimum acceptability figure for reliability established for the equipment type. These tests shall be designed to be performed either in addition to, or in conjunction with whatever performance evaluations are specified for the equipment.

Task Group #3. Develop basic requirements for tests to be accomplished on pilot-production and on production models which will prove conclusively that the equipment will meet the minimum acceptability figure for reliability established for the equipment type. These tests shall be designed to be performed either in addition to or in conjunction with whatever performance evaluations and operational suitability evaluations are specified for the equipment.

Task Group #4. Investigate and recommend methods of specifying development procedures to insure that equipment designs will have the inherent reliability required. Some factors which might be involved are: (1) theoretical reliability prediction, (2) thorough component selection, qualification, and application for specific circuit and environment requirements, (3) adequate signal levels and feedback, and (4) minimizing the effects of mechanical shock, vibration and temperature on critical components.

Task Group #5. Establish criteria and methods for specifying the reliability of component parts and tubes in terms of failure rate as a function of time and environment. This is considered essential to a determination of the amount of improvement demanded in various components to meet the over-all reliability requirements of the various types of electronic equipments.

Task Group #6. Study present procurement and contracting practices and regulations to determine their compatibility with reliability objectives. Make recommendations for specific changes as found necessary during the study. Some of the factors involved might be: (1) assessing the implementation of DOD Directive No. 4105.10, "Amplification of Policy Governing Award of Initial Production Contracts for Technical or Specialized Military Supplies", dated March 17. 1955, (2) methods of selection of contractors for development and production and the possibilities of including evaluation of the potential contractors' ability to produce reliable designs, and (3) evaluation of combined R&D production contracts, (4) in considering award to lowest bidder - the over-all cost including operation and maintenance might be considered (might be determined on basis of predicted reliability).

Task Group #7. Investigate present practices of packaging for shipment and transportation methods and recommend specific improvements which will enhance reliability.

Task Group #8. Investigate the effects of storage of electronic equipment upon reliability and recommend improvements where desirable.

Task Group #9. Review present methods and procedures to assure that the reliability of equipment in service is kept up to the inherent design level. Factors which might be included are: (1) maintenance based on performance measurement rather than to meet rigid time schedules, (2) marginal testing, and (3) personnel training.

1. SUMMARY

The purpose of maintenance is to sustain designed performance and continued operation of equipment and systems in order to attain the best degree of operational and material readiness.

Maintenance of electronic equipment is dependent upon such factors as equipment maintainability, personnel training, standards and procedures for checking equipment performance, preventive maintenance procedures and quality of support material such as technical manuals, test equipment, and test facilities.

Study of the over-all maintenance picture verifies that major engineering effort must be devoted to improvement of inherent equipment reliability. However, the designer must thoroughly consider the maintenance of his equipment; he must also minimize the requirement for highly trained personnel in the field and reduce complex maintenance procedures if high performance is to be attained.

To assist the designer in this area, it is important that a rigorous operational definition of maintainability be formulated. Once defined, a maintainability requirement should be included in the specifications for each new system. When the system is undergoing its evaluation tests prior to quantity production, its maintainability should be demonstrated by rigorous testing. The personnel performing maintenance during such a test should be service technicians of average skill level adequately trained on the system under test. Such a procedure will assure that the required system maintainability can be realized under more closely simulated field conditions.

It has been noted that design trends apparent in electronic equipment such as modular construction, printed circuitry, encapsulation and miniaturization, point toward a disposal-at-failure maintenance philosophy. Such a philosophy, if economically justifiable, would result in a reduction of high-skill training requirements since a lesser technical competence could achieve quality corrective maintenance in the field. Mean net time to repair failures would be decreased and the possibility of retaining a given reliability level through the life of a system would be improved.

In recent years a continued advance of technological standards has taken place, and in the future greater numbers of scientists, engineers and technicians will be required to support and further this advancement. The military departments must also face an ever-increasing need for skilled manpower as a result of the increasing complexity of weapons systems brought into operational use. If this need is to be satisfied, interest in the sciences must be stimulated in students at the earliest possible age.

To alleviate the problem of the present shortage of skilled technicians in the services before it reaches damaging proportions, steps must be taken to enhance the military career and reduce dependence on civilian contract personnel in vital assignments. If men could be persuaded to remain in the service for longer periods, the

resultant dollar savings in training could be expended in improving pay scales, housing facilities, fringe benefits and so on. The existing high turn-over rate of trained men represents a very large annual dollar wastage.

The present extensive training of technicians is resulting in very inefficient utilization of manpower. To improve this situation, the limit of one-third of the total remaining enlistment could be adopted as a desirable maximum time for training. Basic training for technicians should be limited to elementary electronic concepts with minimal mathematical content followed by the application of fundamentals to specific systems emphasizing fault analysis, repair methods, and practical use of test equipment. Naturally, such training programs must depend upon the basic policies and procedures demanded by the equipment involved. Advanced or college training should be reserved for those men with longer service commitments.

To organize a successful training program, it is essential that production equipment be available for training at the earliest possible time. In addition, information on fundamental changes in a system not included in original training courses must be made available through technical publications or field training courses.

Every effort must be made to maintain a high degree of interest in trainees and technicians. Consequently, technical information should be provided in simplified form with adequate explanations and perhaps illustrated by cartoons avoiding the vernacular and unquantitative phrasing.

Investigations of equipment reliability have shown that great difficulty in determining reliability in terms of mean life has been the lack of a standard for judging satisfactory performance. Without such criteria, the engineer cannot design for a specified reliability. Therefore, upon such criteria depends the entire reliability program.

To realize the inherent reliability of an equipment in the field, it is essential that performance standards be established which permit rapid recognition of unsatisfactory performance.

Since equipments are expected to deteriorate with time and usage, it is essential that a preventive maintenance program suitable for the equipment involved be adopted. However, preventive maintenance of all components and parts which do not obey a wear-out law of failure must be discontinued. In order for an effective preventive maintenance program to be established, equipment manuals should list components and parts which allow for such maintenance and should specify the period. Unnecessary handling of electronic components should be avoided, particularly such practices as routine mass testing of electron tubes. In order for electronic components and parts to approach a wear-out law, design engineers must be educated in conservative design and derating practices.

Marginal checking is consistent with preventive maintenance and has been used in limited forms quite successfully for some years, resulting in improved equipment performance and a reduction in complex maintenance problems. It is presently being employed in large vacuum tube computers and early data indicates it is essential as a maintenance tool. It is recognized that considerable military equipment is of an analogue nature, and marginal checking, in the present state of the art, is not considered a suitable maintenance tool in this application. However, it is desirable that research in this area be extended. Since transistors are being employed in ever-increasing quantities, present investigations on marginal checking methods for this device should be completed.

All equipment in the field requires adequate support in the form of test equipment, tools, maintenance facilities, and spare parts. These items should be available for maintenance as soon as new equipments are placed in the field.

Performance of any of the maintenance functions described above requires the use of test equipment. Equipment tuning or testing using test equipment necessitates periodic calibration of the tester. A positive calibration program would be one using standards regularly compared to those available at the National Bureau of Standards. It seems desirable, therefore, to establish calibration centers based upon such dependable standards.

Such factors as air conditioning of maintenance facilities contribute significantly to equipment reliability and must be given adequate attention by both designers and the military departments.

In the following pages, specific recommendations relating to various studies of the task group are included. Additional supporting details for all topics can also be found.

2. RECOMMENDATIONS TO THE DEPARTMENT OF DEFENSE

2.1 EQUIPMENT MAINTAINABILITY

All future contracts awarded by the Department of Defense should include a maintainability requirement. The contractor should be made to demonstrate by rigorous testing that his equipment has met this requirement prior to quantity production.

Maintainability should be defined as the reciprocal of mean net time to repair failures with this parameter being measured under conditions specified in this report.

Service technicians of average skill level should be available to perform maintenance during equipment evaluation tests to insure maintainability based upon the ability of this average technician.

For its value to maintainability design and personnel planning, the approach for determining the operation value of an equipment given in Appendix A, paragraph 6.3 should be u d and improved.

2.2 AVERAGE TECHNICIAN

The Department of Defense should establish guide lines for a study to evaluate an absolute average technician on a common basis. A continuing review should be made so that the definition may progressively become more accurate, enabling requirements for technical manpower to be more precisely evaluated in the future and to enable determination of deficiency areas in current skill levels.

To provide average technicians for evaluation tests specified by DD-3222.1, it is recommended that the Department of Defense use as a standard for average technician the 0.25 to 0.75 limits as derived by dividing the graduate's training class position by the total number in his class. Several classes must be considered to secure the required number of technicians and the group structure should reflect the current military grade dispersal of the services.

2.3 DESIGN CONCEPTS

The Department of Defense should prepare instructions to the military departments to jointly establish economically justifiable limits within which modular units may be disposed of rather than repaired and parameters so established should be released to industry for inclusion in design philosophy.

2.4 EDUCATION OF ENGINEERS

To alleviate the increasing shortage of engineering personnel, the Department of Defense should recommend to the appropriate Federal agency and to the National Committee for the Development of Scientists and Engineers that emphasis on subjects such as mathematics, physics and chemistry be increased at the secondary school level. Arrangements should be made for an investigation into the psychological reasons which are currently responsible for the antipathy toward engineering sciences in the teen-age population, and from this devise effective means for countering antipathy.

2.5 SHORTAGE OF SERVICE TECHNICIANS

To reduce the high turn-over rate of technicians in the service.

a. All possible steps must be taken to enhance the military career by representing to Congress the adverse effects of financial and fringe benefit limitations on the long-term efficiency of the services.

b. More effort and emphasis should be given to utilization of service personnel for routine maintenance, with correspondingly diminished emphasis on contract technicians for this requirement.

c. Consideration must be given to mobilizing contract technical personnel in their present assignment (until b is implemented) in an appropriate status immediately upon declaration of a state of emergency.

2.6 TRAINING OF SERVICE TECHNICIANS

The long training time for technicians is resulting in an inefficient utilization of manpower. It is therefore recommended that:

a. The military departments establish the three levels of training described in this report.

b. The maximum time for training be limited to approximately one-third of the remaining enlistment.

c. The Department of Defense conduct conferences and symposiums between all the military departments to provide the stimulation for each department's introspection and re-appraisal of training effectiveness.

2.7 SYSTEM PERFORMANCE CHECKING AND PERFORMANCE STANDARDS

In order for the performance of a system to be evaluated in accordance with established standards, it is essential that:

a. The military departments determine the minimum number of performance indices required for each class or type of equipment or system.

b. Wherever feasible, the required performance indices be included in the original specification and designed into the equipment or system in the simplest manner. Where impractical to build in, provisions for easily accessible test points should be brought out (ordinarily to the front panel) in such a way that these measurements can be easily and quickly made.

c. A performance standard be prepared for each operational equipment or system, and used to determine that the equipment or system is operating satisfactorily after any maintenance (as defined in DOD Directive 3232.1).

d. Operators and technicians be trained to recognize and use the information derived from performance indices.

2.8 PREVENTIVE MAINTENANCE

To take full advantage of the benefits of preventive maintenance, it is recommended that:

a. Preventive maintenance be limited to components and parts which obey a wearout law of failure.

b. The MIL-SPEC on equipment manuals be supplemented by the requirement that such manuals give complete listing of parts and components obeying a wearout law specifying the period for their preventive maintenance as well as the procedure.

c. The definition of preventive maintenance given in paragraph 4.3 of this report be substituted for that given in DOD 3232.1.

2.9 MARGINAL CHECKING

Marginal checking is an effective maintenance tool in its proper applications and would reduce operational failures. Therefore, it is recommended that:

a. Consideration be given to the potential benefits versus the additional cost for marginal checking in all vacuum tube digital equipment.

b. The manufacturer be required to furnish initial prescribed margins and the testing frequency for all effected sections of a system or equipment.

c. Present investigations of the application of marginal checking in transistorized equipment be continued.

d. Research in the field of marginal checking applied to analog devices be extended.

2.10 EQUIPMENT CALIBRATION

To assure uniform and adequate calibration of test equipment throughout all military installations it is recommended that:

a. Calibration centers be established at various locations to supplement existing facilities and employing standards regularly compared against those available at the National Bureau of Standards. (NBS)

b. Handbooks be provided which include complete calibration information based upon NBS standards.

c. Mil Spec include a requirement for specifying test equipment accuracy and precision in two ways; standard deviation and maximum deviation.

2.11 SUPPORT MATERIALS

Since any maintenance program is so dependent upon the availability of adequate support material, it is recommended that:

a. Department of Defense expand the maintainability section of DOD Directive 3222.1 to require concurrent purchase of all supporting facilities for new production equipments.

b. Each set of technical maintenance publications be supplemented with one or more handbooks, written informally, well illustrated, in simplified form and covering broad principles of function, maintenance and operational use.

3. SUPPORTING DETAILS FOR EACH REPORT SECTION

3.1 EQUIPMENT MAINTAINABILITY

DISCUSSION

3.1.1 DEFINING MAINTAINABILITY

Before progress toward better maintainability can be expected, the formulation of a rigorous definition is essential. One reference (24)* uses this definition:

"Maintainability is a function of the rapidity and ease with which maintenance operations can be performed to help prevent malfunctions or correct them if they occur."

While this provides notions of what the concept may be, it does not provide a univocal basis of agreement and seems to entail considerations of both corrective and preventive maintenance. The definition is lacking in that it does not give the operations which specify the concept maintainability. (16)

* Numbers in parentheses refer to the bibliography in Section 5.

To overcome this situation it is proposed that maintainability (M) be defined in terms of a measurable quantity----mean net time to repair failures ($\bar{x}$). If the individual net times to repair failures are x_1, x_2, x_n, then

$$(1) \qquad \bar{x} = \sum_{i=1}^{n} x_i / n$$

Maintainability, M, is then defined by

$$(2) \qquad M = 1 / \bar{x},$$

using the reciprocal form to make maintainability increase as mean net time to repair failure decreases.

3.1.2 MEASURING MEAN-NET-TIME TO REPAIR FAILURES

To measure $\bar{x}$, the following conditions are required:

(a) The measurement of each x_i should be made with the system or equipment in an operational environment or one closely approximating that condition.

(b) Net time to repair should include all time lost due to failures in any part of the system including time lost due to deficient manuals. Time lost in making repairs due to lack of parts, unavailability of power, or any other factors which are not within the control of the designers of the system should not be charged to net time to repair a failure. However, a record of all such times and their causes would prove valuable for eliminating future bottlenecks.

(c) Service personnel of average skill should perform the maintenance rather than engineers or contractor representatives. The subject of average technician is treated more fully in the next section.

(d) The maintenance personnel employed should be given adequate schooling in the system prior to the test.

(e) Any special test equipment needed for the maintenance of the system should be provided together with the normal test equipment found in the environment in which the system is expected to be located.

3.1.3 CONFIDENCE LIMITS

For assurance that the test results are meaningful, the confidence limit of the parameter being measured should be calculated. (Note 1)

To arrive at the confidence limit for $\bar{x}$, it is necessary to also determine s, the standard deviation of $\bar{x}$, during the maintainability test, where;

$$(3) \qquad s = \left[\sum_{i=1}^{n} (x_i - \bar{x})^2 / (n - 1) \right]^{1/2}$$

where n is the number of failures repaired.

From $\bar{x}$ and s, the confidence limits of the parameter being measured can be determined.

Confidence limits are distributed sensitive; therefore the probability distribution of the mean should be determined, where feasible, for each maintainability trail. (Note 2)

The case of the normal distribution may be used as an illustration of confidence limit computation. This method is very oftern used when the data are too scant to allow determination of the distribution involved. (Note 3)

The confidence limits, L_1, L_2 (y), for the mean of a normal distribution are given by:

$$(4) \qquad L_1, L_2 = \bar{x} \pm s t_{(y,\, n-1)} \quad n^{1/2},$$

where L_1 is the lower limit, L_2 is the upper limit, $\bar{x}$ is defined by equation (1), s is defined by equation (3), and $t_{(y,\, n-1)}$ is the critical value of t for n-1 degrees of freedom at y probability level. This function is extensively tabulated (Note 4); however, table 1 is included as an aid to clarify the computation and a completed example can be found in the Appendix A. Section 6.1.

TABLE 1. CRITICAL VALUES OF STUDENT'S t

Degrees of Freedom	Failures (n)	Probability Levels (y): 90%	95%	99%	99.9%
1	2	6.314	12.706	63.657	636.619
2	3	2.920	4.303	9.925	31.598
3	4	2.353	3.182	5.841	12.924
4	5	2.132	2.776	4.604	8.610
5	6	2.015	2.571	4.032	6.869
6	7	1.943	2.447	3.707	5.959
7	8	1.895	2.365	3.499	5.408
8	9	1.860	2.306	3.355	5.041
9	10	1.833	2.262	3.250	4.781
19	20	1.729	2.093	2.861	3.883
Infinity	Infinity	1.645	1.960	2.576	3.291

The table shows that the critical values of t decreases very slowly for $n > 20$. This offers reasonable hope that significant data can be obtained in tests of moderate length. It should be pointed out however, that s increases with n, although it tends to do so very slowly. This increase can be quite rapid if relatively few extreme values occur. For this reason, it may be advisable to adopt a method for rejection of outlying observations. (15)

Since the Task Group having cognizance of reliability measurement is using the 90% (77) level of probability, and this practice should be followed in this instance. In any event, confidence limits must be given or the tests will be much less adequate.

The confidence limits should prove of considerable value to planning officers and operational commanders, but if, in addition, the probability distribution of mean net time to repair failures is determined, maintainability can be stated as a probability that a repair of the system will take given time. This would then be analogous to the usual definition of reliability: i.e., the probability of no failure. P_0, in T hours is given by.

$$P_0 = \exp(-Tm), \qquad (5)$$

where m is the arithmetic mean of the times between failures. (26) This is the desirable type of definition; and can be obtained if it is found that the distribution of mean net times to repair failures is as consistant as is the distribution of the failures themselves. (12)

Notes

1. The confidence limits of a parameter, e.g. u, the population mean, are those limits which, for random samples from the population in question, have a probability of y/100 that u is included within them. Where 0 - y/100 -1, the limits are called the y% confidence limits. See e.g., references (3), (10), (18) for the general theory.

2. For tests for probability distribution, see references (13) and (15). If, e.g., a Poisson distribution is found for x, reference (5) can be employed to compute the confidence limits. For non-parametric confidence limits, see references (11) and (17). Obviously, every effort should be made to avoid use of these limits.

3. The method is based on the classic paper of W. S. Gosset, who used the pseudonym "Student" whence comes the name "Student" t, reference (6).

4. See references (1), (2), (4), (8), (9) and (14).

5.1 4 OBTAINING MAINTAINABLE EQUIPMENT

A great deal of sound work has been done to enable engineers to design easily maintainable electronic systems, but they must be educated in the subject and compelled to study it, assimilate it, and incorporate it in the systems which they are presently designing. The surest way to do this is to include an ironclad maintainability requirement in the specifications for each new system, giving maintainability an operational definition of the type set out above and rigorously testing and enforcing it. If this is done, the design engineer will provide the maintainability the services so desperately need.

3.1.5 RECOMMENDED DESIGN REFERENCES

Some of the better works on designing maintainable equipment are references 19 to 38 and 62. Further references may be found in the following bibliographies; for the older literature, Gen Gasiorowski's 6,352 item bibliography gives fairly good coverage, though much of the material in his book, reference (25), is not germane to our topic; for the more recent literature, see references (27), (30), (31), (35), (76), (78), and particularly reference (20), which is a serial publication. Among the design manuals themselves, references (24), (35), and (62) are particularly recommended.

CONCLUSIONS:

It is concluded that the principal need in the field of maintainability is an operational definition of maintainability which should be included in all future contracts for equipment or systems.

3.2 AVERAGE TECHNICIAN

DISCUSSION:

In the maintainability section of this report, one of the required conditions stated for measuring mean-net-time to failure during system evaluation tests was the use of average-skill service technicians for all maintenance functions.

This was stated because a maintenance capability is dependent to a large extent upon the technician available to maintain the required equipment. Actually, the "average" technician is the key to the maintenance problem. He must be considered when training programs are established, when test equipment is designed, when accessibility of components is considered and when publications are written. With a standard for "average" technician available, it should be possible to re-emphasize to designers the need to consider the capability of this technician, particularly with regard to the provision of adequate and accessible test points within systems, ease of adjustments, accessibility, etc.

CONCLUSIONS:

1. A standard for "average" technician is essential so that a system maintainability can be designed with this technician in mind. A group of "average" technicians for the purpose of checking the equipment maintainability could be obtained by dividing the graduate's class position by the total number of students in his class and using the limits 0.25 to 0.75 as defining the "average". *

2. The evaluation of the "absolute average" technician should also be bases upon IQ, an electronic aptitude test, high school grades completed, college years completed, special service schools and years of service maintenance experience.

* See Appendix B.

3.3 TRAINING

DISCUSSION:

3.3.1 GENERAL

Before a successful maintenance program can be realized, maintenance personnel must be given adequate training on their equipment or system. Many factors contributing to successful training must be reviewed. This study resolved itself into six major areas, each affecting the maintenance training. These are:

1. Education of Engineers
2. Shortage of Service Technicians
3. Training of Service Technicians
4. Manuals and Publications
5. Support Material
6. Disposable-at-failure Maintenance

3.3.2 EDUCATION OF ENGINEERS

The deficiency of skilled engineers and technicians is not peculiar to the services, but is a national problem. (45, 47) A continuing deficiency will adversely affect the nation's economic and industrial growth, and in addition, have repercussions on defense potential. (51) In the long run, this shortage can only be remedied by increasing the output of suitably trained students from schools and colleges. In a democratic nation, this must be achieved by stimulating interest in engineering at the earliest possible age. A commendable start in this direction has been made at Bay City, Michigan. (50)

Enrollment in mathematics, physics and chemistry have declined,* partly due to the shortage of suitably qualified teachers, and partly due to the cost of providing and supporting adequate laboratory facilities. Industry has realized the necessity of insuring adequate numbers of technicians in future years, and has made offers to aid by means of part-time teachers and financial support. (46)

CONCLUSION:

It may be concluded that our technological standards will continue to advance, and that in future even greater numbers of scientists, engineers and technicians will be required to support and further this advancement. (47) Similarly, the services will be faced with a need for skilled men, increasing in proportion to the complexity of the weapons systems brought into operational use by the need to uphold peace from a position of strength.

3.3.3 SHORTAGE OF SERVICE TECHNICIANS

DISCUSSION:

The general shortage of skilled personnel previously discussed is enhanced for the services by the relative attractiveness of employment in industry, with its present high wage levels and the introduction of ever-increasing fringe benefits. (52) Service life imposes many restrictions on the technician by requiring the performance of non-technical routine duties, such as K. P., guard duty, etc. In addition, housing in many areas presents a problem to the married man.

* Appendix A Section 6.2.

Because of the shortage of skilled technical personnel, ever-increasing use is being made of contract services. (53) For sake of discussion, the categories of services obtained from a contractor will be oversimplified into technical and non-technical. An example of the former is the maintenance of electronic systems; the latter, preparation and serving of food. The group feels that the more complex the task and the more essential the function performed is to the completion of combat activities, the more necessary it is for the military to have control of the personnel executing the tasks. Accordingly, the trend to contract catering is condoned, while contract maintenance, with its present limitation amplified below, is condemned.

Actually the increased use of contract services aggravates the original shortage, since this creates more opportunities for civilian employment for the service technician, who can leave the service and return to carry out the same duties as a civilian, not subject to military discipline, free of domestic-type chores, on a higher pay scale, and with many more privileges than before. Actually, in one service, more than one-half of its maintenance is accomplished by contract personnel. (54, p.148) This process is diluting the operational capability and effectiveness of the armed services, and will restrict mobility in time of emergency. Additionally, contract personnel tend to fill states-side posts, leaving the less desirable areas to be manned by military personnel and so further decreasing morale.

The existing high turn-over rate of trained men represents a very large annual dollar wastage. If men can be persuaded to remain in service for longer periods, the resultant dollar saving in training may be expended in improving pay scales, housing facilities, fringe benefits, etc. For example, considering a man who is to carry out eight years of service, two years of which will effectively be training. To provide men on four year terms to cover the same period in the field requires three men to be trained in succession. This is illustrated in the figure 1 below:

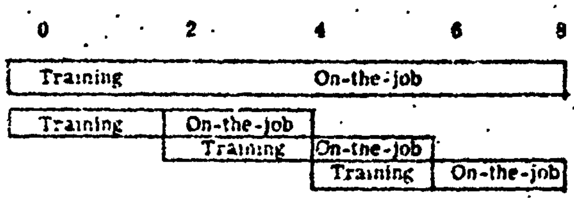

Figure 1. Training Comparison----Long term vs. short term enlistments

The saving of training expenditure on two of these men would in itself enable increased pay to be given to the long term man, and further economies would be effected by virtue of the reduction of personnel required to provide supporting services. There are also intangible but significant gains to be expected in the form of increased skill and efficiency from the long term man as he gains experience.

The fallacy in the use of the contract services is that there are no existing directives to immediately mobilize contractor personnel in their present jobs upon declaration of an emergency. In addition, some contractor personnel, presently performing functions essential to the services, have a reserve status and a mobilization assignment that would pull them away from their present position. The relocation of personnel who are presently performing essential functions at the moment of emergency is viewed with trepidation.

CONCLUSION:

A very real problem exists in this area, although it is difficult to distinguish between cause and effect. However, it is necessary to attempt some alleviation of the problem before it reaches damaging proportions. Operational capability is likely to be impaired by the excessive use of contract personnel unless they are retained in time of national emergency. The task group has no knowledge of such directives.

3.3.4 TRAINING OF SERVICE TECHNICIANS

DISCUSSION:

The maintenance requirements of the three services, due to differing equipments and operational applications, coupled with the broad but unique geographical environments, make a general assessment of training methods difficult.

Under the present maintenance concept, and until a better educational system provides men with improved background, it is unlikely that the demand for technically qualified maintenance personnel at organizational and field levels can be met in the near future. In addition, changing techniques necessitate a continual examination of training and manpower requirements.

When reliability is increased, it will reduce the number of maintenance operations to be carried out in a given period, thus easing the burden on the skilled technician. It is likely that trends to miniaturization, encapsulation, modular construction and the use of printed circuits will lead to two main changes in maintenance operations at user activities. First, where economically feasible, a disposal-at-failure maintenance concept may develop. This will further relieve maintenance operations at user levels. Second, where repair is justifiable on economic grounds, it is likely that higher echelon maintenance will be necessary, using dip-solder techniques, re-potting and re-sealing of units and modules. If so, this will again ease maintenance requirements at field levels, although adding further problems in other areas such as spares support.

The long training times for technicians is resulting in a very inefficient utilization of manpower. A longer time in the field for a less broadly trained man seems to offer greater total returns to the services for their manpower input. Reference (44) is quoted in part: "Hence the draftee graduates . . . . were functioning as satisfactory repairmen for about seven months in the field before being discharged."

In view of the above, it seems appropriate to re-orient the training to provide three depths of training: basic, advanced, and college. While it is recognized that any training program must depend upon the basic maintenance policies and procedures determined for the equipment involved, it is felt that basic training would consist of:

a. Basic and elementary electronic concepts, sufficient for an understanding of further training, but having a minimal mathematical content.

b. Application of the fundamentals of electronics to specified systems and equipments, with the object of teaching fault analysis.

c. The principles and practical use of test equipment utilized for fault analysis on systems.

d. Repair methods, including special handling techniques, and demonstrating good maintenance methods and practices.

The advanced training would be for men with at least two years service and would include more math and theory. The college training would be for men with four years service and would encompass courses to qualify as a maintenance engineer. The Task Group felt that approximately one-third of the total remaining enlistment was a desirable maximum time for training.

To insure the success of the training program, it is axiomatic that training activities should receive production equipments at the earliest possible time. To divert equipment intended for training purposes into operational use is false economy in that systems cannot be operationally effective without adequate maintenance support.

A long period frequently elapses between design, prototype manufacture, and production for field use. Some technicians will have passed through training schools at too early a stage to receive training on new equipment, but will meet it in the field. Hence designers and manufacturers must feed information to training activities whenever new techniques will cause new maintenance procedures to be adopted, in order that the trainee may have some foreknowledge of the characteristics of the system. This should not be done at too early a stage, for obvious reasons.

CONCLUSION:

The service training programs can be made more efficient by review of their requirements and means of attaining them.

3.4 PERFORMANCE CHECKING AND PERFORMANCE STANDARD

DISCUSSION:

To recognize the need for immediate maintenance of equipment and to be certain an equipment is in satisfactory condition after either corrective or preventive maintenance, it is essential that standards for judgment be provided (55), (56), (57).

Periodic performance testing against known standards will indicate degradation and unsatisfactory performance with relative certainty. Such testing is distinct from preventive maintenance and differs from marginal checking since it is not intended to detect or aggravate a potential failure. It is intended to provide both operators and maintenance personnel with approved and accurate means of recognizing an unsatisfactory situation.

Reliability as well as maintainability should automatically improve by providing a positive indication that an equipment performance exceeds minimum standards.

CONCLUSION:

It is concluded, therefore, that:

1. Equipments or systems should be designed to provide evidence of satisfactory performance in as simple a manner as possible. Hence,
2. Performance standards are required in order to determine when equipments or systems are operating satisfactorily either before or after any maintenance (as defined in DOD Directive 3232.1) has been performed.
3. In addition, practical performance standards can be used advantageously in the training of both operators and maintenance personnel. However,

4. Consistent performance indices are required so that the services have a common denominator of performance standards.

3.5 PREVENTIVE MAINTENANCE

DISCUSSION:

Past experience has shown that preventive maintenance in its proper application is a valuable method of improving an equipment's performance. However, this is only valid when applied to components and parts which obey a wearout law of failure, such as mechanical parts and rotating electrical machinery. Thus, lubrication, cleaning, brush checking, etc. should be continued.

Preventive maintenance is an invalid procedure for all entities for which an exponential failure law prevails (26, 39). This presently includes electron tubes, resistors, capacitors, inductors, transformers, and most electronic parts (40). It fails for this category because their failures cannot be localized in time in order to present a uniquely advantageous period for maintenance.

Preventive maintenance of electronic components and parts should be avoided because it causes man malfunctions. Tubes are replaced in the wrong sockets, connectors and cables are damaged, circuits are detuned, servos are unbalanced, thus emergency maintenance is often necessary as soon as equipment has undergone preventive maintenance. Routine mass testing of electron tubes is particularly undesirable.

Marginal checking (41) is consistent with preventive maintenance since it does allow the failures to be localized in time, and in the technique may lie at least part of the answer to the preventive maintenance problem. However, failure prediction (42) is not consistent with preventive maintenance because it is a sequential technique and thus does not provide the indispensable localization in time.

CONCLUSION:

1. It is concluded that three processes offer some hope of allowing the application of preventive maintenance, in its traditional sense, to electronic equipment. These are:

   a. Education of design engineers in conservative design and derating practices. Where this has been done, the wearout law has been approached by electronic components and parts (43). The most immediate promise is offered by this process.

   b. Parts can be improved so that they obey a long-term wearout law when properly applied. This process depends on (a) above.

   c. Marginal checking techniques can be applied to permit localization of failures in time. These techniques require some development, particularly as regards their application to analog device.

Other conclusions are:

2. Preventive maintenance should be limited to components and parts which obey a wearout law. As yet, this does not include electronic components.

3. Preventive Maintenance of electronic components and routine mass testing of electron tubes should be avoided.

4. Marginal checking is a valid form of preventive maintenance but failure prediction is not.

3.6 MARGINAL CHECKING

DISCUSSION:

3.6.1 GENERAL

To accomplish the detection of potential system failures by marginal checking, it is necessary to alter the normal operating conditions of the system so as to cause failures whenever components, wheih have objectionably deteriorated, are present. (60) System performance can be greatly improved by detection and removal of those components which could cause operational failures before the next maintenance period.

The more common means of marginal checking is to vary a selected service voltage supplied to system circuits. (60) However, it is conceivable that marginal checking could be accomplished by variation of other circuit or system parameters. The means selected should provoke failures which can be rapidly isolated for correction.

3.6.2 MARGINAL CHECKING DIGITAL DEVICES

Systems, such as digital computers, with a go-no-go characteristic in their basic circuits lend themselves well to marginal checking. (61)

In large digital computers which involve thousands of multiple use vacuum tube circuits, marginal checking is considered an essential feature for effective maintenance. (60) Here, circuits performing similar or related functions are grouped and marginal checked together. This grouping is carefully done so that marginal failures can be isolated. Even so, many groups may exist in large systems; hence, it is necessary to employ automatic marginal checking through computer programming to test the entire system in a reasonable length of time.

3.6.3 MARGINAL CHECKING ANALOG DEVICES

In general, analog computers have continuous rather than go-no-go characteristics. Electro-mechanical and electronic analog computers normally use closed loop circuitry with negative feed back to stabilize the circuits against internal component deterioration and external disturbing factors. Marginal checking, as described above, applied to an analog device would result in a gradual deterioration of performance, such as reduced system velocity constant or overshoot, etc. rather than indiscrete failures which would cause maintenance personnel to suspect their equipment without providing ample isolation of potential failures. In addition, setting the rejection levels for components would be difficult therefore a means for marginal checking other than the simple varying of service voltages would be required.

3.6.4 LIMITATIONS OF MARGINAL CHECKING

Marginal checking apparatus usually represents a significant part of the equipment cost. Therefore, the inclusion of this capability in a highly reliable system would be difficult to justify. However, the benefits in eliminating potential failures and isolating intermittent faults would normally always be realized to some degree. This would even be true for small systems although here faults can usually be readily isolated by other techniques.

For each system, it would be necessary to evaluate the need for a marginal checking capability, recognizing its benefits and comparing this against its cost and the suitability of other techniques.

From information received, a successful method of marginal checking transistor circuits has not been found. It is known that transistors fail more by deterioration rather than catastrophically and their reliability is high. Unless resolved, the lack of marginal checking may present maintenance problems in systems using transistors extensively.

While a manufacturer should recommend the prescribed margin to use and the testing frequency, it will be necessary for the using organization to alter them as experience dictates (62).

However, this would require the using organization to maintain sufficient performance records for their own analysis before approving changes. Accurate details for such a record may be difficult to acquire in view of past history in this area.

3.6.5 ENVIRONMENT

It was generally felt that marginal checking would have practical value for fixed or shipboard digital systems provided space were available.

Consideration of weight and size in airborne digital systems offers problems which might prohibit its inclusion. This equipment is relatively new and it is understood marginal checking for such systems is under study. Its application in modified forms should be possible.

CONCLUSIONS:

1. It was generally agreed that marginal checking is a valuable maintenance tool (63). In particular, its most valuable application is in vacuum tube digital systems and here the benefits as described by the definitions would certainly be experienced.

2. A marginal checking capability may require considerable additional costly equipment. Therefore, it is felt that marginal checking has questionable justification if the inherent reliability of a system is high or if the system, being small, lends itself well to other maintenance techniques.

3. In view of the present state of the art, characteristics of analog systems are such that marginal checking is not considered feasible. However, it is considered desirable that research in this field be extended.

3.7 EQUIPMENT CALIBRATION

DISCUSSION:

Maintenance of electronic equipment requires the use of precision test equipment for a variety of measurements. These include frequency, power, and sensitivity, along with many others, each being measured to optimize equipment performance or diagnose trouble. In many instances an equipment is tested at more than one facility or circumstances require that two or more equipments calibrated at different locations operate within their specified ranges for compatibility. This requirement imposes a need for uniform calibration standards throughout all military installations.

Since the National Bureau of Standards (NBS) could provide uniform standards, it would be highly desirable to develop a calibration program employing standards originating at NBS.

Calibration centers located in selected areas dependent upon NBS for checks on standards could be established to implement the calibration program. Such centers adequately staffed and properly equipped could supplement existing facilities, particularly overseas. They could be available to more than one service if this results in economy without loss in efficiency.

To implement such a program, it would be necessary for DOD to establish a coordinating group for monitoring purposes who could ascertain the number of measurements to be made on specified parameters, and develop a calibration program insuring that all field calibration activities have proper capability to maintain high standards of accuracy and precision. Once the program is developed, the assistance required from NBS should be specified.

Information required to perform complete calibration of equipment should be included in handbooks and based upon common definitions of standards used by NBS. Mil. Specs should require that test equipment accuracy and precision be stated in two ways: Standard deviation and Maximum deviation over one year measured by scientific methods.

Overall calibration checks on equi[illegible] only in narrow ranges are not necessary, yet account should be taken of new equipment expected.

A report to be published by C. G. Moore of Naval Aviation Electronics Service Unit and Task Group 9 considers the general problem of what accuracy of standards is required to insure a given accuracy at calibration centers. It solves the main problem by mathematical theory of probability and treats the limitations of measurement from both a physical and psychological view point. It justifies the use of standard deviation and a scientific determination of maximum deviation in specifications and gives a method for reducing errors. In addition, consideration is given to the compounding of errors through a chain of calibrations.

Most of the pertinent information on the subject is included in an indexed bibliography of more than 600 items on electrical measurement, metrology, theory or errors, and human factors in measurement.

CONCLUSION:

1. Present calibration facilities should be supplemented by calibration centers with standards regularly compared against those available at the National Bureau of Standards.

2. Common definitions of standards should be employed in Handbooks offering complete calibration information.

3. Mil Specs should include a requirement for specifying test equipment accuracy and precision in the two ways specified above.

3.8 SUPPORT MATERIAL

DISCUSSION

3.8.1 GENERAL

Field maintenance requires that all of the following material conditions be provided concurrently with a system for an effective program:

a. Test equipment and tools (both standard and special)
b. Test facilities
c. Spare parts
d. Adequate publications
e. Provision for training material

Items c, d and e apply to items a and b as well as the equipment supported.

New equipments are placed in the field before adequate support for them has been provided. This results in extra efforts to make field improvisations which would not be necessary if adequate support were provided in advance. This practice also results in degradation of operational effectiveness.

A variety of factors contribute to this situation: operational demands; procurement laws; service organization for development, procurement, maintenance, etc. An example of the flagrant disregard of past experience is the fact that spare part procurement negotiations had not been initiated on the scheduled delivery date for a large radar.

3.8.2 MANUALS AND PUBLICATIONS

Many excellent suggestions for improved maintenance handbooks and technical manuals are available (24), (26), (58). However, maintenance handbooks and technical manuals as required for higher level maintenance, naturally contain highly technical data and complex circuit diagrams, which provide the source of reference data for the experienced systems analyst and repairman technician. This content and format does not provide the right approach nor level of delineation and readability to the trainee. The trainee, by and large, has considerable difficulty in arousing self-interest and present manuals are [illegible] extracurricular study. The flow analyst is forced to wade through a manual much more complex than necessary to extract the more primary level of implementation required of his station of training.

In many cases, manuals give information in qualitative form when quantitative form would be very desirable. Expressions such as "current readings may be above normal during run-up periods" are meaningless. This points to a requirement for one or more supplementary publications, written down in technical level and in less formal style, to familiarize trainee and inexperienced personnel with any given system.

It is recognized that all military departments and services do not have exactly the same problem in detail; nevertheless, the problem is the same in principle. It may well be that:

a. For army tactical ground repair support troops, as many as three additional supplementary handbooks are advisable because of the more definitive five echelon structure or steps of maintenance.

b. For naval shipboard or air force implementation, only one supplementary handbook may be desirable due to the trend toward combining the first four steps of maintenance aboard ship, shore station or airfield respectively.

c. For army fixed station equipment support, it is also likely that one supplementary book would suffice, since the shipboard or airfield situation of combining the first three and sometimes four steps of maintenance are combined at the Site.

CONCLUSIONS:

1. New equipments are being procured without adequate support. This practice results in inefficiencies and loss of operational effectiveness.

2. In order to awaken and maintain interest in trainees, inexperienced technicians with a need to know information for lower level maintenance, it is desirable to publish one or more supplementary, informally written manuals, containing adequate explanatory and simplified diagrams and perhaps illustrated with pertinent cartoons to emphasize important points; avoid the vernacular and unquantitative phasing.

3.0 DISPOSAL-AT-FAILURE MAINTENANCE

DISCUSSION:

The military services are faced with deteriorating technical skills to maintain equipment of increasing complexity. It may be assumed that technically qualified personnel in numbers great enough to achieve quality maintenance in the field will not be available in the foreseeable future. The present concept of maintenance is based on adequate technical ability at the lower echelons. Here is a condition affording no escape but that of tailoring equipment and concepts to lower skills. It is proposed that a Disposal-at-Failure concept of maintenance, supported by a correlated equipment design philosophy, be considered jointly by the military services, which will achieve quality corrective maintenance when accomplished by the average technician of the future.

Design trends apparent in the electronic field, such as, modular construction, printed circuitry, encapsulation, miniaturization, all point to an era of disposal-at-failure maintenance. It is evident that the maintenance concept of the future must evolve to fit this trend. One approach, then, is to further the above trend and design modular units which, cost being within defined limits, may be disposed of rather than repaired. Therefore, limits within which it is economically justifiable to employ disposal-at-failure maintenance should be defined.

The cost of such a program must be weighed against the benefits, tangible and intangible, which will accrue to the services. This concept should reduce the necessity for training personnel to high skill levels since a lesser technical competence will achieve quality corrective maintenance in the field. This, however, must be relat[illegible] to the reduced experience gained in fault analysis brought about by minimized repair at field level.

Mean net time to repair failures should decrease since with appropriate test equipment and test points for localizing faults, repair will then consist of replacing the defective unit by a serviceable one thus returning the equipment to operable status in a minimum of time. It may be assumed, however, that under peculiar circumstances a complete system may be disposed of more than once by increments during its useful life depending on the distribution of failures within the system.

The revised concept will assist greatly to maintain a given reliability level through the life of a system. Reduction of excessive maintenance procedures, which are known to decrease reliability, and purging the logistic system of maintenance spare parts manufactured to lower level specifications than those applied by the system contractor to the original reliability requirement are supporting arguments. Faults due to mishandling during transportation will be minimized.

Much is to be gained by the adoption of the disposal-at-failure concept of maintenance. It must be supported by a correlated design philosophy to allow the accrual of quality maintenance by personnel of limited technical skill.

The release from the necessity to provide highly skilled personnel for field level maintenance will allow concentration of trained resources at depot type facilities and the number of technical representatives necessary to support systems in the field will be reduced substantially.

The antithesis of the disposal-at-failure philosophy are those of repair in the field or of return to a depot for repair. The recommended basis for comparison is cost to repair vs. new equipment cost. The results in the depot repair situation should be obtained more easily. The cost in the depot situation must include packing, handling, and transportation of the equipment from the field to the repair facility as well as the direct and indirect expenses of the depot. If the time to repair at a depot is appreciably different from new part procurement time, the two costs should be adjusted to reflect this effect on operating capabilities.

In the field maintenance situation, the cost of training and supporting different numbers and quantities of men who would be performing under opposing philosophies will be difficult to assess. Data on this matter is essential to valid conclusions. Other considerations that are germane to this investigation are the effect of disposal-at-failure maintenance on weight, reliability, performance, etc.

CONCLUSIONS:

1. It is concluded that a maintenance concept which will allow disposal rather than repair of modular units will reduce the level of training required by field maintenance personnel. It is also concluded that the system suggested above is a feasible basis for establishing a disposal-at-failure design concept.

4. SUMMARY OF DEFINITIONS FOR TERMS USED IN THIS REPORT

4.1 MAINTAINABILITY

Maintainability (M) is defined as the reciprocal of mean net time to repair failures ($\bar{X}$). Limiting conditions are specified in paragraph 3.1.

If the individual net times to repair failures are $x_1, x_2 \ldots x_n$, then

$$\bar{x} = \sum_{i=1}^{n} x_{i/n}$$

and $M = 1/\bar{x}$

4.2 SYSTEM PERFORMANCE TERMS

1. Performance checking is a procedure to determine that operational performance meets prescribed system or equipment standards.

2. Performance Standards are published instructions and requirements setting forth the procedures, methods, and techniques for measuring the designed performance of electronic equipments or systems in terms of the minimum number of essential technical measurements required for a specified operational capability.

3. Performance indices are those technical measurements required to indicate that an equipment or system meets its prescribed characteristics.

4.3 PREVENTIVE MAINTENANCE

Preventive Maintenance is a procedure of inspecting, testing, and reconditioning a product at regular intervals and according to specific instructions in order to prevent failures in service and to retard deterioration.

4.4 MARGINAL CHECKING TERMS

1. Marginal checking is: (1) A means of varying circuit or system parameters in such a way as to detect potential operational failures in a system; and (2) A means of altering circuit or system performance to render intermittent faults continuous thereby simplifying troubleshooting.

2. Prescribed Margin (Rejection Level) is the established range to which a circuit or system parameter can be varied without failure of the tested function.

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6. APPENDIX A

6.1 MAINTAINABILITY

The following computation [illegible] confidence limits is offered as an example of application of the formulas.

Given, $y = 95\%$, $x_1 = 2.33$ (hours), $x_2 = 1.48$, $x_3 = 1.79$, $x_4 = 2.37$, $x_5 = 1.85$

Solution:
Obviously, $n = 5$
From equation (1), $\bar{x} = 1.950$
From equation (2), $M = 1/1.950 = 0.513$
From equation (3), $s = 0.364$
From Table I, then, entering it for $y = 95\%$ and $n = 5$, $t_{(y, n-1)} = 2.776$

Therefore taking equation (4) in two steps,

$$L_1 = 1.95 - (2.776 \times 0.364) / 2.236 = 1.498$$

$$L_2 = 1.95 + (2.776 \times 0.364) / 2.236 = 2.402$$

Therefore, there is, on the basis of the first 5 failures, a probability of 95% that the mean net time to repair failures is between 1.498 and 2.402 hours, and M has the corresponding values 0.416 and [illegible].

These numbers are, of course, merely illustrative; they do not pretend to represent experience.

6.2 TECHNICAL COURSE ENROLLMENT IN U S HIGH SCHOOLS

Precentage of Algebra Enrollment

1900	5[illegible].3
1922	4[illegible].2
1928	3[illegible].3
1934	3[illegible].4
1949	26.[illegible]

References: (47), (49) Section 5

Percentage of Physics Enrollment

1895	23.0
1900	19.0
1922	8.9
1928	6.8
1934	6.3
1949	5.4
1952	4.3

References: (47), (48), (49) Section 5

6.3 MEASURING THE OPERATION VALUE OF AN EQUIPMENT

INTRODUCTION:

If all of the tasks performed by maintenance personnel are subdivided into three categories, the effect of design on maintainability may be more clearly shown. Further, the data obtained according to these categories may be combined to furnish numbers of assistants into personnel planning.

It is recognized that the simple approach given below does not do full justice to the complexity of the problem, but by viewing the problem in this way, its salient points are more clearly discerned. Careful investigation of the frequency distributions and correlation of the parameters defined below is an essential requirement for practical use of this approach.

DISCUSSION:

The tasks of maintenance personnel can be grouped into two broad catagories: activities to anticipate or prevent failure and those to repair failure. The former functions are generally considered preventive maintenance; the latter, corrective maintenance. Alignment is not inherent in either term; conditions can be specified by which alignment is measured as one of the other two.

The two main ingredients of the maintenance personnel input are time and talent. The talent portion is considered as fixed; hence the remaining concern is time.

In the formula developed, the terms are defined as follows:

R - Reliability -- mean time to failure. units -- equipment hours.

M - Maintainability -- mean net time to repair failure. units -- manhours.

P - Preventive Maintenance -- mean net time to perform all functions intended to prevent failure. units -- manhours

I - Preventive Maintenance Interval -- equipment operating time required for one cycle of preventive maintenance units -- equipment hours

V - mean net time to verify that a system is performing satisfactorily.

T - equipment operating times between occasions for ascertaining that equipment is operating properly.

D - Deficiency -- computed measure of maintainability. units -- manhours/ equip. hours

D_1, D_2, D_3 sub units of D

A, B - constants

O - Equipment Operation -- equipment operating time. units -- equipment hours per day (month, etc.)

N - Number of equipment -- number of equipments used by a command. units -- none

H - Man-hours -- ber man-hours needed to support the scheduled equipment ...urs. units--manhours.

H_1, H_2 - individual equipment man-hours required

$D_1 = M/R$

$D_2 = P/I$

$D_3 = V/T^*$

$D = D_1 + A\,D_2 + B\,D_3$

$D = \frac{M}{R} + AP/I + B\,V/T$

For the remainder of the development A and B = 1

$D = \frac{M}{R} + \frac{P}{I} + \frac{V}{T}$

Additional variations on the data are possible. The ratio D_1/D_2 would indicate the relative effort between preventing and repairing failures. A normalizing of D by dividing by the number of tubes, sum of all compo...nts, or weig...d sum would provide a measure of equipment relative to the state of the art. Is it optimistic to state that trade-off curves could be established for equipment accuracy vs D, or R vs D? For equipment installed in aircraft it may be desirable to divide M and P into components to reflect the time required to get the equipment out of the plane and that required to perform necessary shop functions.

The following formula can be used to estimate manpower requirements to support a specific equipment.

$H_1 = O\,N\,D$

The technical personnel requirements for the aircraft configuration would be the sum of all the individual manpower requirements.

$$H_{total} = \sum_{1}^{n} H_i$$

The method of obtaining all the data needed for the calculations would be to conduct an evaluation of pilot production equipment in a squadron manned by average technicians. Capable impartial observers to monitor the test would be necessary. Determination of D would be in accordance with the intent of DOD Directive 3222.1 of 5 July 1956.

CONCLUSIONS

Formula $D = \frac{M}{R} + \frac{P}{I} + \frac{J}{K}$ can be used to measure maintainability and formula $H_{total} = \sum_{1}^{n} H_i$ can assist in determining man-power requirements.

7. APPENDIX B

Determining the Average Technician

The determination of "normal" or "average" performance of a given task has a long history in industry and well-recognized methods exist in the field. (64) (69) (72). While all testing of human abilities is beset by certain hazards (67), the use of test results to predict performance in a task has been found to be satisfactory (66), (71).

Using the ratio of class standing to number in a class as a parameter, it is possible to determine what the range of abilities about the mean (0.5) will be for various groups. The range ratio for any percentile range can be found from empirical data. For the mean (M) and the standard deviation (S), the range ratio (M + 3S)/(M - 3S) is found to be equal to 2. The distribution is normal and S = M/9.

Therefore, in order to find a particular range ratio, multiple values of S can be substituted in

$$(1) \quad (M + 3S)/(M - 3S) = 2$$

The multiples can be determined as follows: The central area of the normal curve is given by

$$(2) \quad a_x = \frac{1}{(2\pi)^{1/2}} \int_{-x}^{x} \exp.(-1/2\, t^2)\, dt$$

where $t = (X-M)/S$

This function is tabulated in reference 75. Since the answer is in terms of S, the multiple values in equation (1).

Results for a few values are:

Central Percent	Range Ratio
20	1.058:1
40	1.124:1
50	1.162:1

Even for the central 50 percent, (i.e., for those with a ratio of class standing to number in class of 0.25 to 0.75), the ratio of 1 1/6 to 1 between the abilities of the best and the worst man in the group does not seem excessive. It would simplify the problem of supplying technicians for evaluation if the central 50 percent were used, and would not seem to exert an undue effect on the results of the evaluation.

Inasmuch as the technicians selected for an evaluation will be, to some extent, a select group, a certain improvement may be expected over their normal performance due to the so-called "Hawthorne" effect. It is very difficult to evaluate the magnitude of this effect but the mathematics have been worked out for an analogous situation in physics and the curious can consult reference (74).

As a final caution, it should be noted that relatively slight changes in the environment can cause very large variations in the performance of such tasks being considered here; see reference (68).

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