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MAINTENANCE REPLACEMENT FACTORS

Naval Aviation Integrated Logistic Support Center
Patuxent River, Maryland

18 October 1971

NAVAL AVIATION INTEGRATED LOGISTIC
SUPPORT CENTER
Patuxent River, Maryland

TECHNICAL REPORT

MAINTENANCE REPLACEMENT FACTORS

NAILSC REPORT 03-7

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Prepared for the
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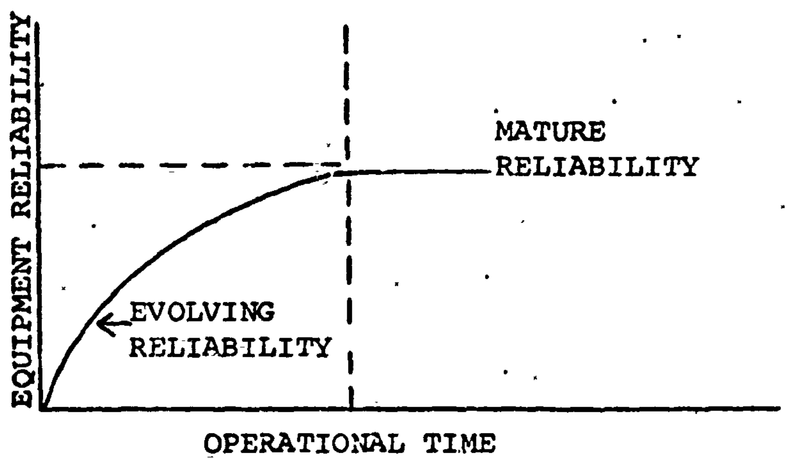
Headquarters

Date 18 October 1971

EXECUTIVE SUMMARY

1. Introduction

a. In the final report by NAILSC (Naval Aviation Integrated Logistic Support Center) on A-7E "Logistics Lessons Learned" study, it was pointed out that mature reliability of equipment does not occur instantaneously but evolves over some period of time and that predicted reliability numbers are usually referenced to mature reliability of equipment as shown in the accompanying figure.



From these facts it is easily inferred that the result of initial provisioning based upon mature reliability estimates would be an insufficient number of spares or repair parts. As a consequence, development of a more refined method--possibly using both 3-M data and reliability growth curves--was recommended.

b. NAILSC was tasked to evaluate replacement factor determinations in the provisioning process. Specific objectives associated with this effort were identified by the following statements:

(1) Examine current methods of producing replacement factors.

(2) Determine the means for using actual or predicted distribution curves rather than the quantity MTBF (Mean Time Between Failures).

(3) Develop a procedure to include a more accurate reliability estimate as one of the factors considered at provisioning conferences.

(4) Define types of documentation required for determining reliability factors and treatment of these documents to obtain the best factors.

(5) Develop plan to implement improvements.

2. Discussion

a. To examine current methods of producing replacement factors, representatives of NAILSC contacted personnel in the Naval Supply System and private industry and reviewed technical documents on reliability. Findings are summarized in Appendix I. The most important result is that many procedures to compute replacement factors or to derive reliability relations have been available for years. Furthermore, contractors and the Navy tailor computations to particular equipment by using that procedure which best merges with readily available data. This means THERE IS NO COMMON DATA BASE WHICH CAN BE USED EITHER TO MEASURE THE WORTH OF ANY PROCEDURE OR TO ESTABLISH A BETTER PROCEDURE. NAILSC compiled a procedure that could be used with two existing computational methods to provision avionic equipment. In an attempt to standardize the computational method, both were used to compute a Flight Hour Failure Base for the RT848/ALQ100 system. These results were compared with failure data from the naval 3-M system. One method used MIL-HDBK-217A; the other used a curve and weighting factors generated by NADC (Naval Air Development Center). Both methods were validated; however, it was ascertained that use of the curve and weighting factors generated by NADC requires less time and effort than use of MIL-HDBK-217A. A possible weakness of the method is that failure rates of mature systems are used to simulate failure rates for systems that are neither tested nor mature. These considerations form the basis for the recommendations that appear under a separate heading.

b. Determination of the means for using actual or predicted distribution curves rather than Mean Time Between Failures plus assumed Poisson Distribution of failures is a technical problem addressed in Appendix II.

c. The objective to "Develop a Standardized Procedure to Include Estimates of Reliability at Provisioning Conferences" was accomplished for avionics equipment. Procedures and examples of their application to cover any contingency are included in Appendices II and III. Specific usage is recommended as follows:

(1) Non-Avionics. Use either procedure described in Appendix II under the heading "Time Dependent Rate of Degeneracy." (At this time, these procedures are computer-oriented and it is anticipated that the contractor should be responsible for their implementation.)

(2) Avionics. Use general procedure described in Appendix III in conjunction with the computational method demonstrating use of the weighting factors and curve generated by NADC. Documentation needed to use this procedure consists of top-to-bottom breakdown structure of system and level of repair for each part of each subassembly through the active element level.

3. Recommendations

a. It is recommended that NAVAIR-412 coordinate with ASO to incorporate the NADC computational method into the provisioning process on a selected basis.

b. It is recommended that NAVAIR-04 task NAILSC to track and analyze the application of the procedure.

c. Upon completing a reasonable evaluation effort, NAVAIR-04 sponsor preparation of a Military Standard on "Method for Deriving Maintenance Replacement Factors for Use in Provisioning Spares and Repair Parts."

4. Schedule. It is anticipated that the recommended tracking and evaluation program can be accomplished in accordance with the following schedule.

TRACKING AND EVALUATION PROGRAM SCHEDULE

EVENTS	TIME (Months)												
	1	2	3	. . .	1	2	3	4	5	6	7	8	9
Define tracking procedure, establish systems to be tracked, and set up controls.	Δ	—	Δ	Indefinite delay until systems are introduced into Fleet.									
Compile and evaluate data.					Δ	—	—	—	—	Δ			
Prepare MIL-STD.							Δ	—	—	—	—	—	Δ

NAVAL AVIATION INTEGRATED LOGISTIC SUPPORT CENTER
ACTION RECOMMENDATION

NO: 03-7-1

SUBJECT: Development of a Standardized Procedure to Include Estimates of Reliability at Provisioning Conferences

PROBLEM: There is no standardized procedure for computing reliability factors that are needed in initial provisioning.

ANALYSIS: Many procedures to compute reliability factors have been available for years. Furthermore, contractors and the Navy tailor computations to particular equipment by using that procedure which best merges with readily available data. This means there is no common data base which can be used either to measure the worth of any procedure or to establish a better procedure. In an attempt to select a standardized procedure to be used with avionics equipment, NAILSC used two computational methods to compute a Flight Hour Failure Base for the RT848/ALQ100 system and compared these results with failure data from the naval 3-M system. One method used MIL-HDBK-217A; the other used a curve and weighting factors generated by Naval Air Development Center. Both methods were validated; consequently, further evaluation is necessary before a decision to use either method for standardization can be substantiated.

RECOMMENDATION: To obtain data required for evaluation purposes, the following sequential program of activities is recommended:

a. NAVAIR-412 coordinate with ASO to incorporate the NADC computational method into the provisioning process on a selected basis.

b. NAVAIR-04 task NAILSC to track and analyze application of the NADC procedure, the MIL-HDBK-217A procedure, and the current method used at ASO.

c. Upon completing a reasonable evaluation effort, NAVAIR sponsor preparation of a Military Standard on "Method for Deriving Maintenance Replacement Factors for Use in Provisioning of Spares and Repair Parts."

Approved [signature]
Commander, NAILSC

Date 10/18/71

TABLE OF CONTENTS

INTRODUCTION

1. General Objectives. By references (1) and (2), NAILSC (Naval Aviation Integrated Logistic Support Center) was tasked to evaluate replacement factor determinations in the provisioning process. General instructions listed in these references include the following:

a. Examine current methods of producing replacement factors (reference (1), paragraph 3e(1)).

b. Determine the means for using actual or predicted failure distribution curves rather than MTBF plus assumed Poisson Distribution of failures in the provisioning process (reference (2), paragraph 3d).

c. Develop a procedure to include a more accurate equipment reliability estimate as one of the factors considered at provisioning conferences (reference (1), paragraph 3d).

d. Define types of documentation required for determining reliability factors and treatment of these documents to obtain the best factors (reference (1), paragraph 3d(2)).

e. Develop plan to implement improvements (reference (1), paragraph 3e(3)).

2. Approach

a. NAILSC created an action team to perform the following:

(1) Conduct a preliminary survey of practices and procedures now used by the Navy and naval contractors to establish maintenance replacement factors and reliability functions used in the provisioning process.

(2) Use results of survey to define a tentative program to comply with stated objectives.

(3) Execute program.

b. During the preliminary survey, relevant definitions were compiled for use as ready reference material and a tentative conceptual program was evolved.

(1) Definitions

(a) MC (Maintenance Cycle). A common denominator base (months, hours, flights) established for computing spare parts requirements. This base is a fixed four months for ground support equipment and is normally 100 hours for an aircraft, its installed equipment and engines.

(b) MRF (Maintenance Replacement Factor)

1. With respect to a consumable item, the MRF denotes the number of times the item will require replacement in an aircraft or equipment in one maintenance cycle at the intermediate level of maintenance and below. To establish the factor, determine the time that will be accumulated on the part before it must be replaced. The maintenance factor is obtained by dividing the time between removals into the maintenance cycle base. (An alternative definition is this: The MRF is simply the failure rate multiplied by the maintenance cycle base or the mean time between failures divided into the maintenance cycle base.)

2. With respect to a repairable, the MRF denotes the number of times an assembly will be beyond the repair capability of intermediate and organizational levels in one maintenance cycle and will be reworked by a Naval Air Rework Facility. To establish the factor, determine the time that will be accumulated on an assembly before it will require rework by the Naval Air Rework Facility. The maintenance percentage is obtained by dividing the time accumulated before rework into the maintenance cycle base. (An alternative definition is this: The MRF is the failure rate to a Naval Air Rework Facility multiplied by the maintenance cycle base

or the mean time between failures to a Naval Air Rework Facility divided into the maintenance cycle base.)

(c) RPF (Rotatable Pool Factor). The predicted number of times a repairable will require removal from an aircraft/equipment and generation to an intermediate level of maintenance for restoration to a ready-for-use condition during one maintenance cycle. (An alternative definition is this: The RPF is simply the failure rate of a repairable to an intermediate level of maintenance multiplied by the maintenance cycle base or the mean time between failures of a repairable to an intermediate level of maintenance divided into the maintenance cycle base.)

(d) TAT (Turn-Around-Time). As applied to an IMA rotatable spare pool, it is the average number of working days between removal of a specific repairable for necessary processing at the IMA level or below until it is restored to a ready-for-use condition.

(e) RPR (Rotatable Pool Rate). The predicted number of repairables required in a pool to support operations for one maintenance cycle based on Rotatable Pool Factor and TAT in a 90-day period. The RPR is obtained by multiplying the RPF by the established TAT and dividing the result by 90, i.e., the number of days to be supported in the Initial Outfitting List.

(f) SRF (System Recoverability Factor). Percentage of the total quantity of a repairable item that is recovered (a) at the end issuing level, (b) by screening units and (c) at depot level and returned to ready-for-issue condition.

(g) MTBF (Mean-Time-Between-Failure). The predicted number of total equipment operating hours, both ground and flight time, that will accumulate prior to the experience of any failure.

(h) Ratio of Flight to Ground Operating Hours. The predicted ratio indicating the hours of equipment operating time in flight in relationship to hours of equipment operating time on the ground. The sum of these times equate to total equipment operating time expressed in hours.

(i) Flight Utilization Rate. The predicted time expressed in percentage that the equipment will actually be in operation during total aircraft flight hours.

(j) FHFB (Flight Hour Failure Base). The total number of predicted aircraft flight operating hours that will accumulate prior to the experience of any predicted failure.

(k) Reliability. The probability that an item will perform its intended function for a specified interval under stated conditions.

(2) Tentative Conceptual Program. Facts highlighted during the A-7E study conducted by NAILSC were used to establish the tentative conceptual program. These particular facts are:

(a) The contractor provides an estimated MTBF for his equipment.

(b) Operational commanders usually are confronted with a FHFB considerably less than the MTBF.

(c) As a consequence, provisioning based upon the estimated MTBF is not adequate to fill initial demands from operational commanders.

(d) Using these facts, a program consisting of a primary and an alternative plan was defined.

1. Primary Plan. Objectives of the primary plan were defined as follows:

a. Ascertain the feasibility of either computing degrading factors to convert an estimated MTBF to a realistic FHFB or computing and plotting reliability as a function of FT (Flight Time) and FHFB against the reliability function provided by the contractor.

b. Check or demonstrate feasibility.

c. Establish requirements for implementing procedures.

2. Alternative Plan. Objectives of the alternate plan were defined thusly:

a. Develop procedures to establish better maintenance replacement factors, rotatable pool factors, or reliability equations for provisioning of non-avionics or avionics.

b. Check or demonstrate use of procedures.

c. Establish requirements for implementing procedures.

3. Decision Rules. As a guide to determine which plan should be executed, the following decision rules were used:

a. Feasibility of primary program would be established only if the following statements are true:

(1) The fundamental theorem of provisioning could be used to demonstrate the soundness of the concept.

(2) All reliability functions and maintenance replacement factors are derived from a common baseline--that is, both the manufacturer and the Navy always employ identical methods for similar equipment operating under similar environments.

(3) Available data base must provide the capability to obtain sequential time failure data for equipment over a critical time base which ranges from date of inception to initial stabilization. (To be truly useful, such data should be available for several environments, e.g., ship, shore, type squadron, type aircraft.)

b. If feasibility of primary program cannot be demonstrated, use the alternate plan.

4. Program Activities. Activities that were undertaken to assess the feasibility of the primary program consisted of:

a. Compiling and evaluating methods and procedures of incorporating reliability via personal contacts with contractors and defense agencies and perusal of reliability documents.

b. Ascertaining availability and applicability of data.

5. Program Concept. Ultimately, the action team chose to pursue the alternate task. Reasons for this decision include the following:

a. As shown in Appendix I, there is no such thing as a common procedure to establish maintenance replacement or reliability factors and there is no way to obtain sequential time failure data for equipment over a critical time base which extends from day of inception into the fleet until such time as maturity of equipment becomes an obvious fact.

b. As shown in Appendix I, several procedures are available but none has been used to the exclusion of all others. This means that a common data base across all sources is not available; hence, use of collective data in generating factors to convert an MTBF to an FHFB is a meaningless exercise.

c. A mathematical theory of provisioning that could be used to establish the soundness of the primary plan was not found. In fact, a fundamental mathematical theory of provisioning was not found; consequently, one was hypothesized and used to explain the need for different provisioning procedures to account for fundamental differences in equipment being provisioned. This theory is described in Appendix II.

ANALYSIS

3. Examine Current Methods of Producing Replacement Factors. To ascertain current methods of computing replacement factors and using reliability equations to predict provisioning requirements, representatives of NAILSC contacted experts at various agencies (e.g., Aviation Supply Office, Westinghouse Corporation and Grumman Aerospace Corporation) and reviewed current literature on the subject of reliability. Results of these activities are presented in Appendix I. Significant results are summarized as follows:

a. Aviation Supply Office. Incorporation of reliability into the provisioning process usually begins with a contractor providing a quantity called the MTBF. This quantity is then adjusted by the provisioning team. This adjustment is almost always based upon historical usage data of similar equipment operating under the same adverse environmental conditions anticipated for the equipment during operational employment. This adjusted quantity is discussed with the contractor and may be changed to reflect substantive arguments presented by the contractor. The final figure arrived at by either mutual agreement between the Aviation Supply Office and the contractor or an override by the Aviation Supply Office is used to provision the equipment. To arrive at a final provisioning number, the adjusted MTBF is transformed to comply with the current provisioning practices of incorporating flight hours, a maintenance cycle base of 100 hours, and such quantities as Rotatable Pool Rates or Rotatable Pool Quantities. Factors used in this conversion process include Ground Operating Time on Equipment, Flight Operating Time on Equipment, Flight Time, Maintenance Replacement Factor, Turn-Around-Time, and Predicted on Equipment Flight Line Work. Insofar as possible, these factors are almost always estimated from historical usage data of similar equipment operating under the adverse environmental conditions anticipated for the equipment being provisioned, i.e., the provisioning process is tailored to fit the equipment.

b. Private Industry. As shown in Appendix I, several procedures for predicting the Failure Rate of equipment or, in many specialized instances, the inverse of the MTBF are available to the contractor. In general, contractors combine the use of these procedures with various sources of data to provide the Navy with an MTBF that is tailored to fit the equipment. Frequently, the computed MTBF is degraded in accordance with specialized knowledge or expertise acquired over a long period of time. Sources of data used by contractors include MIL-HDBK-217A, experimental tests, Naval Aviation Maintenance and Material Management System (MDCS), reports from field representatives or reports from Aircraft Carriers.

c. Reliability and provisioning personnel within private industry and the Aviation Supply Office believe that elements of data contained in MIL-HDBK-217A are not valid for provisioning of current aircraft systems. Reasons stated to support this belief are that failure rates of equipment are based upon laboratory tests, state-of-the-art in design of some elements has progressed beyond the state-of-the-art available when MIL-HDBK-217A was compiled, and the environmental degrading factors are not adequate. It is generally recognized that the elements of data included in MIL-HDBK-217A are needed for provisioning; however, it is also recognized that the elements of data should have been referenced to a Flight Hour Failure Base that had been established during early stages of operation in the Fleet. That is, a new document (say, MIL-HDBK-217B) that includes elements of data contained in MIL-HDBK-217A referenced to a Flight Hour Failure Base established over the interval of time between initial inception of equipment into the Fleet and stabilization of equipment would be a valuable provisioning document.

4. Determine Means for Using Actual or Predicted Failure Distribution Curves Rather than MTBF plus Assumed Poisson Distribution of Failures. Resolution of this objective entails a comprehensive understanding of the interactions that occur between maintenance replacement factors and reliability. Such an understanding should be based upon and derivable from a unified mathematical theory that accounts for specific differences or similarities in design of equipment, operation of equipment, modes of failure, or maintenance plans and provides the basis for a rationale to determine the conditions under which either Failure Distribution curves or Poisson Distribution of failures and MTBF should be used. Because of this need for a unified theory, a primary goal of the early

effort expended on this project was to discover, review and understand the unified theory defining the roles of reliability and maintenance replacement factors in the provisioning process. Such a theory was not discovered. As a consequence, a simple theory based upon the classical definition of a probability density function, the principle of standby redundancy, and the assumption of a continuous probability space was developed. Complete details of the theory along with computational procedures are included in Appendix II. Direct consequences of the theory are summarized as follows:

a. For provisioning purposes, use of reliability is a fundamental concept; whereas use of replacement factors is a secondary concept.

b. If failure rate is a time dependent function, reliability as defined by failure distribution curves should be used to provision. (An example of the use of reliability when failure rate is a time dependent function is included in Appendix II under the heading, "Time Dependent Rate of Degeneracy.")

c. Use of the Poisson Distribution of failures and the quantity MTBF is a logical consequence if equipment is characterized by a constant failure rate and the principle of standby redundancy applies to provisioning--provided there is no redundancy in design of equipment or the maintenance policy is so stated that redundancy in design of equipment is ignored.

5. Develop a Procedure to Include a More Accurate Reliability Estimate at Provisioning Conferences

a. Recommended Procedures. As shown in Appendix I, many procedures to include accurate reliability estimates have been available for years. Furthermore, as previously mentioned, contractors tailor reliability predictions to particular equipment by using the particular procedure that merges best with readily available performance data. The consequence is that there exists no common data base which can be used either to measure the worth of any procedure or to establish a more accurate procedure. Early discovery of these facts and recognition of the consequence provided an opportunity to restate this objective and to pursue the new objective with no lost effort. In essence, this objective was changed to "Develop a Standardized Procedure to Include Estimates of Reliability at Provisioning Conferences." To comply with this objective, procedures and examples of their application to cover any contingency are included in Appendices II and III. Specific usage is recommended as follows:

(1) Non-Avionics. Use either procedure described in Appendix II under the heading, "Time Dependent Rate of Degeneracy."

(2) Avionics. Use general procedure described in Appendix III. Major steps to be performed in applying this procedure are as follows:

(a) Define what is meant by failure of equipment.

(b) Define what is meant by failure of parts and identify all parts for which a failure contributes to a failure of equipment.

(c) Classify these parts as consumables or repairables.

(d) Subdivide repairables into two categories. One category contains those repairables that are to be repaired at the NARF. The other category contains those repairables that are to be repaired at the IMA.

(e) Using only consumable parts, compute a maintenance replacement factor for consumables.

(f) Using only those parts repaired at the NARF, compute a maintenance replacement factor for repairables.

(g) Using only those parts repaired at the IMA, compute a rotatable pool factor.

(h) In computing these quantities, use either computational method demonstrated in Appendix III until such time as enough performance data are acquired to establish the fact that one is inferior to the other. (One of these computational methods is based upon use of MIL-HDBK-217A; the other is based upon a set of weighting factors and a curve generated at NADC.)

b. Check of Avionics Procedures

(1) To assess these computational methods for degree of validity and ease of application with respect to avionics, an analysis to obtain measures of the FHFB was conducted. The subject of the analysis was the RT848/ALQ100 system developed by Sanders Associates, Inc. The analysis consisted of the following activities:

(a) Failure data were collected over a period of approximately 21 months. Elements of data were obtained from NATSF (Naval Air Technical Services Facility) and MSO (Maintenance Support Office).

(b) Design data were collected. These data included types of components, number of types of components, purpose of components, and stress to which components were subjected during operation. Sources of data included Weapons Systems Test of Naval Air Test Center and Sanders Associates, Inc.

(c) Design data were used to compute a measure of the FHFB using operational data presented in MIL-HDBK-217A.

(d) Design data were used to compute a measure of the FHFB by the process of first computing the AEG (Active Element Group) and then using the curve of Figure 1 to obtain the corresponding value of the FHFB. To compute the AEG, a circuit analysis of the system was accomplished and 1622 components were accounted for using the categories listed in Table I. Number of components per category were weighted in accordance with factors included in this same table. These results were summed across all SRAs (Subassembly Replacement Assemblies) to obtain a Weighted Active Element Group count number of 861.48 for the RT848/ALQ100.

(e) A measure of the FHFB was computed using the failure data.

(2) The results of this assessment are summarized as follows:

(a) The measure of the FHFB, as computed using performance data compiled in MIL-HDBK-217A, is 131 hours.

(b) The measure of the FHFB obtained from the curve generated by NADC is 100 hours.

(c) The measure of the FHFB obtained from failure data is approximately 84 hours with a standard deviation of 39 hours.

(3) These results more or less validate the use of both computational methods; however, an evaluation of both methods based upon a larger sample should be conducted with the intent of ultimately eliminating that method which consistently gives a greater departure from operational performance data.

(4) In performing this assessment, it was ascertained that the process of classifying elements and evaluating avionic equipment to obtain provisioning factors frequently imposes a need for the evaluator to make decisions that require an understanding of principles of reliability, probability, and operational characteristics of the equipment. In particular, with respect to avionics, a fundamental background in electronics is required to perform circuit analysis at the level of recognizing operational redundancy or failure modes and classifying active elements by type and function. From this finding, it is concluded that production of provisioning factors for technical equipment should be accomplished or supervised by people with requisite technical training.

6. Define Types of Documentation Required for Determining Reliability Factors

a. If factors are computed using the MIL-HDBK-217A, the required documentation is defined as follows:

(1) Top to bottom breakdown structure of system and level of repair for each part or subassembly through bit and piece level.

(2) A listing of expected operational conditions or a listing of expected stress ratios down to the bit and piece level.

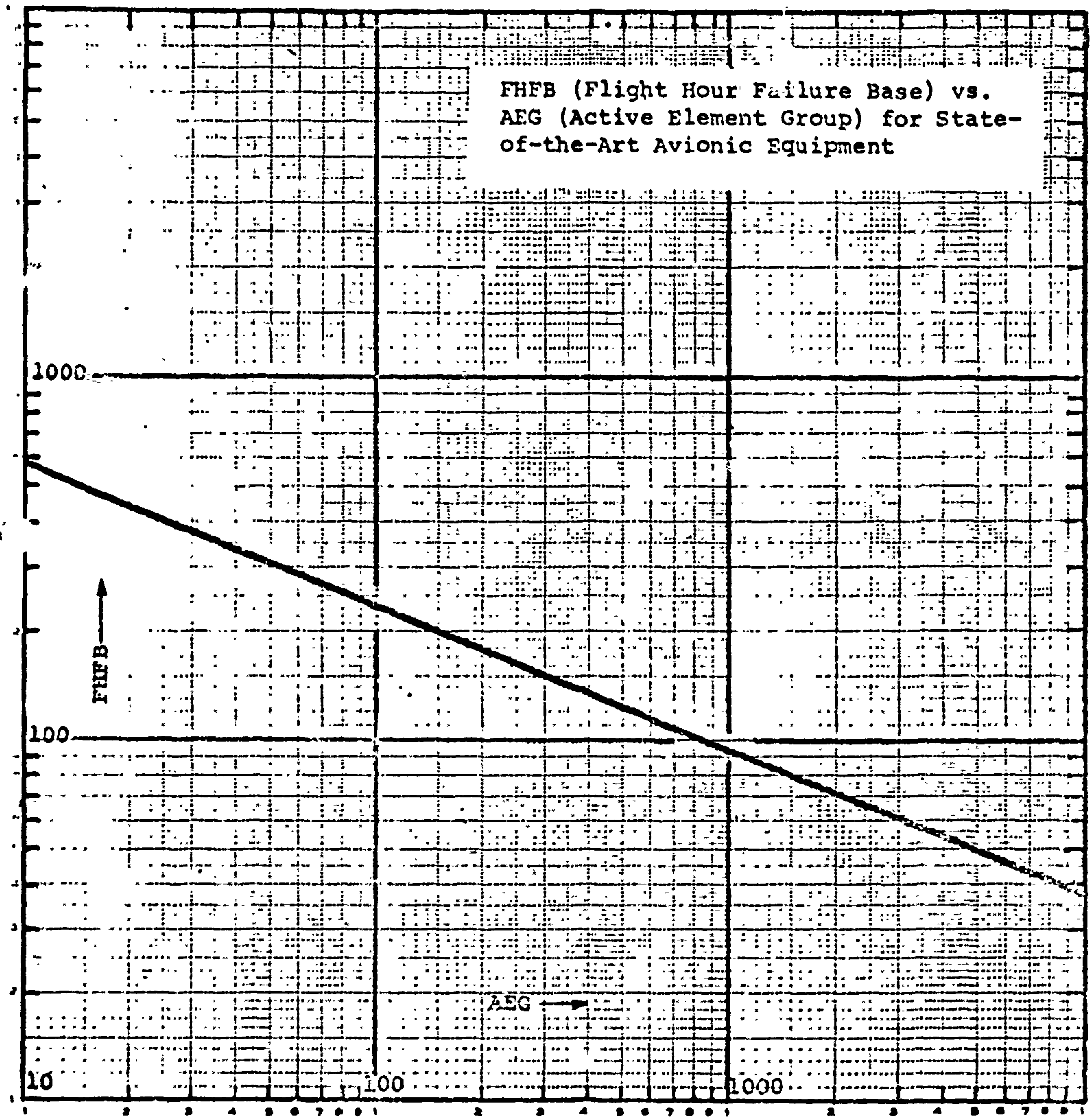


Figure 1.
FHFB VS. AEG

TABLE I

REPLACEMENT FACTORS WORKSHEET

1. Nomenclature: ____________
2. Work Unit Code: ____________
3. Assembly Level: ____________
4. Next Highest Assembly: ____________

5. Component Part Type	6. AEG Weighting Factor	7. Number Replaced or Repaired At		8. Component AEG (6 x 7) At	
		IMA	NARF	IMA	NARF
Transistor - Analog	1.0				
Transistor - Digital	0.5				
Transistor - Power	4.0				
Diode - Switching	0.1				
Diode - Microwave, Varactor	0.8				
Integrated Circuit - Analog	0.12				
Integrated Circuit - Digital	0.06				
Tube - Display, Radar	20.0				
Relay/Switch	0.2				
Rotating Device	3.6				
Lamp	0.4				

9. AEG Count ____________

10. FHFB (Add AEG Count of IMA and NARF. Use the result to obtain FHFB from Figure 1.) ____________

11. RPF (Use AEG Count to IMA to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the RPF in percent.) ____________

12. MRF (Use AEG Count to NARF to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the MRF in percent.) ____________

Definitions:

MRF - Maintenance Replacement Factor as defined in ASO INST 4441.15A.

AEG - Active Element Group as defined in MIL-HDBK-217A.

FHFB - Mean Flight Hours Between Failures.

Weighting Factor - A factor based upon relative part failure rates.

RPF - Rotatable Pool Factor as defined in ASOINST 4441.15A.

(3) The expected Flight Utilization Rate and the expected ratio of ground operating time to flight operating time.

b. If factors are computed using the weighting factors and curve generated by NADC, the required documentation is defined as top to bottom breakdown structure of system and level of repair for each part of subassembly through the active element level. (Active elements must be identified in accordance with item 5 of Table I.)

c. Using MIL-HDBK-217A, the appropriate documentation should be used to compute replacement factors in the manner demonstrated in Tables II and IV through VII of Appendix III.

d. Using the NADC curve, the appropriate documentation should be used to compute replacement factors in the manner demonstrated in Tables II and VII through XI of Appendix III.

7. Develop Plan to Implement Improvements. Use of the NADC computational method to compute replacement factors is synonymous with using mature data to predict factors for systems that are not stabilized. To determine the degree of accuracy for such a procedure, the following test plan is provided:

a. NAVAIR-412 coordinate with ASO to incorporate this procedure into the provisioning process on an interim basis.

b. To validate completely the process of using mature data to predict factors for systems that have not stabilized, new systems should be tracked to obtain failure time histories from the first cruise or until it becomes obvious that the systems have stabilized.

c. To detect or correct flaws in the method or to determine whether or not mature data can be easily and accurately transformed to simulate initial data, the method should be used to compute provisioning requirements to be compared with failure time histories.

d. To determine whether or not this method is better than the current procedure, the computed provisioning requirements should be compared with items that are actually provisioned under current methods.

e. To determine whether or not this method consistently provides better results than use of MIL-HDBK-217A, this document should be used to compute provisioning requirements to be compared with failure time histories.

f. To accomplish these objectives, NAVAIR-04 should task NAILSC to pursue and coordinate a joint tracking effort on the S-3A program (or possibly F-14 program) in which NAILSC is responsible for the tracking procedure and analysis of data, the contractor or the Fleet collects the data, and NADC validates the data.

g. Upon completing this evaluation program, NAILSC, NAVAIR-411, and NAVAIR-412 should jointly select the computational model to be used. NAVAIR-04 should then sponsor preparation of a Military Standard on "Method for Deriving Maintenance Replacement Factors for Use in Provisioning Spares and Repair Parts." NAILSC should assist in preparing the format but the task of preparing the document should be given to a private contractor or WESO (Weapons Engineering Standardization Office).

Backing into an existing program to accomplish the stated purposes is not recommended because data are not available to establish failure time histories for equipment from day of inception into the Fleet until stabilization becomes a fact.

CONCLUSIONS AND RECOMMENDATION

8. Conclusions. Many procedures to compute reliability factors have been available for years. Furthermore, contractors and the Navy tailor computations to particular equipment by using that procedure which best merges with readily available data. This means THERE IS NO COMMON DATA BASE WHICH CAN BE USED EITHER TO MEASURE THE WORTH OF ANY PROCEDURE OR TO ESTABLISH A BETTER PROCEDURE. NAILSC compiled a procedure that could be used with two existing computational methods to provision avionic equipment. In an attempt to standardize the computational method, both were used to compute a Flight Hour Failure Base for the RT848/ALQ100 system. These results were compared with failure data from the naval 3-M system. One method used MIL-HDBK-217A; the other used a curve and weighting factors generated by NADC (Naval Air Development Center). Both methods were validated; consequently, further evaluation is necessary before a decision to use either method for standardization can be substantiated.

9. Recommendation. To obtain data required for evaluation purposes, the following sequential program of activities is recommended:

a. NAVAIR-412 coordinate with ASO to incorporate the NADC computational method into the provisioning process on a selected basis.

b. NAVAIR-04 task NAILSC to track and analyze application of the NADC procedure, the MIL-HDBK-217A procedure, and the current method used at ASO.

c. Upon completing a reasonable evaluation effort, NAVAIR sponsor preparation of a Military Standard on "Method for Deriving Maintenance Replacement Factors for Use in Provisioning of Spares and Repair Parts."

APPENDIX I

FINDINGS: PRACTICES AND PROCEDURES

PRACTICES: NAVY AND PRIVATE INDUSTRY

Aviation Supply Office. Representatives of the Aviation Supply Office described the current method of using reliability in the provisioning process and arranged for representatives of the Naval Aviation Integrated Logistic Support Center to observe a demonstration of the process being used to provision. The life cycle provisioning process which incorporates the MTBF, a parameter related to reliability, is shown in Figure I-1. As noted in this figure, the contractor begins the process by providing an MTBF. Usually this MTBF is then adjusted by the provisioning team. The adjustment is almost always based upon historical usage data of similar equipment operating under the same adverse environmental conditions anticipated for the equipment during operational deployment. This adjusted figure is discussed with the contractor and may be changed depending upon the arguments presented by the contractor. The final figure arrived at by either mutual agreement between ASO and the contractor or an override of the contractor by ASO is used to provision the equipment. To arrive at a final provisioning number, the MTBF is transformed to comply with the current provisioning practices of incorporating flight hours and a maintenance base of 100 hours. Formulae used in this conversion are defined as follows:

- Total operating time is equal to flight operating time plus ground operating time.

- Flight utilization rate is equal to the time equipment is used during flight divided by total flight time.

These formulae are used to transform the MTBF to a quantity called the FHFB, the basic quantity used for provisioning purposes.

The actual computational procedure used to estimate the number of repairables assigned to a rotatable pool is defined by the following definitions and equations.

- Definitions:

M = Number of maintenance cycles.
W = Predicted on-equipment flight line work in percentage.
MTBF = Mean time between failures as specified by ASO.
GOPT = Ground operating time on equipment.
FOPT = Flight operating time on equipment.
FT = Flight time.
FUR = Flight operating time on equipment divided by flight time.
MRF = Mean time between failures to NARF.
FHFB = Flight hour failure base.
FHFBA = Flight hour failure base adjusted.
TAT = Turn-around-time to IMA.
RPF = Rotatable pool factor.
RPR = Rotatable pool rate.
RPQ = Rotatable pool quantity.
A = An arbitrarily selected level of spares availability (ASO usually assigns a value of 0.9 to this measure).
N = Number of spares assigned to rotatable pool.

- Equations:

$$FHFB = MTBF/FUR\ (1 + GOPT/FOPT) \quad (1)$$

$$Y = 100\ ((1/FHFB) - MRF) \quad (2)$$

$$RPF = 100/Y \quad (3)$$

$$FHFBA = RPF + W\ (FHFB/100) \quad (4)$$

$$RPR = (100)\ (TAT)/(90)(FHFBA) \quad (5)$$

$$RPQ = M\ (RPR) \quad (6)$$

$$A = e^{-RPQ}\left(1 + \sum_{i=1}^{N} (RPQ)^{i}/i!\right) \quad (7)$$

N, the number of spares to the rotatable pool, is computed by an iterative process using the relation:

$$e^{-RPQ}\left(1 + \sum_{i=1}^{K} (RPQ)^{i}/i!\right) \geq 0.9 \quad (8)$$

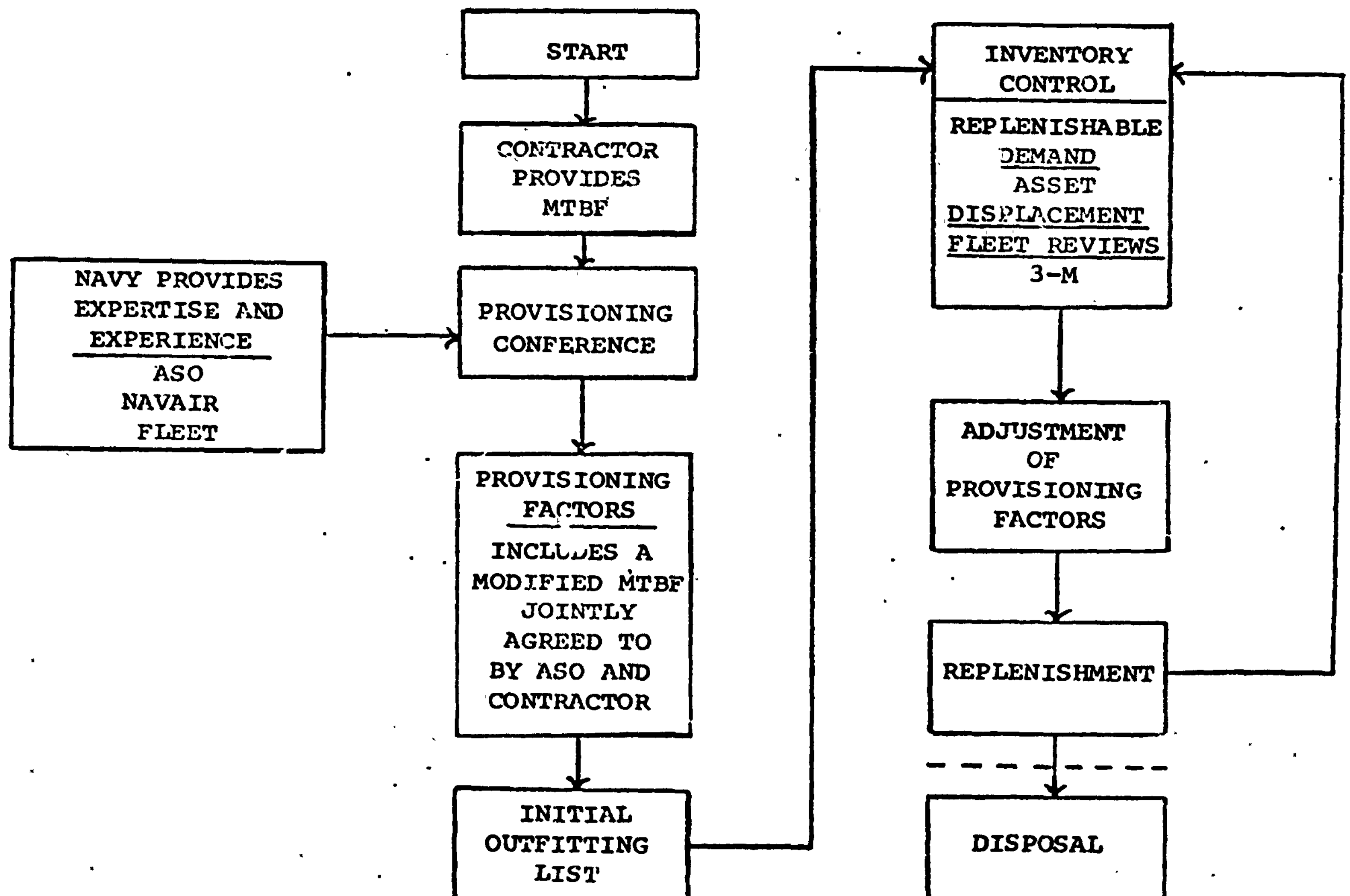


Figure I-1. LIFE CYCLE PROVISIONING PROCESS

The iterative process consists of computing the quantity to the left of the inequality sign for successive values of K beginning with K = 1. N is the least value of K satisfying the relation. (Note: Such quantities as FUR, MRF, GOPT, FOPT, and W are almost always estimated from historical usage data of similar equipment operating under the adverse environmental conditions anticipated for the equipment being provisioned.)

Westinghouse Corporation. As described by Mr. E. R. Levitt, the Westinghouse Corporation uses the concept of failure rate in deriving a reliability equation for avionics equipment. In general, the failure rate is computed using test data in conjunction with conversion factors and the Active Element Group (AEG) Process included in reference 5. This failure rate is then converted to a 100-hour maintenance cycle base and inserted into the reliability equation. Using the principle of standby redundancy, the reliability equation is then used to compute the minimum number of spares needed to ensure the achievement of a pre-specified level of spares sufficiency or availability. In general, Westinghouse uses the best available information that can be obtained for each system and tailors procedures to fit the task.

Mr. Cave provided information on handling and treatment of replacement factors. In particular, Westinghouse handles the rotatable pool and system recoverability factors in accordance with the manner prescribed in reference 3. Maintenance replacement factors for consumable items usually represent fixed percentages mutually agreed to by representatives in attendance at the provisioning conference. To arrive at a maintenance replacement factor for repairable items, Westinghouse computes an MTBF based upon the concept of active element groups and degrades this by a factor of four to convert to use in a detrimental environment. This number is then further degraded at the provisioning conference by naval representatives.

Grumman Aerospace Corporation. As described by Mr. R. Siegel, the procedures for computing and using reliability are essentially the same as those used by the Westinghouse Corporation. Differences are that Grumman places much greater emphasis upon the use of self-generated test data and recommends procurement of spares using a decision rule that minimizes the expected loss in investment dollars. In general, Grumman uses the best available information that can be obtained for each system and tailors each procedure to the task.

<u>Naval Aviation Technical Services Facility and Maintenance Supply Organization</u>. These agencies were asked to provide sequential time failure data for selected equipment over a critical time base ranging from date of inception into the fleet to initial stabilization. Selected equipment included engines, fire control systems, radar systems, radio systems, and defensive electronic countermeasure systems. Data to be provided over a sequential time base consisted of total failures and mean number of flight hours between failures. In addition to these data, estimates of mean times between failures as provided by contractors were requested. The responses of the Naval Aviation Technical Services Facility and the Maintenance Supply Organization to this request were that such data cannot be extracted from their data systems. The reason is that initial date of inception and initial date of stabilization are not part of the reporting system.

A review of documents on reliability revealed that analytical and procedural methods which could have been used to include reliability in the provisioning process have been available for years. Examples of such methods are described by the following verbatim statements extracted from the cited references.

Reference 6, pages 2 to 6. A reliability evaluation shall be performed for the product which will consist of the following steps:

1. Prepare a functional diagram for the product.

2. List product's characteristics.

3. Construct the reliability block diagram including title, statement of conditions, statement of success, and blocks with identification and reliability variables specified.

4. List product divisions not appearing on block diagram with accompanying reasons for omissions.

5. Develop reliability equation.

6. Determine reliability parameters.

7. Solve reliability equation.

A mathematical equation shall be developed for the product and for each block in the reliability block diagram. The equipments involved in a product usually can be broken down into three major categories, determined by their mode of operation. These are continuous, cyclic, and one-shot operations. The reliability of continuous-operation equipments, such as computer and radar, or electronic equipment in general, are determined by means of the reliability parameter of failures per unit time or mean time between failures; cyclic equipment, such as magazines and load and launch equipments are determined by means of the reliability parameter of failures per cycle; and one-shot operations (go/no-go)--(where time of operation is very short, such as in fuze and squib operation) are determined by means of the reliability parameter of failures per event or attempt to operate. It is necessary to establish the reliability for each block of the reliability block diagram, because the reliability of the blocks will be used in the product reliability equation. There are four general equations for determining the reliability of the blocks. These equations are:

$$R = \exp(-\lambda t) \tag{9}$$

where:

R is block reliability

exp is base of natural logarithms
λ is number of failures/unit time
t is required block operating time

$$R = \exp(-t/T) \tag{10}$$

where:

R is block reliability
exp is base of natural logarithms
T is block MTBF (Mean-time-between-failure)
t is required block operating time

$$R = (S/X)^n \tag{11}$$

where:

R is block reliability
S is number of successful events
X is number of successful events plus number of failure events
n is number of required events

$$R = (S/C)^n \tag{12}$$

where:

R is block reliability
S is number of successful cycles
C is number of successful events plus number of failure events
n is number of required events

Each block of the reliability block diagram represents the reliability of one piece of equipment or function contained within the product. The reliability of the blocks are combined to produce the reliability of the product. All blocks of the reliability block diagram must be drawn in either series, parallel, or standby configuration. The reliability equation for equipment in simple series is specified by the product rule. A redundancy equation should be chosen which describes the situation encountered by the product (i.e., end-item). These redundant, standby, and series values are combined (by rules of probability) to produce the product (i.e., end-item) reliability.

Reference 7, page 2-21. The following basic steps apply to the use of this past experience in the estimation of reliability feasibility and the allocation of reliability requirements:

1. Develop the Reliability Block Diagram.
2. Derive mathematical models.
3. Estimate complexity and MTBF of the system.
4. Estimate subsystem failure rates.
5. Estimate feasible MTBF and reliability.
6. Allocate failure rate and reliability.
7. Consider redundant configurations.
8. Evaluate feasibility of allocated requirements.

(Detailed analytical techniques to be used in performing these basic steps are presented throughout this reference. In general, of all documents reviewed on reliability, this is the best source of analytical techniques.)

Reference 8, pages 5 and 6. A reliability analysis of the system/equipment shall be initiated at the start of the contractual effort. This analysis should be an integral part of the overall system/equipment analysis which is conducted to obtain a balance between effectiveness, schedule, and total resources. The reliability program plan shall outline the steps to be used in performing the reliability analysis. Coverage should include but not necessarily be limited to the following paragraphs.

1. Model Inputs

a. Identify required functions for each phase of each required mission, and define what constitutes a failure.

b. Identify critical time periods in the exercise of each function.

c. Identify the external environmental stresses under which the system must function. Identify the stresses on each functional element, generated both externally and internally.

d. Analyze and quantitatively include in the model the planned and defined operational and maintenance concepts.

2. Functional Model

a. Identify hardware and non-hardware system elements required for the execution and support of each function.

b. Create models on this functional basis.

c. Identify functional redundancies required.

3. Reliability Apportionment/Prediction

a. Apportion required system of mission success to each function.

b. Determine the reliability of hardware items and other system elements executing or supporting each function.

c. Reliability estimates and predictions shall be made relating to the mathematical model such as those contained in MIL-STD-756, MIL-STD-757, and MIL-HDBK-217. Current estimates and predictions shall be made for each mission or mode of operation. Where other equipments, Government or contractor-furnished are to be integrated, data furnished by the Government on known or estimated values of reliability shall be used as applicable in the contractor's judgment.

4. Model Outputs

a. Exercise the model to make predictions of system reliability. Predictions should be made relative to those failures affecting safety, mission abort, and unscheduled maintenance.

b. Compare model outputs with the initial requirements.

c. Identify reliability problem areas and recommend corrective action.

d. Reiterate model as necessary.

5. Model Updating

a. Assure that proposed design and other relevant changes are reflected in the model and the effects on system/equipment reliability are brought to the attention of top management.

b. Update operational reliability predictions using test data and identify problem areas for timely corrective action.

Reference 5, pages 4-1 to 7-1. This section provides guidelines for making rapid reliability predictions based on generalized information during early stages of an equipment contract and during the proposal stage. Various prediction techniques are shown. Highlights of some of the most prominent techniques are extracted and summarized in the following paragraphs.

1. <u>Similar Equipment Techniques.</u> The most rapid way of estimating reliability is to compare equipment under consideration with a similar equipment whose reliability has previously been determined by some means, preferably field evaluation. Depending on the degree of similarity of equipment and application, these methods can be more accurate than any other for predicting reliability. The difficulty of using these techniques in military systems is the restricted availability of field data which have been produced with sufficient control to ensure that reliability has been accurately measured.

a. Deficiency technique. Activities basic to this technique are:

(1) From records of the previous operation of similar equipment, determine the number of equipment deficiencies which have been noted in the previous design, for which effective corrective action has not been demonstrated

(2) Estimate the number of introduced deficiencies in the new design. Modify this estimate to reflect the relative complexity of the two designs.

(3) Estimate the number of deficiencies which will be eliminated during the period in which the new design is subject to correction.

(4) Estimate the total number of deficiencies which will remain in the new design after said design is "frozen".

(5) Estimate the new equipment failure rate.

b. NAVSHIPS 93820 (Method A) Technique. Activities basic to a refinement of this technique are:

(1) Identify the nearest equivalent equipment and note its failure rate.

(2) Multiply the number of active elements in the new equipment divided by the number of active elements in the equivalent equipment by the equivalent equipment failure rate. This is the predicted failure rate for the new equipment.

c. Similar Circuit Technique. Activities basic to this technique are:

(1) Determine or estimate the number of each type circuit or function in the equipment.

(2) Use similar circuit or function failure rate data to estimate failure rate for each circuit or function.

(3) Multiply the number of each circuit type by its respective failure rate and sum all these figures to yield an equipment failure rate.

2. Active Element Techniques. The objective here is to describe prediction methods based on the number of active elements anticipated in a new design. Appearing in this reference are tables which indicate the number of other parts per active element in many past equipment designs.

a. NAVSHIPS 93820 (Method B) Technique. This provides failure rates per active elements per equipment type. In other words, an active element in a receiver would have a different failure rate from an active element in a radar, presumably because of different usage and a varying number of types of associated parts.

b. MIL-STD-756 Technique. Activities basic to this technique are:

(1) For each functional block, estimate the number of active elements necessary to perform the function.

(2) Determine the corresponding failure rate of each block for the number of active elements (use Figure 4.4 on page 4-23).

c. Part Class and Part Type Technique. Activities basic to this technique are:

(1) Count the number of parts of each class or type.

(2) Multiply the number of parts of each class or type by the generic failure rate for each part class or type (use Tables IV-V through VIII).

(3) Sum over the products formed in completing the second activity to obtain the failure rate for the equipment.

3. Minimum/Maximum Technique. The objective of the technique is to predict a range of MTBF values possible for a new piece of equipment. This procedure does not require detailed knowledge of part deratings, types of parts, and specific environmental conditions. Activities basic to this technique are:

a. Define the components.

b. Estimate the maximum number of each part type for each component.

c. Assign a maximum, a minimum, and two intermediate derating levels to each part type.

d. Select an anticipated temperature as the normal equipment thermal environment; and add 10°C for tube environment.

e. Assign a failure rate to each of the part types for all four stress levels. (Use the data from Section 7.0.)

f. Add part failure rates for each stress level to obtain a failure rate at four stress levels for a component.

g. Repeat the last activity for components to yield equipment failure rate. Determine MTBF by taking the reciprocal of each of four equipment failure rates.

h. Calculate four MTBF values for each value obtained in completing the above activity by multiplying by appropriate complexity factors. The smallest and largest MTBF values represent a prediction of the range of MTBF values possible for the equipment.

APPENDIX II

THEORY AND APPLICATION

1. Fundamental Theory of Provisioning

a. Improved methods of establishing maintenance replacement factors or reliability entails a comprehensive understanding of the interactions that occur between maintenance replacement factors and reliability. Such an understanding should be based upon and derivable from a unified mathematical theory that accounts for specific differences or similarities in design of equipment, operation of equipment, modes of failure, and maintenance plans. With a unified theory, hypothesized changes can be easily evaluated to determine whether or not they are likely to be improvements: without a unified theory, there is no basis for predicting the ultimate effect of hypothetical changes. Because of the need for a unified theory, a primary goal of the early effort expended on this project was to discover, review, and understand the unified theory defining the roles of maintenance replacement factors and reliability in the provisioning process. Such a theory was not discovered! As a consequence, a simple theory was developed to justify the recommended methods of computing and using maintenance replacement factors or reliability. This theory is based upon the classical definition of a probability density function, the principle of standby redundancy, and the assumption of a continuous probability space.

b. The probability density function, $g(t)$, is so defined in continuous probability space that $g(t)dt$ is the probability that a degeneracy occurs between the times t and $t+dt$. (Note: Within the context of provisioning, a degeneracy must be defined. In particular, a degeneracy may be a failure, a removal, a disposal, or something else--depending upon the whim of the analyst.)

c. Now, consider the principle of standby redundancy. In essence, this principle is defined by the statements:

(1) N is the number of end items.

(2) One of the end items is installed in the weapon system.

(3) (N-1) end items are available for use if the installed end item fails. These end items are said to be in a standby readiness state--hence, the term standby redundancy.

(4) When an installed end item fails, it is removed and then replaced with an end item that had been in the standby readiness state.

d. To determine the required number of spares, let:

(1) $g(t_i)dt_i$ be the probability that the ith installed end item degenerates during the interval of time between t_i and $t_i + dt_i$.

(2) $R(N-1;T)$ be the probability that an operational end item is available at time T.

(3) R^* be an arbitrarily imposed minimum acceptable level of $R(N-1;T)$. (Current policy at ASO seems to be that R^* is greater than or equal to 0.9.)

and use the following computational algorithm.

- With no spares:

$$R(0;T) = \int_T^{\infty} g(t_1)dt_1 \tag{1}$$

- With one spare:

$$R(1;T) = R(0;T) + \int_0^T g(t_1)dt_1 \int_{T-t_1}^{\infty} g(t_2)dt_2 \tag{2}$$

- With two spares:

$$R(2;T) = R(1;T) + \int_0^T g(t_1)dt_1 \int_0^{t_1} g(t_2)dt_2 \int_{T-t_1-t_2}^{\infty} g(t_3)dt_3 \tag{3}$$

. - Or, in general, for N-1 spares:

$$R(N-1;T)=R(N-2;T)+\int_0^T g(t_1)dt_1 \cdots \int_0^{t_{k-1}} g(t_k)dt_k \cdots \int_{T-\sum_1^{N-1} t_i}^{\infty} g(t_N)dt_N \quad (4)$$

continue computing terms of the algorithm until the relation $R(N-1;T) \geq R^*$ is first satisfied. When this occurs, the number of required spares is equal to N-1. (Note: This is the decision rule currently used by ASO (Aviation Supply Office) and Westinghouse Corporation. This is not a universal rule. For example, it is not used by the Grumman Aerospace Engineering Corporation nor is it basic to the computer model that is being programmed to conduct future provisioning activities at ASO.)

e. To complete the theory, it is necessary to define g(t) in more explicit terms. This is done using the procedure established by G. E. Kimball.[9] By his procedure, a mathematical equation relating degeneration rate and a monotonically decreasing survival curve (i.e., a graph of probability of survival vs. time) is generated. The equation is:

$$g(t) = -dR(t)/dt = h(t)R(t) \quad (5)$$

where:

t is an arbitrary operating time greater than, or equal to, zero. (In naval aviation, units of t are flight hours.)

h(t) is the rate of degeneracy as a function of t.

R(t) is probability of survival of end item to time t or, alternatively, the probability of non-degeneracy to time t. By definition, this is also known as the reliability of the end item.

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[9] "Notes on Operations Research 1959," The Technology Press, Massachusetts Institute of Technology, Massachusetts, pgs. 179-181.

$dR(t)$ is an incremental change in $R(t)$.

dt is an incremental change in t.

Equation (5) can be manipulated to obtain the result:

$$g(t) = h(t) \exp\left(-\int_0^t h(t)\,dt\right) \tag{6}$$

Finally, if the FHDB (Flight Hour Degeneracy Base or Mean Number of Flight Hours Between Degeneracies) is really required to compute an MRF (Maintenance Replacement Factor), it is computable from the relations:

$$FHDB = \int_0^\infty t g(t)\,dt = \int_0^\infty R(t)\,dt \tag{7}$$

and the MRF is then computable from the relation:

$$MRF = 100/FHDB \tag{8}$$

f. Equations (1) through (8) more or less comply with the spares provisioning prediction process that is now used by ASO and, as such, provide a fundamental theory of the provisioning process. As should be expected, they also provide the flexibility to account for major differences between end items. This fact is readily demonstrated by the succeeding discussions on predictive methods to be used with end items characterized by a time dependent rate of degeneracy or end items characterized by a constant rate of degeneracy.

2. Application

a. Time Dependent Rate of Degeneracy

(1) Under the assumptions that the principle of standby redundancy is valid and the rate of degeneracy is a time dependent function, equations (1) through (6) provide a basis for describing procedures that might be incorporated as part of the provisioning process. One such procedure is defined thusly:

(a) Using Fleet operational data on similar type of equipment, construct a curve of probability of survival to time t versus time t for the particular end item. Express t in flight hours for airborne equipment.

(b) Use regression analysis to obtain an equation for probability of survival to time t versus t. (That is, probability of survival to time t is the dependent variable and t is the independent variable.)

(c) Multiply the equation for probability of survival to time t by minus one and write the derivative of the result with respect to t. Multiply the result by dt. The quantity thus obtained is g(t)dt.

(d) With respect to the computational algorithm defined by equations (1) through (4), set every element of the type $g(t_i)dt_i$ equal to g(t)dt and compute value~ for the general quantity R(N-1;T).

(e) Specify a minimum acceptable level for R(N-1;T). Call this R*. Use the lowest computed value of R(N-1;T) that satisfies the relation $R(N-1;T) \geq R^*$ and set the number of required spares equal to N-1.

(2) An alternative procedure that should be easier to implement is defined by the following statements:

(a) Using Fleet operational data on similar type of equipment, construct a curve of rate of degeneracy versus time t for the given end item. Express t in flight hours if end item is installed in aircraft.

(b) Use regression analysis to obtain an equation for rate of degeneracy as a function of time. This equation is h(t).

(c) Substitute the equation for rate of degeneracy into equation (6), perform the indicated integration, and multiply the result by dt. The quantity so obtained is g(t)dt.

(d) With respect to the computational algorithm defined by equations (1) through (4), set every element of the type $g(t_i)dt_i$ equal to g(t)dt and compute values for the general quantity R(N-1;T).

(e) Specify a minimum acceptable level for $R(N-1;T)$. Call this R^*. Use the lowest computed value of $R(N-1;T)$ that satisfies the relation $R(N-1;T) \geq R^*$ and set the number of required spares equal to N-1.

(3) Again, it is emphasized that statement e. of these two procedures expresses the current practice at ASO with R^* equal to 0.9; however, this is not universally accepted and used as a naval procurement policy. As a consequence, more useful procedures might be defined if statement (e) were replaced with the statement: "Use the quantities generated in statements a. through d. as required by whatever decision rules are used to complete the provisioning process." Other than this statement of emphasis, the procedures are perfectly general and are not subject to any operational limitations. In this perfectly general case, it is worth noting that MAINTENANCE REPLACEMENT FACTORS ARE NEITHER COMPUTED NOR NEEDED.

(4) As an example in the use of these procedures, the results from the Component Operating Life Data Production Program conducted by NAILSC are used. During this investigation, NAILSC scientists discovered that the probability of survival of an Air Conditioning Turbine Fan to time t is given by the relation:

$$R(t) = e^{-at^{b}}$$

where a and b are constants. In particular, a has the value 0.0028 and b has the value 0.832. Combining the given relation for R(t) with equation (5) yields the result:

$$g(t) = abt^{b-1} e^{-ab^{t}}$$

Application of step (d) of either procedure yields the result:

$$g(t_1) = g(t_2) = \cdots = g(t_N) = g(t)$$

Whence, the first three equations of the computational algorithm are:

$$R(0;T) = e^{-at^{b}}$$

$$R(1;T) = R(0;T) + \int_0^T abt^{b-1} e^{-at^b} e^{-a(T-t)^b} dt$$

$$R(2;T) = R(1;T) + \int_0^T abt^{b-1} e^{-at^b} dt \int_0^t abt_1^{b-1} e^{-at_1^b} e^{-a(T-t-t_1)^b} dt_1$$

Successive relations can be generated as necessary and solved on a digital computer until the relation $R(N-1;T) \gtrsim R^*$ is satisfied. For provisioning of spares, this is the procedure that should be used. For those who insist upon using a maintenance replacement factor, equations (7) and (8) can be used as follows:

$$FHDB = \int_0^\infty R(t)dt = \int_0^\infty e^{-at^b} dt = (1/b)(1/a)^{1/b} \Gamma(1/b)$$

= 1137 flight hours between failures (that is, the measure of degeneracy is number of failures). By equation (8)

MRF = 100/1137

Indiscriminate use of equations (7) and (8) for items that are characterized by time dependent rates of degeneracy is not recommended.

b. Constant Rate of Degeneracy.

(1) The assumption of a constant rate of degeneracy is peculiar to provisioning of avionics, an area wherein a fundamental theory must be able to account for redundancy in design, operational modes, and differences in maintenance policies. For example, redundancy of design within black boxes has meaning if the stated maintenance policy is to remove and replace the black box when it fails to perform its intended function. Otherwise, if the maintenance policy is to check all components in the black box after each flight and replace all malfunctioning components then redundancy of design has no meaning because the effect produced by the maintenance policy is treatment of components as though they are part of a series configuration.

(2) Under the assumption that h(t) is a constant denoted by the symbol λ, substitution into equation (6) defines the probability density function g(t) as follows:

$$g(t) = \lambda e^{-\lambda t} \qquad (9)$$

Substituting this result for every element of the type $g(t_i)$ included in the computational algorithm defined by equations (1) through (4) and performing the indicated mathematical operations generates elements included in the expansion of the Poisson Distribution Function; hence, by mathematical induction, one obtains the general result:

$$R(N-1;T) = e^{-\lambda T} \sum_{i=o}^{N-1} (\lambda T)^i/i! \qquad (10)$$

(As the quantity to the right of the equal sign is the Poisson Distribution, it should be recognized that for avionics equipment, use of the Poisson Distribution is not based upon an assumption. Instead, it is a derivable result based upon the assumptions of a constant rate of degeneracy and applicability of the principle of standby redundancy.)

(3) Equations (7) and (8) of the fundamental theory of provisioning apply to provisioning of avionics equipment provided the necessary mathematical quantities are properly defined using methods that are well documented in the available literature.[10] That proper definition is necessary is demonstrated by the following examples.

(a) Example 1. The end item consists of a black box with two identical redundant paths (i.e., each path is wired in the same manner, each path contains the same types of components, and each path contains the same number of each type of component) Each path has a constant rate of degeneracy denoted by λ'. The maintenance policy is defined by the statement: remove and repair the black box only if a specified signal applied at the input terminals fails to arrive at the output terminals (i.e., components have failed in both paths).

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[10] MIL-HDBK-217A, "Reliability Stress and Failure Rate Data for Electronic Equipment," 19 June 1964, pgs. 3-1 to 3-16.

Compliance with these statements requires that R(t) be defined by the relation:

$$R(t) = 2e^{-\lambda' t} - e^{-2\lambda' t}$$

Substitution into equation (7) yields the result:

$$\text{FHDB (Black Box)} = \int_0^\infty (2e^{-\lambda' t} - e^{-2\lambda' t})\,dt = 3/2\lambda'$$

and, by equation (8):

$$\text{MRF (Black Box)} = 100/3\lambda'/2 = 200\lambda'/3$$

(b) Example 2. The end item consists of a black box with two identical redundant paths (i.e., each path is wired in the same manner, each path contains the same types of components, and each path contains the same number of each type of component). Each path has a constant rate of degeneracy denoted by λ'. The maintenance policy is defined by the statement: after each flight, check continuity of both paths and if either path fails the continuity test, remove and repair the black box.

Compliance with these statements requires that R(t) be defined by the relation:

$$R(t) = e^{-2\lambda' t}$$

Substitution into equation (7) yields the result:

$$\text{FHDB (Black Box)} = \int_0^\infty e^{-2\lambda' t}\,dt = 1/2\lambda'$$

and, by equation (8):

$$\text{MRF (Black Box)} = 100/1/2\lambda' = 200\lambda'$$

(c) Example 3. The end item consists of a black box with one continuity path having a constant rate of degeneracy denoted by λ'. The maintenance policy is defined by the statement: after each flight, check continuity of path. If box fails the continuity test, remove and repair the box.

Compliance with these statements requires that R(t) be defined by the relation:

$$R(t) = e^{-\lambda' t}$$

Substitution into equation (7) yields the result:

$$\text{FHDB (Black Box)} = \int_0^\infty e^{-\lambda' t}\, dt = 1/\lambda' .$$

and, by equation (8):

$$\text{MRF (Black Box)} = 100/1/\lambda' = 100\lambda'$$

Comparing the MRF of this example with that of the second example leads to an interesting conclusion; namely, the maintenance policy of the second example imposes a penalty on provisiong of black boxes possessing the property of redundancy.

Under the assumption that the black box of the third example is a consumable rather than a repairable, a procedure to compute the number of spares is described by the following statements.

- Use equation (10).

- Specify a lower acceptable limit for R(N-1;T). Call this R*.

- In equation (10), set λT equal to N(MC)x MRF where N(MC) is the total number of maintenance cycles included in the flight program.

- Using equation (10) with the above change, generate successive values for R(N-1;T) until the relation R(N-1;T)

R* is satisfied. The number of spares is given by the value of N-1 associated with the first value of R(N-1;T) satisfying the given inequality.

If the black box of the first example was a consumable, it should not be provisioned by this procedure. The reason is that EQUATION (10) APPLIES ONLY IF THERE IS NO REDUNDANCY OF DESIGN--or, in other words, EQUATION (10) APPLIES ONLY IF THE EQUIPMENT BEING PROVISIONED HAS A SERIES CONFIGURATION. Of course, avionic equipment usually is not characterized by the property of redundancy; however, if the situation described by the first example is the prevailing situation then the procedure to be used is described by the following statements.

- Write the relation for R(t).

- Use equation (5) to define g(t).

- Use the computational algorithm defined by equations (1) through (4). Set every element of the type $g(t_i)dt_i$ equal to g(t)dt and compute values for the general quantity R(N-1;T).

- Specify a minimum acceptable level for R(N-1;T). Call this R*. Use the lowest computed value of R(N-1;T) that satisfies the relation $R(N-1;T) \geq R^*$ and set the number of required spares equal to N-1.

The following comments are included to emphasize some of the more important aspects of the above discussion.

1. The measure of equipment performance used to define reliability equations and algorithms that could be used in the provisioning process is referred to as rate of degeneracy. The reason for using this term is that two factions exist within the naval community. One faction prefers to use rate of failure or its inverse, the flight hour failure base, as a measure of performance. The other faction prefers to use rate of removal or its inverse, flight hour removal rate, as a measure of performance. Regardless of which measure is used, equations (1) through (8) apply.

2. No unified theory of provisioning that can be used to account for differences in modes of failure or redundancy was encountered in contacts with personnel or review of existing literature. As such a theory is necessary to assess consequences of proposed changes without recourse to a time consuming experimental program, such a theory is provided in this section. It is incomplete because it does not account for all factors used in the provisioning process; however, it is adequate for the stated purpose.

3. Procedures described in this appendix should be used with data covering the interval from inception into the Fleet until such time as mature reliability becomes a fact. Such data are not available at this time.

APPENDIX III

RECOMMENDED PROCEDURES, EXAMPLES AND STATUS QUO

1. Background Information. The methods described in Appendices I and II can be combined or modified and combined to produce several conceptual procedures to incorporate better methods of computing reliability, maintenance replacement factors, and rotatable pool factors to be used in the provisioning process. Needless to say, all such procedures have been neither evolved nor evaluated (to attempt the performance of such a task is not recommended as data necessary for its accomplishment do not exist). From this fact and the additional fact that any procedure reflects individual precepts held by the writer, it should be understood that the procedures herein described may not be optimal; however, they should improve current methods of estimating the stated quantities. The procedures are based upon the following precepts:

a. Reliability, by definition, is a probability concept; therefore, a knowledge of basic probability theory is necessary for a full understanding of prediction and evaluation methods used in the study of reliability.

b. The most rapid way of estimating reliability is to compare equipment under consideration with a similar equipment whose reliability has previously been determined by some means, preferably field evaluation.

c. Procedures must comply with and incorporate those decisions that establish the level of repair.

2. Procedures

a. Non-Avionic Equipment. The recommended procedures to be used are described in Appendix II under the heading of TIME DEPENDENT RATE OF DEGENERACY.

b. Avionic Equipment

(1) General Procedure. The recommended procedure to

compute the quantities MRF (consumable), MRF (repairable), or RPF (repairable) is defined by the following activities.

(a) Classify end item as being either a consumable or repairable.

(b) Classify and describe operational functions performed by end item.

(c) Prepare a functional block diagram of operational functions performed by end item. Consign only one function to each block.

(d) Define what constitutes successful performance of the end item and, with respect to the functional block diagram, specify all combinations of blocks that ensure a successful performance.

(e) Using implicit notation for probability of success per functional block (e.g., P(A) is probability of success associated with Block A, P(B) is probability of success associated with Block B, etc.), write a probability of success equation for the functional block diagram taking into account all combinations of blocks that ensure a successful performance of end item. (Use analytical methods included in MIL-HDBK-217A.)

(f) Define what constitutes successful performance for each functional block included in functional block diagram..

(g) Prepare an operational diagram of successful performance for each functional block included in functional block diagram. As applicable, include operational redundancy or operational modes.

(h) Using definitions generated by activity (f), write an equation of success for each functional block using implicit notation to denote probability of success per operational path or mode.

(i) Transform implicit terms for probability of success per operational path or mode to explicit reliability relations per operational path or mode.

1. For each operational path or mode, identify elements (i.e., hardware) that are necessary to provide the operational path or mode.

2. For each operational path or mode, consign elements to one of the following categories:

a. If the element fails, it is not repaired.

b. If the element fails, it is repaired at a Naval Air Rework Facility.

c. If the element fails, it is repaired at the intermediate level of maintenance.

3. Compute failure rate of each operational path or mode for each category defined in (i)2.

a. Classify elements per operational path or mode by type or class (e.g., power transformer, electrolitic capacitor, etc.).

b. Count the number of elements of each class or type contained in each operational path or mode.

c. For each operational path or mode, multiply the number of elements of each class or type by generic failure rate (either use generic failure rate data in MIL-HDBK-217A or use field failure data on similar equipment subjected to similar anticipated operational conditions).

d. For each operational path or mode sum the products formed in (i)3c over each category to obtain failure rate for each operational path or mode per category.

4. Write reliability relations for each operational path or mode for each category. In general, these should have the following form:

$$R = \exp(-\lambda t) \quad \text{or}$$

$$R = \exp(-t/T)$$

where:

R is reliability
exp is base of natural logarithms
λ is number of failures/unit time
T is Mean Time Between Failures
t is operating time

(j) Write three explicit reliability equations for each functional block. To do this, substitute relations per category from (i)4 into the block probability of success equations generated during activity (h). (One equation expresses block reliability for active elements that are not repaired, another equation expresses block reliability for active elements that are repaired at a Naval Air Rework Facility and the other equation expresses block reliability for active elements that are repaired at the intermediate level of maintenance.)

(k) Write three explicit reliability equations for the end item. To do this, substitute the block reliability equations per category generated by the preceding activity into the equation generated by activity (e) (one equation expresses end item reliability for active elements that are not repaired, another equation expresses end item reliability for active elements that are repaired at a Naval Air Rework Facility and the other equation expresses end item reliability for active elements that are repaired at the intermediate level of maintenance.)

(l) Multiply each reliability equation by minus one and take the derivative with respect to time. Multiply the derivatives by t dt and integrate the products from zero to infinity. By mathematical definition, this gives three MTBF values. Divide each MTBF into the maintenance cycle base. One of the three results so produced is the MRF (consumable), another is the MRF (repairable, and the other is the RPF (repairable).

As written this general procedure applies to all possible combinations that might arise in the design of avionic equipment having either redundant paths or operational modes. Because it is a general procedure, it also applies if redundancy of function or operation are not designed into equipment; however, if redundancy of function or operation are not designed into equipment then the procedure essentially degenerates to an evaluation of a series circuit with lumped parameters.

(2) Specific Procedures. When avionic equipment does degenerate to a series circuit, the procedure to be used with MIL-HDBK-217A is defined by the following activities:

(a) Define what constitutes successful performance of the equipment and identify all active elements, or components, that are needed to ensure a successful performance.

(b) Consign these needed elements to one of the following categories:

1. If the element fails, it is not repaired.

2. If the element fails, it is repaired at a Naval Air Rework Facility.

3. If the element fails, it is repaired at the intermediate level of maintenance.

(c) Compute failure rate of equipment for each category defined in the above activity.

1. Classify all elements by type or class (e.g., power transformer, electrolitic capacitor, etc.).

2. Count the number of elements per category of each type or class.

3. Multiply the number of elements per category of each type or class by generic failure rate (use data from MIL-HDBK-217A or use field failure data on similar equipment subjected to similar anticipated operational conditions or use factors in item 5 of Table I).

4. Sum the products formed in (c)3 over each category to obtain three failure rates per equipment (one is failure rate for consumables, another is failure rate to NARF, and the third is failure rate to the IMA).

(d) Multiply each failure rate generated in (c)4 by the maintenance cycle base to obtain three replacement factors (one is the maintenance replacement factor for consumables (i.e., MRF), another is the maintenance replacement factor for the NARF (i.e., MRF), and the third is the maintenance replacement factor to the IMA (i.e., RPF)).

(e) Write a reliability equation for each category. (In general, these should have the form of the reliability equations shown in 2b(1)(i)4.)

(3) For a series configuration, the following alternative procedure developed by NADC can be used.

(a) Step 1 - Using the worksheet of Table 1, fill in items 1 through 4 for the assembly for which factors are to be computed.

(b) Step 2 - Using the latest parts list for the assembly, fill in item 7, the quantity for each component part type listed in item 5.

(c) Step 3 - For each row, multiply item 6 by item 7 and place the result in item 8 to two decimal places.

(d) Step 4 - Add all of the column entries in item 8 and place the sum in item 9.

(e) Step 5

1. If the assembly under consideration is at the AN level, Figure 1 can be entered directly as follows: Using item 9, enter Figure 1 at the bottom scale marked "AEG," trace up to the line, trace to the left scale marked "FHFB," read the result, perform the indicated division and fill in items 10, 11, and 12.

2. If the assembly is at the SRA or WRA level,

corresponding worksheets must be completed for all other SRA or WRA assemblies which make up the complete AN equipment. The AEG count in item 9 must be summed for all such worksheets to give a single AN equipment level AEG count. Figure 1 can now be entered as in 1 above.

3. Examples

a. Non-Avionic Equipment. See paragraph (4) under the heading of TIME DEPENDENT RATE OF DEGENERACY in Appendix II.

b. Avionic Equipment. To assess the specific procedure using data from MIL-HDBK-217A and the alternative specific procedure using the NADC curve for degree of validity and ease of application with respect to avionic equipment, an analysis to obtain measures of the FHFB, MRF, and RPF was conducted. The subject of the analysis was the RT848/ALQ100 system developed by Sanders Associates, Inc. The analysis consisted of the following activities:

(1) Average failure rate data on the RT848/ALQ100 system were collected from the naval 3-M system. Data covered three-month intervals over a period of 21 months beginning in January 1969 and ending in September 1970. Elements of data were obtained from NATSF (Naval Air Technical Services Facility) and MSO (Maintenance Support Office). From these data, it was determined that the average FHFB for a three-month period is 84 with a standard deviation of 39.

(2) Design data were collected on the 1,622 active elements and 2,600 passive elements of the RT848/ALQ100 system. These data include types of components, number of types of components, purpose of components, and expected stress conditions during operation. Sources of data included Weapons Systems Test of Naval Air Test Center and Sanders Associates, Inc.

(3) Using the specific procedure based upon MIL-HDBK-217A, design data on all elements were used to compute the quantity MTBF which was subsequently converted to the quantity FHFB by the method used at ASO under the assumption that the ratio of ground operating time to flight operating time is 0.25. This FHFB was then used to compute the quantities RPF and MRF.

Preliminary preparations included the development of an identification system in accordance with the following schema. The RT848/ALQ100 Receiver/Transmitter is referred to by the designator 3A. Three immediate lower assemblies are referred to by the designators 3A1, 3A2, and 3A3. The 3A1 is the Upper Deck Assembly. Subsystem Replaceable Assemblies of the 3A1 are referred to as 3A1A1, 3A1A2, 3A1A3, ..., etc. Each subunit of each Subsystem Replaceable Assembly is referred to by using the designator of the Subsystem Replaceable Assembly plus an added indicator for the subunit. As an example, PWA Board #1 in the LVPS is the 3A1A1A1. The complete breakdown structure formed in this manner is shown in Table II.

To obtain some measure of the relative contribution of active elements, the same procedure was used to compute the quantities FHFB, RPF, and MRF using only active elements. These results are shown in Table III. A sample of the computational procedure used is shown by Tables IV through VII.

Sources of literature used in this procedure include:

(a) MIL-HDBK-217A, Reliability Stress and Failure Rate Data for Electronic Equipment, dated 1 December 1965.

(b) IBM Parts Lists, dated 12 July 1969.

(c) Drawing 34215, Level Breakdown, AN/ALQ-100, Unit 3 Lot #3 Configuration.

(d) Contact Report CR-16-046 from C. Chleboski Concerning Failure Rates of Leadscrew Actuated, Variable Wirewound Resistors, dated 25 September 1967.

(e) Reliability/Maintainability Memorandum 1-1613-580, Failure Rate Calculations for Selected AN/ALQ-81/100 Cubes, dated 16 September 1968.

(4) In applying the procedure, the following conditions were observed:

(a) Part failure rates were assumed to be functionally independent and to occur randomly in time, i.e., the equipment is free from early life failures.

(b) Part failure rates were assumed to remain constant throughout their useful life.

(c) Part temperatures were assumed to be 70°C maximum except for tubes and transformers. For these devices, the specification temperature requirements were utilized as the maximum ambient temperature.

(d) A serial system reliability dependency is assumed, i.e., a failure of any part constitutes a failure of the entire system.

(e) A part failure is defined as an open, short or parameter change greater than the specified tolerance.

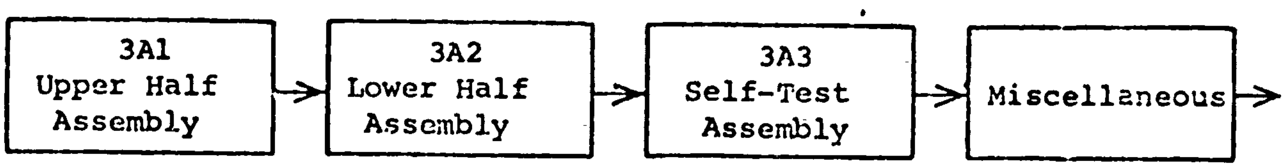
(f) References (b) and (c), equipment parts list and level breakdown, were utilized as the basic source of data for computations in this prediction.

(g) Failure rates of leadscrew actuated, variable wirewound resistors were taken from reference (d).

(h) Failure rates for selected cubes were taken from reference (e).

(i) Equipment operating environment was assumed to correspond to the airborne environment of MIL-HDBK-217A.

(j) The operational block diagram of the system is defined as follows:



(5) Design data confined to active elements were used to compute the quantities AEG (Active Element Group) of the

hours on similar types of avionic equipment while operating under adverse environmental conditions anticipated for equipment being provisioned. As such information is not now available from current data reporting system, an experiment must be designed to track avionic systems from time of initial inception to time of stabilization, compile performance data, and compute predicted provisioning factors to be compared with performance factors. (Until such an experiment has been designed and evaluated, performance data that can be obtained from any source, e.g., MSO, ASO, or contractors should be used.)

In the process of compiling and using the described procedures, it was ascertained that prediction by any procedure entails an understanding of the principles of reliability and probability and operational functions of engineering equipment. In particular, with respect to avionics, a fundamental background in electronics is required to perform circuit analysis at the level of recognizing operational redundancy or failure modes and classifying active elements by type and function. From this finding, it is concluded that provisioning of technical equipment should be accomplished or influenced by people with requisite technical training.

TABLE II

BREAKDOWN STRUCTURE OF RT848/ALQ100

DESIGNATOR	NOMENCLATURE	LEVEL OF REPAIR
Unit 3A	Receiver Transmitter - RT848/ALQ100	IMA
3A1	Upper Half Assembly	IMA
3A1A1	Low Voltage Power Supply	IMA
3A1A2	Intermediate Power Supply #1	IMA
3A1A3	Intermediate Power Supply #2	IMA
3A1A4	SMT Assembly	IMA
3A1A8	Low Band CMT/TMT	IMA
3A1A9	High Band CMT/TMT	IMA
3A1A10	High Band Video Control	IMA
3A1A11	Low Band Video Control	IMA
3A1A12	Programmer	NARF
3A1A13	Low Coupler Loop Equalizer	IMA
3A1A14	Low Switch Loop Mod Assembly	IMA
3A1A15	High Switch Loop Mod Assembly	IMA
3A1A16	Self-Test Input	(Consumable)
3A1A22	Loop Grid Driver	(Consumable)
3A1A24	Audio Output PWA	IMA
3A1V2	High Band Driver TWT	NARF
3A1V3	High Band Loop TWT	NARF
3A1V4	High Band Input TWT	NARF
3A1V5	Low Band Loop Driver TWT	NARF
3A1V6	High Band Input TWT	NARF
3A1B1	Fan Vane Axial	(Consumable)
3A1B2	Fan Vane Axial	(Consumable)
3A1S2	RF Coaxial Switch	(Consumable)
3A1DC1	High Band Loop Coupler	(Consumable)
3A1DL1	Low Band Delay Line	(Consumable)
3A1DL2	High Band Delay Line	(Consumable)
3A1FL3	Input Diplexer	(Consumable)
3A1FL5,6	CW, SW Limiter	(Consumable)
3A1CP1,2	High Band CMT T-Connector	(Consumable)
3A1CR5,6	Crystal Detectors	(Consumable)

TABLE II--Continued

DESIGNATOR	NOMENCLATURE	LEVEL OF REPAIR
3A2	Lower Half Assembly	IMA
3A2A1	High Voltage Power Supply #1	IMA
3A2A2	High Voltage Power Supply #2	IMA
3A2A3	Low Band Modulator	IMA
3A2A4	High Band Modulator	IMA
3A2A8	Prime Power Control	IMA
3A2A9	200 V Mod "A" Power Supply	IMA
3A2A10	200 V Mod "B" Power Supply	IMA
3A2A11	400 V Mod "A" Power Supply	IMA
3A2A12	400 V Mod "B" Power Supply	IMA
3A2A13	Filament Regulator	IMA
3A2A14	Power Output Coupler	(Consumable)
3A2A15	Cable Driver	(Consumable)
3A2B1	Fan Vane Axial	(Consumable)
3A2FL1	Output Diplexer	(Consumable)
3A2FL2	RFI Filter Cap Fixed	(Consumable)
3A2F1,2,3	Fuses	(Consumable)
3A2HP1	Pump Pack Hyd Coolant	NARF
3A2M1	Meter E.T.I.	(Consumable)
3A2T1,2	Filament Transformers	(Consumable)
3A2V1	Final High Band TWT	NARF
3A2V2	Final Low Band TWT	NARF
3A3	Self-Test	IMA
3A3A1	PWA Self-Test #1	IMA
3A3A2	PWA Self-Test #2	IMA

TABLE III
SUMMARY OF RESULTS
RT848/ALQ100

Number of Elements	Method	FHFB (Flight Hour Failure Base)			Provisioning Factors (%)			Standard Deviation in FHFB
		System	IMA	NARF	System	Rotatable Pool Factor	Maintenance Replacement Factor	
4222 (All)	MIL-HNBK-217A	131	154	854	76.7	65	11.7	
1622 (Active)	MIL-HNBK-217A	178	225	854	56	44.3	11.7	
	NADC	100	110	195	100	90.9	53.7	
4222 (All)	Real World Failure Data (3-M)	84			119			39

TABLE IV

SUMMARY SHEET (MIL-HNBK-217A)
RT848/ALQ100

Designator	N Number of Parts	NK λ 10^6
3A1	1970	3340.07
3A2	1458	2020.05
3A3	784	735.48
Misc.	10	12

Total 4222 6107.6

$$MTBF = \frac{10^6}{NK\lambda} = \frac{10^6}{6107.6} = 163.73$$

TABLE V

SUMMARY SHEET (MIL-HNBK-217A)

3A1 UPPER HALF ASSEMBLY

Designator	Number of Units	Number of Parts Per Unit	Number of Parts	NK λ 10^6
3A1A1	1	329	329	450.67
3A1A2	1	142	142	230.42
3A1A3	1	139	139	237.32
3A1A4	1	93	93	131.60
3A1A8	1	190	190	213.73
3A1A9	1	190	190	213.73
3A1A10	1	258	258	294.28
3A1A11	1	270	270	307.78
3A1A12	1	122	122	248.27
3A1A13	1	1	1	4.80
3A1A14	1	1	1	3.60
3A1V2	5	1	5	500.00
3A1A15	1	1	1	3.60
3A1A16	1	1	1	9.80
3A1A22	1	37	37	35.85
3A1B1,2	2	1	2	34.00
3A1A24	1	70	70	78.28
Other	127	1	127	342.34
Total			1970	3340.07

TABLE VI

SUMMARY SHEET (MIL-HNBK-217A)
3A1A1 LVPS ASSEMBLY

Designator	Number of Units	NK λ 10^6
3A1A1A1	1	48.86
3A1A1A2	1	124.86
3A1A1A3	1	99.74
3A1A1FL1	1	8.93
Misc.	108	168.28
Total		450.67

TABLE VII

SUMMARY SHEET (MIL-HNBK-217A)
3A1A1 LVPS ASSEMBLY

Subsystem Designator	Part Type	N Number of Parts	Stress Ratio	$\lambda\ 10^6$ Failure Ratio	K Environmental Factor	$NK\lambda\ 10^6$
Misc.	Resistor					
	RC Composition	17	0.1	0.0035	10.0	.595
	RN Film	11	0.3	0.2200	0.3	.726
	RW Wirewound	7	0.2	0.0120	50.0	4.2
	RT Variable W.W.	2	0.2	0.9100	3.0	5.46
	Capacitor					
	CK Ceramic	2	0.1	0.0060	5.0	.06
	CSR Tantalum Solid	2	0.3	0.00025	1.0	.0005
	CL Tantalum Wet	1	0.4	0.0450	5.0	.225
	CL Tantalum Foil	3	0.2	0.1000	8.0	2.4
	Transistor					
	PNP <1W	2	TN = 0.4	0.9200	8.0	14.72
	NPN <1W	9	TN = 0.4	0.3250	8.0	23.4
	>1W	9	TN = 0.4	0.6500	8.0	46.8
	Diode					
	Zener	11	TN = 0.4	0.9800	3.0	32.34
	Silicon <1W	28	TN = 0.4	0.3250	3.5	31.85
	Transformers	2		0.2100	10.0	4.2
	Relay	1		0.0020	50.0	.1
	Connector	1		0.2	6.0	1.2
Total		108				168.2765

TABLE VII--Continued

Subsystem Designator	Part Type	N Number of Parts	Stress Ratio	λ 10[6] Failure Ratio	K Environmental Factor	NKλ 10[6]
3A1A1A1	Resistor					
	RC Composition	10	0.1	0.0035	10.0	.35
	RN Film	2	0.3	0.2200	0.3	.132
	RW Wirewound	1	0.2	0.0120	50.0	.60
	Capacitor					
	CL Tantalum Wet	1	0.4	0.0450	5.0	.225
	Transistor					
	PNP <1W	1	TN = 0.4	0.9200	8.0	7.36
	NPN <1W	1	TN = 0.4	0.3250	8.0	2.6
	Diode					
	Zener	3	TN = 0.4	0.9800	3.0	8.82
	Silicon <1W	12	TN = 0.4	0.3250	3.5	13.65
	>1W	6	TN = 0.4	0.6200	3.5	13.02
	Transformers	1		0.2100	10.0	2.1
Total		38				48.857
3A1A1A2	Resistor					
	RC Composition	23	0.1	0.0035	10.0	.805
	RN Film	11	0.3	0.2200	0.3	.726
	Capacitor					
	CL Tantalum Wet	4	0.4	0.0450	5.0	.9

TABLE VII--Continued

Subsystem Designator	Part Type	N Number of Parts	Stress Ratio	λ 10^6 Failure Ratio	K Environmental Factor	NKλ 10^6
3A1A1A2 (Cont.)	Transistor					
	PNP <1W	1	TN = 0.4	0.9200	8.0	7.36
	NPN <1W	12	TN = 0.4	0.3250	8.0	31.2
	>1W	5	TN = 0.4	0.6500	8.0	26.0
	Diode					
	Zener	4	TN = 0.4	0.9800	3.0	11.76
	Silicon <1W	31	TN = 0.4	0.3250	3.5	35.2625
	>1W	5	TN = 0.4	0.6200	3.5	10.85
Total		96				124.8635
3A1A1A3	Resistor					
	RC Composition	13	0.1	0.0035	10.0	.455
	RN Film	9	0.3	0.2200	0.3	.594
	RW Wirewound	5	0.2	0.0120	50.0	3.0
	RT Variable W.W.	2	0.2	0.9100	3.0	5.46
	Capacitor					
	CK Ceramic	2	0.1	0.0060	5.0	.06
	CSR Tantalum Solid	2	0.3	0.00025	1.0	.0005
	CL Tantalum Wet	1	0.4	0.0450	5.0	.225
	CL Tantalum Foil	1	0.2	0.1000	8.0	.018
	Transistor					
	PNP <1W	2	TN = 0.4	0.9200	8.0	14.72
	NPN <1W	6	TN = 0.4	0.3250	8.0	15.6
	>1W	2	TN = 0.4	0.6500	8.0	10.4

TABLE VII--Continued

Subsystem Designator	Part Type	N Number of Parts	Stress Ratio	$\lambda 10^6$ Failure Ratio	K Environmental Factor	$NK\lambda 10^6$
3A1A1A3 (Cont.)	Diode					
	Zener	9	TN = 0.4	0.9800	3.0	26.46
	Silicon <1W	20	TN = 0.4	0.3250	3.5	22.75
Total		74				99.7425
3A1A1FL1	Resistor					
	RN Film	2	0.3	0.2200	0.3	.132
	Capacitor					
	CL Tantalum Foil	11	0.2	0.1000	8.0	8.8
Total		13				8.932

TABLE VIII
SUMMARY SHEET (NADC CURVE)

REPLACEMENT FACTORS WORKSHEET

1. Nomenclature: RT848/ALQ100
2. Work Unit Code: ______
3. Assembly Level: 3A
4. Next Highest Assembly: ______

5. Component Part Type	6. AEG Weighting Factor	7. Number Replaced or Repaired At		8. Component AEG (6 x 7) At	
		IMA	NARF	IMA	NARF
Transistor - Analog	1.0	311	14	311.00	14.8
Transistor - Digital	0.5	199	12	99.50	6.0
Transistor - Power	4.0	1	0	4.00	0.0
Diode - Switching	0.1	794	8	79.40	0.8
Diode - Microwave, Varactor	0.8	206	15	164.80	12.0
Integrated Circuit - Analog	0.12	21	0	2.52	0.0
Integrated Circuit - Digital	0.06	1	0	0.06	0.0
Tube - Display, Radar	20.0	0	7	0.00	140.0
Relay/Switch	0.2	25	0	5.00	0.0
Rotating Device	3.6	3	3	10.80	10.8
Lamp	0.4	0	2	0.00	0.8
9. AEG Count				677.08	184.4
10. FHFB (Add AEG Count of IMA and NARF. Use the result to obtain FHFB from Figure 1.)				100	
11. RPF (Use AEG Count to IMA to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the RPF in percent.)				90.9	
12. MRF (Use AEG Count to NARF to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the MRF in percent.)					53.7

Definitions:

MRF - Maintenance Replacement Factor as defined in ASO INST 4441.15A.

AEG - Active Element Group as defined in MIL-HDBK-217A.

FHFB - Mean Flight Hours Between Failures.

Weighting Factor - A factor based upon relative part failure rates.

RPF - Rotatable Pool Factor as defined in ASOINST 4441.15A.

TABLE IX

REPLACEMENT FACTORS WORKSHEET

1. Nomenclature: Self-Test
2. Work Unit Code: ______
3. Assembly Level: 3A3
4. Next Highest Assembly: RT848/ALQ100

5. Component Part Type	6. AEG Weighting Factor	7. Number Replaced or Repaired At: IMA	7. NARF	8. Component AEG (6 x 7) At: IMA	8. NARF
Transistor - Analog	1.0				
Transistor - Digital	0.5				
Transistor - Power	4.0				
Diode - Switching	0.1				
Diode - Microwave, Varactor	0.8				
Integrated Circuit - Analog	0.12				
Integrated Circuit - Digital	0.06				
Tube - Display, Radar	20.0				
Relay/Switch	0.2				
Rotating Device	3.6				
Lamp	0.4				

9. AEG Count: 120.8

10. FHFB (Add AEG Count of IMA and NARF. Use the result to obtain FHFB from Figure 1.): 220

11. RPF (Use AEG Count to IMA to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the RPF in percent.): 45.4

12. MRF (Use AEG Count to NARF to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the MRF in percent.)

Definitions:

MRF - Maintenance Replacement Factor as defined in ASO INST 4441.15A.

AEG - Active Element Group as defined in MIL-HDBK-217A.

FHFB - Mean Flight Hours Between Failures.

Weighting Factor - A factor based upon relative part failure rates.

RPF - Rotatable Pool Factor as defined in ASOINST 4441.15A.

TABLE X

REPLACEMENT FACTORS WORKSHEET

1. Nomenclature: PWA Self-Test #1
2. Work Unit Code: ____
3. Assembly Level: 3A3A1
4. Next Highest Assembly: 3A3 Self-Test

5. Component Part Type	6. AEG Weighting Factor	7. Number Replaced or Repaired At: IMA	7. NARF	8. Component AEG (6 x 7) At: IMA	8. NARF
Transistor - Analog	1.0	19		19.00	
Transistor - Digital	0.5	44		22.00	
Transistor - Power	4.0	0		0.00	
Diode - Switching	0.1	144		14.40	
Diode - Microwave, Varactor	0.8	22		17.60	
Integrated Circuit - Analog	0.12	14		1.68	
Integrated Circuit - Digital	0.06	0		0	
Tube - Display, Radar	20.0	0		0	
Relay/Switch	0.2	0		0	
Rotating Device	3.6	2		0.40	
Lamp	0.4	0		0	

	IMA	NARF
9. AEG Count	75.08	
10. FHFB (Add AEG Count of IMA and NARF. Use the result to obtain FHFB from Figure 1.)	265	
11. RPF (Use AEG Count to IMA to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the RPF in percent.)	37.7	
12. MRF (Use AEG Count to NARF to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the MRF in percent.)		

Definitions:

MRF - Maintenance Replacement Factor as defined in ASO INST 4441.15A.

AEG - Active Element Group as defined in MIL-HDBK-217A.

FHFB - Mean Flight Hours Between Failures.

Weighting Factor - A factor based upon relative part failure rates.

RPF - Rotatable Pool Factor as defined in ASOINST 4441.15A.

TABLE XI

REPLACEMENT FACTORS WORKSHEET

1. **Nomenclature:** PWA Self-Test #2
2. **Work Unit Code:** ____________
3. **Assembly Level:** 3A3A2
4. **Next Highest Assembly:** 3A3 Self-Test

5. Component Part Type	6. AEG Weighting Factor	7. Number Replaced or Repaired At		8. Component AEG (6 x 7) At	
		IMA	NARF	IMA	NARF
Transistor - Analog	1.0	31		31.00	
Transistor - Digital	0.5	0		0	
Transistor - Power	4.0	0		0	
Diode - Switching	0.1	34		3.40	
Diode - Microwave, Varactor	0.8	14		11.20	
Integrated Circuit - Analog	0.12	1		.12	
Integrated Circuit - Digital	0.06	0		0	
Tube - Display, Radar	20.0	0		0	
Relay/Switch	0.2	0		0	
Rotating Device	3.6	0		0	
Lamp	0.4	0		0	

9. AEG Count ____ 45.72 ____

10. FHFB (Add AEG Count of IMA and NARF. Use the result to obtain FHFB from Figure 1.) ____ 325

11. RPF (Use AEG Count to IMA to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the RPF in percent.) ____ 30.7

12. MRF (Use AEG Count to NARF to obtain FHFB from Figure 1. Divide this FHFB into 10,000. This is the MRF in percent.) ____

Definitions:

MRF - Maintenance Replacement Factor as defined in ASO INST 4441.15A.

AEG - Active Element Group as defined in MIL-HDBK-217A.

FHFB - Mean Flight Hours Between Failures.

Weighting Factor - A factor based upon relative part failure rates.

RPF - Rotatable Pool Factor as defined in ASOINST 4441.15A.

APPENDIX IV

REFERENCES

(1) Work Unit No. 4012A-1, "Developing Improved Replacement Factors," 27 January 1971.

(2) Airtask No. A402012 2014 1402000001, "Evaluation of Provisioning Policies and Procedures for NAVAIRSYSCOM Weapons Systems Equipment," 1 April 1970.

(3) ASO Instruction 4441.15A, "Development of Initial Outfitting Lists; policy and procedures for," 26 August 1970.

(4) MIL-STD-721B, "Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety," 25 August 1966.

(5) MIL-HDBK-217A, "Reliability Stress and Failure Rate Data for Electronic Equipment," 1 December 1965.

(6) MIL-STD-757, "Reliability Evaluation from Demonstration Data," 19 June 1964.

(7) NAVAIR 00-65-502, "Handbook Reliability Engineering," 1 June 1964.

(8) MIL-STD-785A, "Reliability Program for Systems and Equipment Development and Production," 28 March 1969.

Naval Aviation Integrated Logistic Support
Center, Patuxent River, Maryland 20670

MAINTENANCE REPLACEMENT FACTORS

76 pgs
18 Oct 1971
03-7

Mr. Ray R. Boyce
AT1 Louis W. Weinstein

Unclassified

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hours on similar types of avionic equipment while operating under adverse environmental conditions anticipated for equipment being provisioned. As such information is not now available from current data reporting system, an experiment must be designed to track avionic systems from time of initial inception to time of stabilization, compile performance data, and compute predicted provisioning factors to be compared with performance factors. (Until such an experiment has been designed and evaluated, performance data that can be obtained from any source, e.g., MSO, ASO, or contractors should be used.)

In the process of compiling and using the described procedures, it was ascertained that prediction by any procedure entails an understanding of the principles of reliability and probability and operational functions of engineering equipment. In particular, with respect to avionics, a fundamental background in electronics is required to perform circuit analysis at the level of recognizing operational redundancy or failure modes and classifying active elements by type and function. From this finding, it is concluded that provisioning of technical equipment should be accomplished or influenced by people with requisite technical training.