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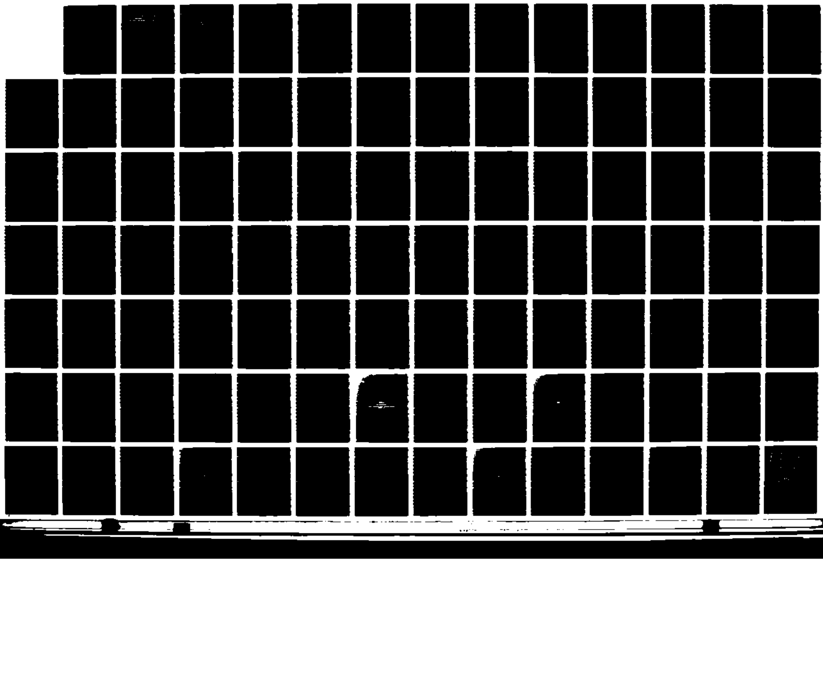

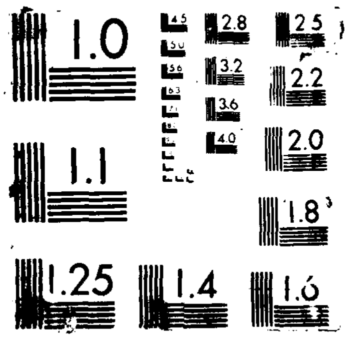
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FEASIBILITY STUDY ON DETERMINING THE EFFECT OF TESTING ON HARPOON MISSILE SYSTEM RELIABILITY

by
E. Oelkers
J. J. Labra, Ph.D., P.E.

FINAL REPORT
SwRI Project No. 15-5607-824

Prepared for
United States Navy
Pacific Missile Test Center (PMTC)
Pt. Mugu, California 93042

Performed as a Special Task for the Nondestructive Testing Information Analysis Center under Contract No. DLA-900-79-C-1266, CLIN 0001AT

June 1985

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The effect of testing on the Harpoon Missile System reliability can be determined by the data retrieval and analyses described in this feasibility study. Emphasis is placed on five missile subassemblies including the guidance section, the guidance section's seeker, altimeter, and midcourse guidance unit, and the midcourse unit's attitude reference assembly, and digital computer/power supply. Extraneous effects on reliability including the several design and environment categories and the multiple types of testing performed on the missile subassemblies can be controlled or measured. A data retrieval plan prepared in cooperation with McDonnell-Douglas Astronautics Company would provide the data needed for the analysis. Statistical analysis methodology to estimate time-between-failure distributions and distribution parameters, and regression analysis with associated ANOVA can be used to relate the subassemblies' reliability characteristics to the cumulative item age, power on-off cycles, and power-on time. Subject to assumption of multicollinearity on the order of 70% to 90%

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correlation among these variables, changes in MTBF on the order of 30% to 50% could be detected in a pilot analysis program employing a population of 500 item histories. Such a pilot program would determine the degree of multicollinearity, and would provide reliability estimates for the missile subassemblies with much tighter error bars than those normally employed.

PREFACE

This project was performed by Southwest Research Institute for the Pacific Missile Test Center (PMTC) as a special task under auspices of the Nondestructive Testing Information Analysis Center (NTIAC). Funding was provided through NTIAC under item No. 0001AT of Contract DLA900-79-C-1266.

The task manager was Dr. John J. Labra of the Engineering and Materials Sciences Division at Southwest Research Institute, and the principal investigator was Mr. Edgar Oelkers of the Quality Assurance Systems and Engineering Division. The technical monitor was Mr. James Hipskind of PMTC. Coordination through NTIAC was provided by Dr. G. A. Matzkanin, Director of NTIAC.

ABSTRACT

The effect of testing on the Harpoon Missile System reliability can be determined by the data retrieval and analyses described in this feasibility study. Emphasis is placed on five missile subassemblies including the guidance section, the guidance section's seeker, altimeter, and midcourse guidance unit, and the midcourse unit's attitude reference assembly, and digital computer/power supply. Extraneous effects on reliability including the several design and environment categories and the multiple types of testing performed on the missile subassemblies can be controlled or measured. A data retrieval plan prepared in cooperation with McDonnell-Douglas Astronautics Company would provide the data needed for the analysis. Statistical analysis methodology to estimate time-between-failure distributions and distribution parameters, and regression analysis with associated ANOVA can be used to relate the subassemblies' reliability characteristics to the cumulative item age, power on-off cycles, and power-on time. Subject to assumption of multicollinearity on the order of 70% to 90% correlation among these variables, changes in MTBF on the order of 30% to 50% could be detected in a pilot analysis program employing a population of 500 item histories. Such a pilot program would determine the degree of multicollinearity, and would provide reliability estimates for the missile subassemblies with much tighter error bars than those normally employed.

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1. INTRODUCTION

The objective of the study reported herein is to determine the feasibility of evaluating the effect of testing on the Harpoon Missile System reliability. The scope of the feasibility study is limited to the Harpoon guidance section and the major subassemblies of the guidance section. However, the methodology developed in this report could be readily applied to other sections and to a finer level of replaceable assemblies for which similar test data are available.

The approach used in this study was to set the hypothetical goal of estimating the reliability characteristics including distribution and failure rate or mean-time-between failures (MTBF)* of the guidance section functional subsystems dependent on normal and test environment, calendar age, power-on time, and power on-off cycles. The necessary relationship between the data needed to estimate these characteristics and the data availability and retrieval feasibility is developed in Section 2. Data organization and analysis methodology are described in Section 3.

The initial application of data retrieval, transformation, and analysis is planned for the guidance section illustrated in Figure 1-1 adapted from Reference 1. The figure shows the relation of the section to the basic Harpoon missile and the major subassemblies of the guidance section. The missile components planned for initial analysis and discussed throughout this report include the guidance section as a component, its three major subassemblies: the seeker, the midcourse guidance unit (MGU), and the altimeter; and two subassemblies of the MGU: the attitude reference assembly (ARA) and the digital computer and power supply (DC/PS).

Although the objective of the present study is limited to feasibility of the effect of testing on reliability, the chronological data histories that would be retrieved for this study would contain test time data. The test time data together with definition of failure date and repair date would provide the basis

*Appendix A is a comprehensive glossary.

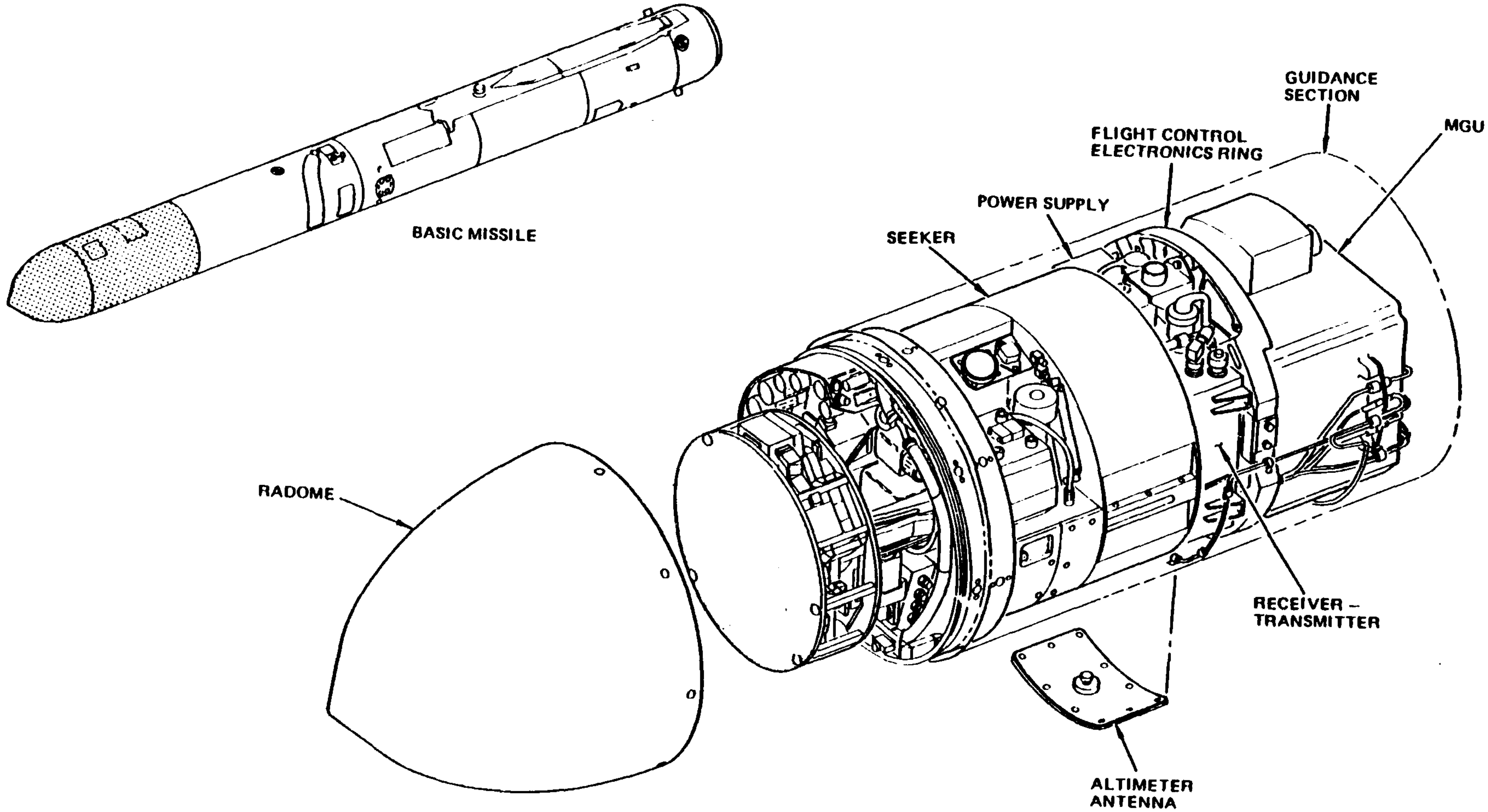

Figure 1-1. The Guidance Section

for estimating maintainability characteristics such as repair time and lead time. The reliability and maintainability characteristics together would define the availability of the missile and its subsystems, a constituent element of operational readiness.

The problem of determining the effect of testing on reliability is complicated by potential extraneous factors. These include historical improvements in the design of missile sections or subassemblies, time spent in depot storage, Naval Weapons Station (NWS) magazine, and the various missile configurations with associated deployment environments. All these effects, as well as the organizational, intermediate, and various depot level testing, can be considered as effects defining categories of like items in missile and subassembly population and environment.

Missile deployment environment is defined by missile configuration, as shown in Figure 1-2, adapted from Reference 1. The four basic missile configurations including air-launched, ASROC, TARTAR, and capsule/canister are illustrated. The air-launched differs from all others in that no rocket booster is used. The air-launched and ASROC configurations both use fully extended missile wings and control fins, and the ASROC booster uses fully extended fins. The TARTAR and capsule/canister configurations both use folded wings, control fins, and booster fins, which must automatically extend upon launching. The TARTAR and capsule/canister folded wing and fin designs differ between the two configurations. Furthermore, the canister configuration may be deployed in either a lightweight or shock-resistant canister launcher, and the encapsulated missile is deployed by submarine tenders and submarines.

As far as the guidance section and other missile components are concerned, a significant indirect effect of the configuration differences lies in the environmental effects such as handling, vibration, and, to an extent, temperature and humidity that would differ among the various configurations due to the geometry, envelope, and platform characteristics. Further refinement of deployment environment categories would be obtained by addition of platform latitude—tropical, middle, or arctic deployment. This further refinement may not be necessary. It is expected to be insignificant where temperature and humidity

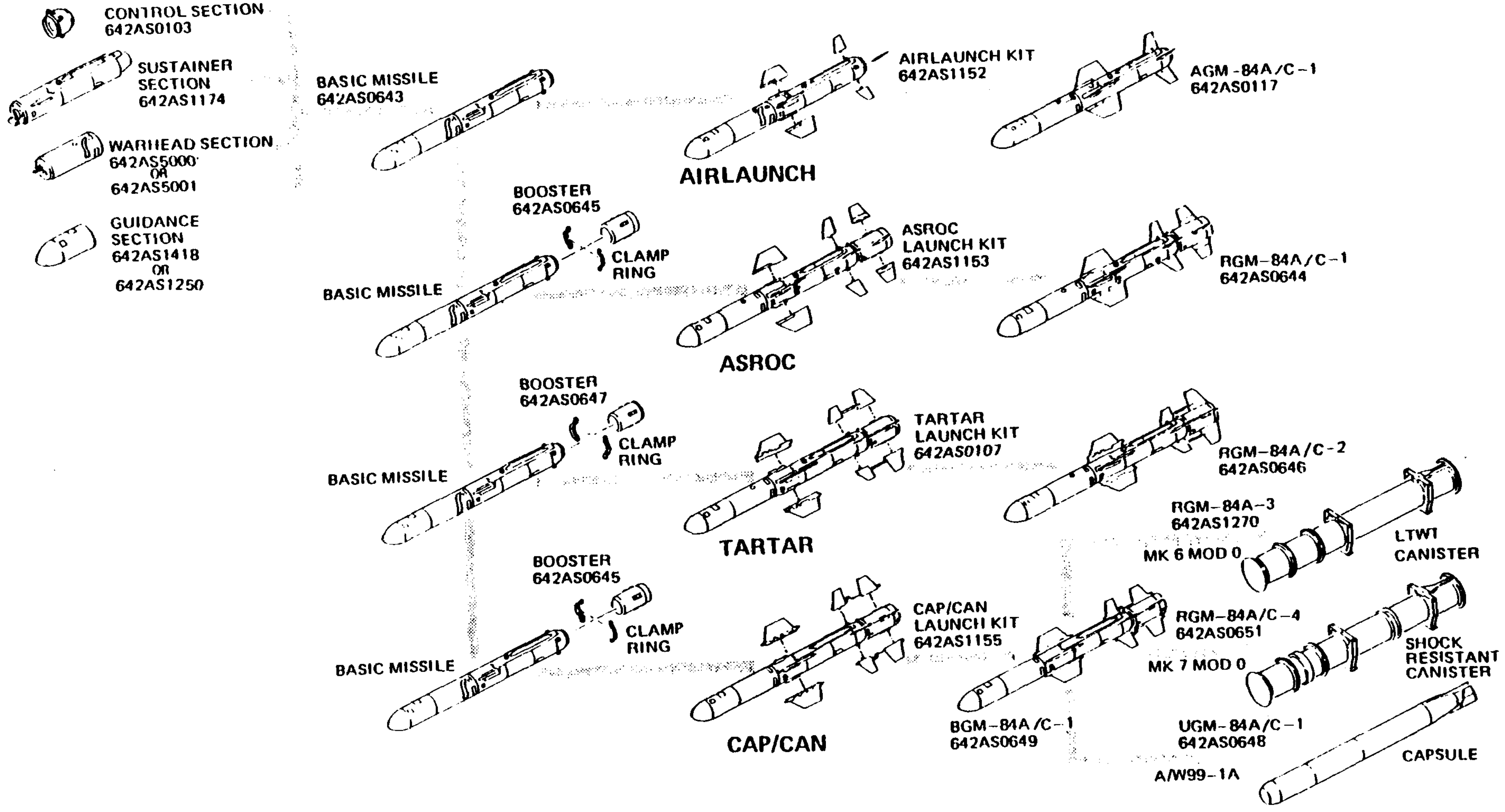

Figure 1-2. Harpoon Missile Buildup to Deployed Environmental Configurations

are consistent for the missiles within the deployed configuration as, for example, in the case of the submarine-launched capsule configuration. Furthermore, with a sufficient number of randomly selected sample population elements, such extraneous effects would be distributed over the range of calendar age, power-on time, and on-off cycles so that these effects would not be confounded (except by unlikely statistical accident) with the effect of testing on reliability.

These organizational level environment categories are summarized in Table 1-1 together with intermediate and depot level categories and testing. Built-in-test (BIT) at the organizational level contributes to the power-on time and on-off cycles for portions of the guidance section and subassembly circuitry. The storage environment at the intermediate level is designated "magazine" although this includes not only quiescent storage but also idle time on test stands, time in removal and installation of missile sections, and time in configuring basic missiles for fleet issue. Intermediate level testing comprises the various missile test module (MTM) exercises implemented in the missile subsystem test set (MSTS), Reference 2.

In addition to the organizational and intermediate levels summarized, Table 1-1 also shows the depot level breakdown. Analogous to the intermediate level case, a one-category depot "storage" category is provided to include the time when the section or subassembly is not under active test. Testing at the depot level includes testing with MSTS and a number of other test sets applicable to the subassemblies. For the guidance section subassemblies, this includes seven test sets for the seeker, one for the MGU as a whole, one for the ARA subassembly of the MGU, and two for the altimeter.

Table 1-2 reiterates the test sets for the guidance section and subassemblies, and the table provides abbreviated descriptions of the tests performed with each. The table shows that the guidance section as a whole is tested by the MSTS modules applicable to the section. Reference 3 indicates two levels of testing with the MSTS: (1) all-up-round (AUR), and (2) section level (S/L) tests. The two levels overlap approximately 50 percent in the testing performed. The reference contains a discussion of a number of the MSTS test MTMs applicable to the guidance section and its subassemblies, and the overlap among the test modules.

TABLE 1-1. ENVIRONMENTAL CATEGORIES AND TESTING

I. Organization Level

A. Missile Configuration

1. Air Launch
2. ASROC
3. TARTAR
4. CAP/CAN

(a) LTWT Canister
(b) Shock-Resistant Canister
(c) Capsule

B. Platform Name, Dates

1. Tropic
2. Temperate
3. Arctic

C. Built-in-Test (BIT)

II. Intermediate Level

A. Magazine
B. MSTS Guidance Section MTM's

III. Depot Level

A. Storage
B. Testing of Guidance Section

1. MSTS Guidance Section MTM's
2. Testing of Guidance Section WRA's

(a) Seeker Testing

(1) SITS
(2) AITS
(3) AACTS
(4) PSTS
(5) XMTRTS
(6) TEMPTS
(7) VIBTS

(b) MGU Testing

(1) MGUATS
(2) Testing of MGU Subassemblies

(aa) ARA

(i) ARATS

(bb) DC/PS

(c) Altimeter Testing

(1) RATS
(2) B/I ALT

TABLE 1-2. TEST SETS AND TESTS PERFORMED ON GUIDANCE SECTION AND ITS ELEMENTS

- Guidance Section

  MSTS Guidance Section MTMs—Acceptance, Recertification, TS

  - Seeker

    SITS—Transitional Zone Environment; Evaluate, TS, Rough MALT

    AITS—Transitional Zone Environment; TS, MALT

    AACTS—Far-Field Environment; TS, MALT, PREFAT, FAT

    PSTS—Seeker Power Supply Test

    XMTRTS—Seeker Transmitter Test, Matching Magnetron and Modulator

    TEMPTS—TEMP (Temperature Testing)

    VIBTS—VIB (Vibration Testing)

  - Midcourse Guidance Unit (MGU)

    MGUATS—TS, TEMP/VIB, MALT, FAT

    - ARA

      ARATS—TS, MALT, FAT

    - DC/PS

  - Altimeter

    RATS—TS, MALT, VIB, FAT

    B/I ALT—TEMP/VIB

For each of these MTMs, the number of measurements and the coded "P-code" test performed by each measurement are presented number by number. MSTS tests applicable to guidance section power-on time and on-off cycles include certain of the power-up MTM 5210 measurements, the MTM 5220 MGU load test, numerous MTM 5300's series seeker tests, MTM 5400's ARA tests, and MTM 5500's altimeter tests. Table 1-2 indicates that the MSTS is used for missile acceptance and recertification testing and for fault isolation troubleshooting (TS).

Seven test systems used on the seeker at the depot level indicated in Tables 1-1 and 1-2 include the system integration test set (SITS), automated integrated test system (AITS), automated anechoic chamber test system (AACTS), power supply test station (PSTS), transmitter test station (XMTRTS), temperature test station (TEMPTS), and vibration test station (VIBTS). SITS (Reference 4 and Appendix B) is a manually or automatically operated test station used to evaluate, troubleshoot, and perform rough alignments on Harpoon seekers in a transitional zone environment. AITS is an automatic or manually operated test system designed to test the seeker in a transitional zone environment. It is used for troubleshooting and for detailed manufacturing alignment test (MALT) before AACTS testing. AACTS is automatic or manually operated to test the seeker in a far-field environment. It is used for troubleshooting, detailed alignment, and selloff testing, or final acceptance testing (FAT), and for trial runs of seeker FAT prior to going into failure-free testing with temperature cycling (PREFAT). PSTS is a test set for the power supply subassembly of the seeker. XMTRTS is a manually operated station utilized to test Harpoon seeker transmitters and to match their component magnetrons and modulators. TEMPTS is a manually or automatically operated test station used for testing seekers under varying temperature environments from -65°F to 170°F. Finally, the VIBTS is a manually operated test station used to monitor seeker operation under random vibration conditions.

The MGU is tested as a component on the midcourse guidance unit automatic test station (MGUATS). This is an automatic or manually operated test system designed for troubleshooting, temperature and vibration tests, detailed alignment and selloff testing of Harpoon MGU's and their component attitude reference assemblies (ARA) and digital computer/power supplies (DC/PS). The ARA is also tested by the attitude reference assembly test set (ARATS) used for troubleshooting, alignment, and selloff testing.

The altimeter, also included in Tables 1-1 and 1-2, is tested by two depot-level systems. The radar altimeter test station (RATS) is a manual test set used for troubleshooting, detailed alignment, random vibration test monitoring, and selloff testing of the Harpoon altimeter. The altimeter burn-in test station (B/I ALT) is a manual test set used to monitor altimeter functions during temperature and vibration testing.

The various test sets and testing described above produce data with which reliability of missile components can be estimated. How the effect of this testing on the inherent reliability can be assessed is the subject of this report.

In addition to the various environmental categories and testing, a traceable progression of missile design improvements has been made. For the missile guidance section, this would result in roughly a half-dozen part code and serial number (P/C S/N) identifiable guidance section population categories. These categories would each contain a guidance section population that could be considered to comprise like items. Initial data analysis on two or more such categories could result in the statistical decision of not rejecting the hypothesis that the populations in the categories are equal. This would provide evidence that the categories could be combined to produce a larger population of like items more useful in detecting reliability changes resulting from testing. Similarly, several design generation population categories exist for the subassemblies. About five such P/C S/N identifiable categories exist for the seeker and for the MGU, three for the ARA and for the DC/PS, and one for the altimeter.

Section 2 of this report describes the data available and feasibly retrievable, and its organization; and the organization needed for analysis is introduced. Section 3 develops the needed organization, indicates how this structure would be obtained, and presents the analysis methodology that would be used to determine the effect of testing on the inherent reliability of the Harpoon missile system. Sections 4 and 5 present estimated costs for the analyses and present the conclusions of this feasibility study.

2. DATA

The data available and needed to determine the effect of testing on reliability comprises missile subassembly population, event, and environment information. The availability and feasibility of retrieving this data are developed in this section along with an introduction to data organization needed for analysis. In Section 3, the needed organization will be developed further and the analysis methodology presented.

The relationship among the missile subassembly population elements is dynamic since serialized sections, weapon replaceable assemblies (WRA's), and shop replaceable assemblies (SRA's) are interchangeable (e.g., upon failure) with other serialized components of the same type. Normally, a repair is achieved by interchange of serialized components. The failed component is repaired, placed in storage, and eventually built into a different missile with new population element neighbors. A sample population of components can be selected for analysis from a set of "as-built configuration lists," or from the corresponding McDonnell-Douglas computerized component buildup information system, STARS. An example as-built configuration list is contained in Appendix C for guidance section P/C 642AS1250-1, S/N GQN-0512. This as-built guidance section included seeker P/C 642AS3400, S/N GQN-0334, and midcourse guidance unit P/C 642AS1214, S/N GQN-0428, and altimeter P/C 642AS4100, S/N GQN-0477. The MGU included its attitude reference assembly P/C 101874-301, S/N 4100, and its digital computer/power supply P/C 642AS7789, S/N GQN-0033. Appendix C also presents the finer level of population detail including the P/C and S/N for the serialized SRA's and parts comprised by the as-built guidance section, seeker, MGU, ARA, DC/PS, and altimeter. Such a finer detail population definition would establish the scope of a larger study than the initial program which is proposed.

Upon interchange of a replaceable item such as a seeker, MGU, ARA, DC/PS, or altimeter, the relation of the P/C S/N population elements would be different in the (modified) configuration due to the introduction of a new serial number. In order to establish chronological histories of the selected population elements, it is necessary to trace each selected serialized element even after it has been removed from the original as-built configuration and subsequently reinstalled in other buildup configurations whether or not the subsequent configurations contain other population components in the selected sample. As discussed in Section 1, several design evolution categories may exist for each missile subassembly to be studied. The P/C S/N population should be chosen to provide an adequate number of sample population elements in each of the design categories to be analyzed. The desirable number of elements is related by the failure rate to the necessary number of failure events to achieve a specified analysis precision. A preliminary estimate for the total number of serial numbers to be traced is five hundred for each missile subassembly (guidance section, seeker, MGU, ARA, DC/PS, and altimeter). The relation between this number, the number of design categories, and the analysis precision will be developed in Section 3.

An organization of the population data is illustrated in Figures 2-1 and 2-2. Figure 2-1 illustrates the hierarchy of the guidance section and its subassemblies. Figure 2-1 also indicates, as an example, six design evolution categories of the guidance section, five design categories of seekers and MGU's, three of ARA's and DC/PS's, and one of altimeters. Corresponding to each defined subassembly category of Figure 2-1, Figure 2-2 illustrates a number of selected sample P/C S/N records constituting the population in a category.

The event information needed is data on the testing and test-revealed failure events of the missile subassemblies in the population sample. The testing information needed is subassembly calendar age, power-on time, and power on-off cycles. The failure event information needed is the subassembly (or subassemblies) failed and the date. Correlation between test date and calendar age is achieved by inservice date. Failure events are keyed to age by test date. Power-on time and power on-off cycles can be determined from appropriate test models, considering variables such as the test set used, the subassembly tested, and total test time. Thus, power-on time and cycles are also correlated to age and failure events by test date.

Figure 2-3 illustrates test data items that may enter the calculations of power-on time and on-off cycles. The combination of end item test level, test

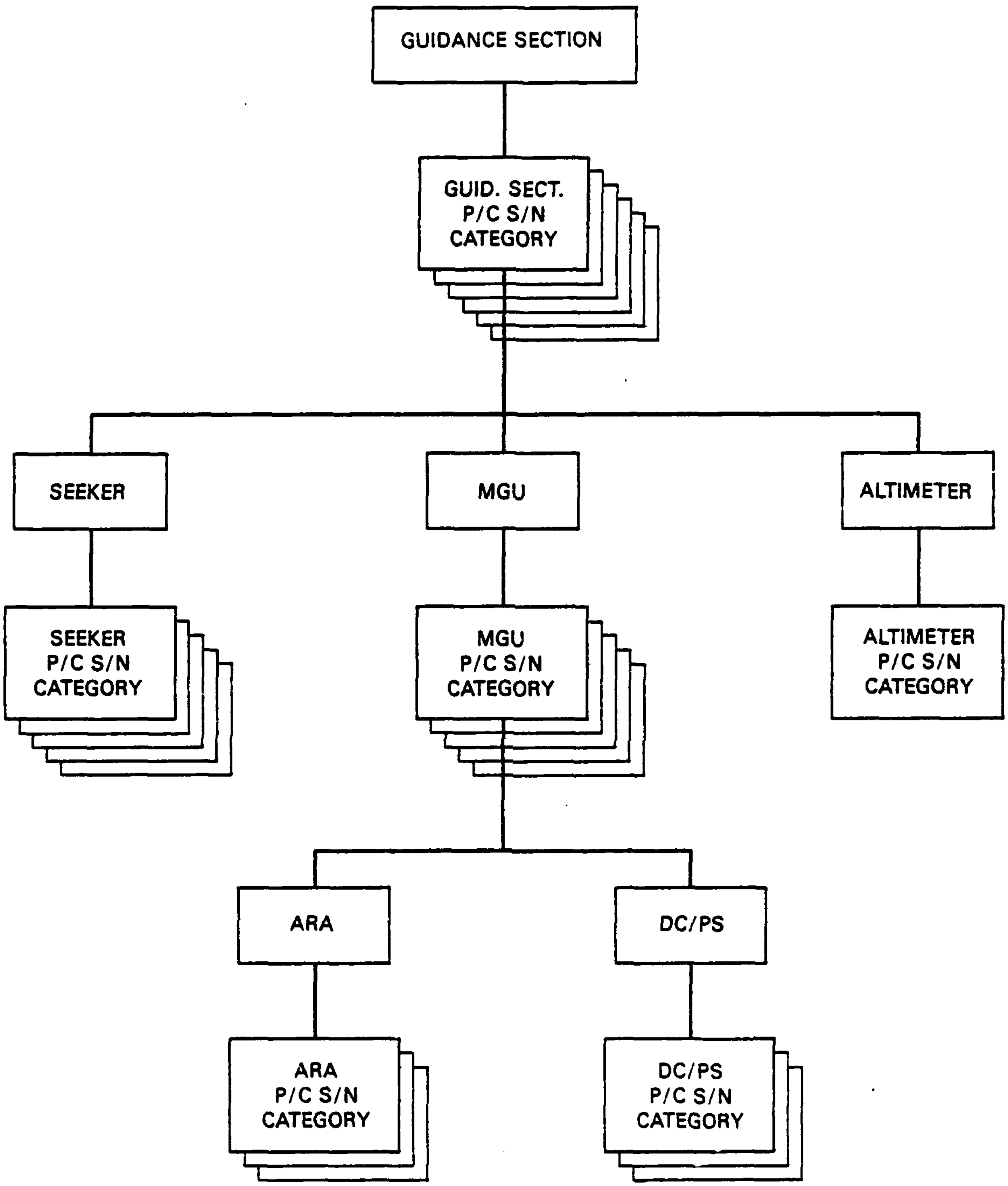

Figure 2-1. Subassembly Design Category Data Tree

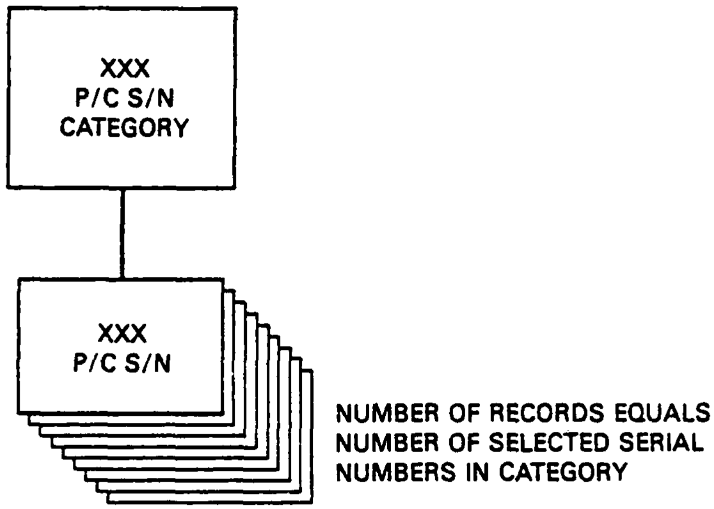

Figure 2-2. Population Data Subtree

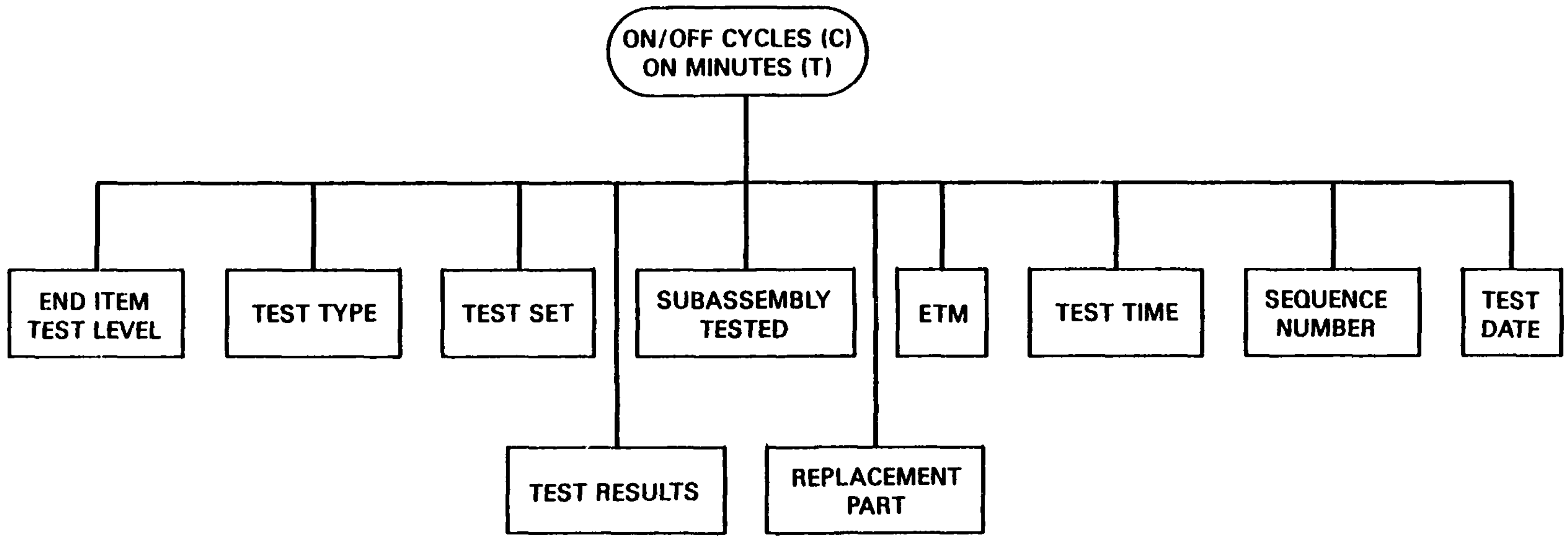

Figure 2-3. Data Items Entering Models of Power-on Time and On-off Cycles

type, test set, and subassembly for which the calculation is made determines the fraction of recorded test time representing power-on time for the subassembly. This combination also determines the increment of power on-off cycles due to the test and is augmented by a sequence number indicating multiple repairs or replacements. Elapsed time meter (ETM) indication is a direct measure of seeker magnetron-modulator power-on time. ETM time includes preservice operation time of the seeker where final acceptance test of the guidance section is used as the inservice event. ETM time recorded for each test is a cumulative time except for re-zeroing in those cases where the ETM has been replaced. Other data items shown in Figure 2-3 which may be useful in modeling power-on time and on-off cycles include test results, replaced part, and test date. The test date is of importance to accommodate changes which have been implemented in test procedures.

The data items cited above are available in several sources including handwritten maintenance logs, test station utilization logs, computerized MSTS test history systems, and the depot operation information system (DOIS). A meeting was held with Mr. Rod Schultz of McDonnell-Douglas Astronautics, St. Louis, to establish feasibility of data retrieval through such systems. The outcome of that meeting, a proposed statement of work on data retrieval in support of the study to determine the effect of testing on reliability, is contained in Appendix D. It is proposed to compile a data file of intermediate and depot testing history for a sample of five hundred each of guidance sections, seekers, MGU's, ARA's, DC/PS's, and altimeters. The guidance section test data would include MSTS tests at both the section level and AUR level [also referred to as missile level, or Harpoon missile body (HMB) level] at either the intermediate (NWS) or depot (MDAC-STL) maintenance level. Subassembly testing of the guidance section would include the depot WRA level tests enumerated in Section 1. It is not proposed to include any vendor or SRA level testing, as a practical matter of data retrieval feasibility. Retrieval data would be organized in computerized fixed length records (rows) with specified data items in columns to create a flat file which can be sorted to expedite generation of chronological histories for each S/N in each P/C S/N category.

The data items specified in Appendix D include those necessary to establish population traceability, the test event and failure data, and certain of the environmental data. Missile type identifies the missile configuration, a key environmental parameter. The missile serial number provides a link to more detailed deployment environmental data if such were desired in an extended scope analysis. The part code (P/C) and serial number (S/N) for the sample guidance section and subassemblies are the keys to the several design categories discussed previously, and are the key to generation of the section and subassembly individual chronological histories. The end item test level, test type, support equipment used, test date, location, ETM, test time, test results, replacement part, and sequence number are data items that would be used in establishing section and subassembly test failure dates, age, power-on time, and on-off cycles. The test location together with test date establishes an approximate basis for transition between the intermediate and depot-level storage and testing environments. The inservice date would correspond to the beginning of the retrieved test history at the final acceptance test of the sample guidance sections.

The applicable environment data include the depot and intermediate level testing and inferred storage mentioned above. In addition, organizational level test and environment data is desirable. The data retrieval discussed above would include missile serial number and configuration for the NWS testing. As outlined in Section 1, the missile configuration is a key to deployment environmental categories of handling, vibration, and, to some extent, temperature and humidity. The extent of organizational BIT testing is not expected to be highly correlated with the missile configuration. Beyond scheduled or recommended BIT testing at six-month intervals, the degree of this testing is expected to be a random phenomenon not practically retrievable for isolated cases where, for example, a certain deployed missile was habitually employed in a training class.

Sample deployment logs for guidance sections GQN-0512 and GQN-0122 obtained from Mr. J. Hipskind at the Pacific Missile Test Center, Point Mugu, California, are included in Appendix E. Such a deployment log augments the Appendix D data retrieval for a guidance section and its subassemblies in that it provides a basis for the transition between intermediate and organizational environments. Furthermore, it provides the deployment platform names and dates not available in the Appendix D retrieval. If it were desirable to do so, this data would link to other data sources providing latitude--tropic, middle, or arctic environment. These deployment logs, if utilized, would have to be obtained for each guidance section in the sample population, and for additional guidance sections into which failed and subsequently repaired guidance section subassemblies in the sample population have been reinstalled.

Figure 2-4 illustrates an example chronological history from data on guidance section 512. The figure is a plot of power-on time versus calendar date. The guidance section age would be the calendar time since inservice date shown in the figure. The power-on time is sketched as though calculated from models of power-on time for the section and the various tests it underwent in the test history presented in Appendix F obtained at MDAC by automated data retrieval. Similarly, with appropriate models of on-off cycles for the various subassemblies and tests, a plot like Figure 2-4, showing on-off cycles versus calendar time, could be prepared. These models would incorporate a standard provision for on-time and cycles due to BIT testing as a function of the length of time spent at the organizational level.

Figure 2-4 also shows the sequence of the guidance section environment designated D (depot), I (intermediate), and O (organizational). The transitions between depot and intermediate are inferred from the automated retrieval presented in Appendix F. If the transitions between intermediate and organizational could not be determined, then a lumped category, I/O, would be used. With the availability of deployment logs such as the one in Appendix E for guidance section 512, the transitions between I and O can also be inferred as sketched in Figure 2-4. Further environmental detailed categories can be developed by categorizing the organizational environment according to missile configuration, and possibly deployment latitude, following the breakdown which was presented in Table 1-1. The intermediate and depot level environment can be further subdivided according to time in storage and the test sets used. Figure 2-4 indicates a seeker failure confirmed early in 1981; the failure actually occurred prior to this date. This phenomenon will be considered in Section 3.2.

Another way to visualize this data is illustrated in Figure 2-5. For a given item, in this case guidance section 512, one would structure as many data "records" as the number of failures of the given item plus one more to cover the

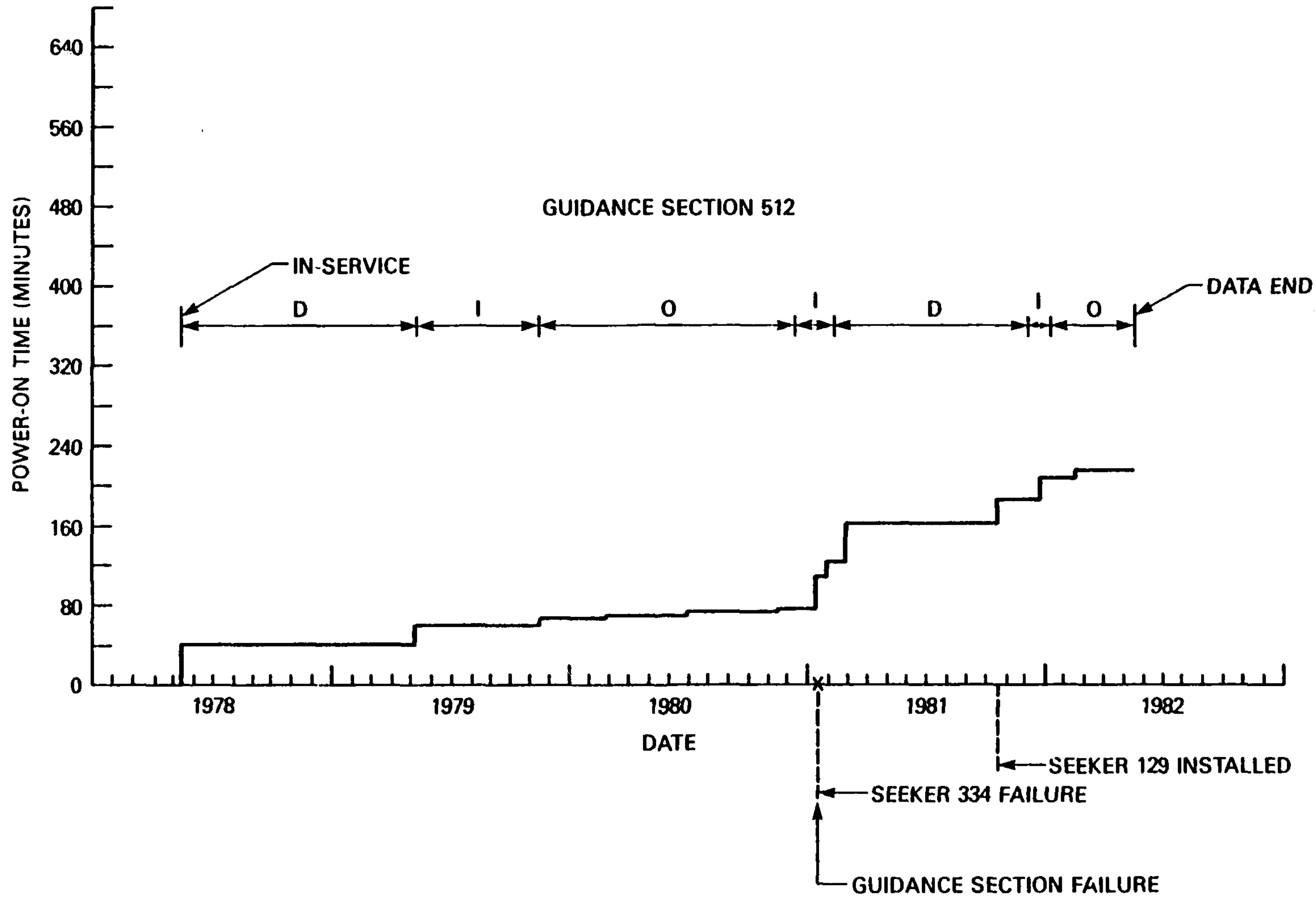

Figure 2-4. Example Chronological History for a Guidance Section

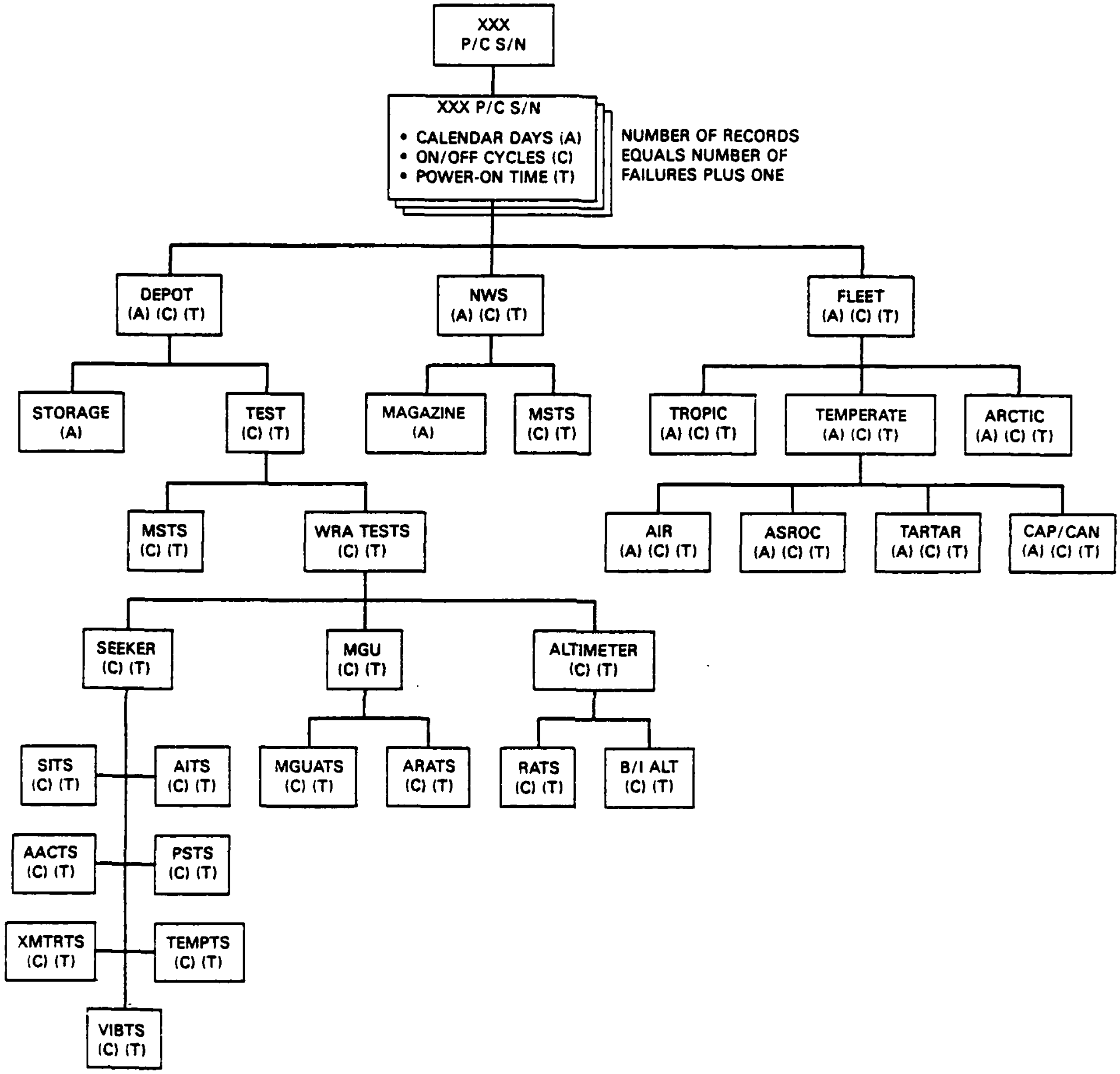

Figure 2-5. Event/Environment Data Subtree

time span from the most recent failure to the data end, or from inservice to data end in the case of no failures. Each such record would include the calendar time between failures (A), the incremental on/off cycles accumulated between failures (C), and the incremental power-on time (T). The data tree shown in Figure 2-5 suggests retaining the environmental categories which cumulatively determine A, C, and T for each time-between-failure (TBF) record. This data tree also enumerates the possibilities that should be covered by the calculational models for cycles and power-on time, and covering each item (guidance section and five subassemblies).

In this section, the population, event, and environment data availability and retrieval feasibility have been summarized. The chronological history and data tree structures used in the figures of this section suggest an organization of the data that will be pursued in Section 3 where the analysis methodology will be developed.

3. METHODOLOGY

The data needed for analysis and which is practically retrievable was introduced in Section 2, above. The methodology that would be used to analyze this data to determine the effect of testing on reliability is developed in this section. Elements of this methodology include considerations of statistical experiment design, data organization, statistical analyses, inference, presentation, and conclusions.

3.1 Statistical Experiment Design

The principles of experiment design include planning to efficiently measure the effects of "treatments" and thereby to reduce or eliminate extraneous effects. In this study, the treatments are varying degrees of testing and the complicating extraneous effects are the potential effects on reliability of the various design categories and environmental parameters. The objective of efficient measurement and elimination of extraneous effects is accomplished with a sufficient number of observations and a balanced distribution of observations and treatments over the categories, or blocks, of extraneous effects. In the present case, the measured variable is reliability, or a reliability characteristic such as MTBF. The variance for estimators of reliability characteristics is notoriously high. This difficulty is countered with a preplanned number of observations. Furthermore, the number of definable categories of environmental effects is large. The latter is not an unusual case and is expected to be amenable to the usual convention of combining such categories to produce a manageable small number of categories. The practical constraints of the data retrieval process do not encourage a preplanned exact balance of observations over the range of test exposure and environment. However, this goal should be kept in mind as a guideline for the sample population selection. It is not a direct objective of the study to compare the reliability of the several design generation P/C S/N categories. Therefore, sample selection within each of these categories may be independent of considerations of selection in the other of these categories. The analysis of data in the design categories also would proceed independently. Subsequently, if significant differences do not manifest themselves among these categories, the similar categories could be combined.

The variance of the reliability estimator and a procedure for testing the advisability of combining environmental categories are addressed further in subsequent paragraphs of this section. First, however, the organization of the data to be processed will be developed further.

3.2 Data Organization

The data introduced in Section 2 is to be used to estimate reliability of individual items; namely, the guidance section, its seeker, MGU, and altimeter, and the MGU's ARA and DC/PS. By estimating the item reliability dependent upon item age, power-on time, and on-off cycles, it is intended to demonstrate the effect (if any) of testing on item reliability. Organizing the data for this analysis requires dealing with several features of the system. Only portions of an item may be powered on and cycled in some of the tests, and different portions are powered on and cycled to differing extents in the various tests. Only a portion of an item is replaced upon failure. The time of failure is previous to detection by testing. Considerable additional time and testing may occur before the failure is confirmed and repaired. Due to repairs of an item, the age of the item becomes multi-element with several ages of components represented in the item. The repair as well as the various tests makes the test history of power-on time and on-off cycles multi-element in a similar manner.

The multi-element character of an item's age, power-on time, and on-off cycles can be handled on one extreme by a convention reducing the multi-elements to single elements for each of the three measures, and on another extreme by determining reliability dependent upon the multi-element measures, and subsequently combining categories of these measures upon test for similarity. The second approach has the theoretical advantage of drawing from the data the decision that different tests and item subassemblies with differing test histories have the same effect on an item's reliability. As a practical matter, however, the increased dimensionality could result in a large number of categories with an insufficient number of observations to make precise reliability estimates, or to make sound statistical decisions on combination of categories. There is also the difficulty that replacement subassemblies may not be elements of the sample population so that the subassembly test history would be unavailable except by iterative data retrieval, or by treatment as missing data where an "average" history would be used.

The first approach, a convention to reduce the multi-elements to a single element, would avoid these difficulties, but the impact of individual test types could not be determined.

It is proposed to use an intermediate convention of describing an item's age, power-on, and cycles according to the test history associated with the item's S/N regardless of the subassembly replacements within the item. This approach is practically equivalent to the second approach where zero or a few components have been replaced in a lower level item's life history. It permits use of the average test history for subassemblies (lower level items and not newly built and not in the sample population) of the higher level items, the guidance section and MGU, because the test histories of sample lower level items (seeker, altimeter, MGU of the section, and ARA and DC/PS of the MGU) will have been compiled. Furthermore, it still leaves open the option of multi-element modeling of the several test types associated with the S/N. A description of the extent and identity of the circuitry in a given item which is powered on and cycled by each test would be helpful to accomplish this modeling. The final decisions on the approach should be made after data retrieval and construction of the chronological histories to determine the extent of subassembly and part replacement.

As a description of the extent of powered-on circuitry is needed to augment the power-on and cycles data, a description of the extent of circuitry replaced in a repair is needed to augment the age data. The second description is an element of the planned data retrieval. The first description would be developed as part of the task of power-on and on-off cycles modeling. The several testing environments and the defined items can be displayed in a matrix identifying the necessary power-on and on-off cycle models which would be supplied with descriptions of the extent and identity of the circuitry powered on and cycled within the item. This matrix follows from Figure 2-5 as was suggested in Section 2.

Presented as a matrix, the models required would be indicated by X's as in Table 3-1. Models may not be needed for every position in the matrix. For example, the seven test sets applicable to the seeker would result in no power-on or cycles applied to the altimeter or MGU unless the tests are applied to the seeker while it is installed in the guidance section and these other parts of the section are powered on during the seeker test. Such positions in the matrix have been designated N/A and are not applicable upon confirmation that the subassembly test does not power on the other subassemblies. The positions left blank in the matrix are for the guidance section and MGU where their power-on and cycles have been X'ed for items they comprise. However, three positions for the section and one for the MGU do require models for those portions of these items not included in the defined item list. For the section, the items not included in the seeker, altimeter, and MGU are the power converter and antenna. For the MGU, the parts not included are the balance of the MGU beyond the ARA and DC/PS.

The time of a failure is at or prior to the time of the test which detected the failure. The difference in the reliability interval estimate (point estimate with "error bars") is expected to differ insignificantly among the conventions of assuming failure at previous test, halfway to failure detecting test, at failure detecting test, etc. Additional time and testing before failure confirmation and repair will be added to the item history for its effect on subsequent failures.

Figure 3-1 summarizes the tree structure of the event data introduced in Section 2. At the top of the tree, the guidance section design categories are shown. The right branch represents the section serialized elements of the populations within the categories and the time-between-failures (TBF) records of these population elements. Associated with each TBF record are the serialized section's age (A), on-off cycles (C), and power-on time (T). The left branch of Figure 3-1 illustrates the analogous data structure for the subassemblies of the section. The serialized item's age, cycles, and power-on time are determined at the calendar times corresponding to the end of each TBF period.

TABLE 3-1. MATRIX OF REQUIRED POWER-ON AND CYCLE MODELS

TEST	ITEM: Guidance Section	Seeker	Altimeter	MGU	ARA	DC/PS
BIT	X	X	X	X	X	X
MSTS-AUR	X	X	X	X	X	X
MSTS-Section	X	X	X	X	X	X
SITS		X	N/A	N/A	N/A	N/A
AITS		X	N/A	N/A	N/A	N/A
AACTS		X	N/A	N/A	N/A	N/A
PSTS		X	N/A	N/A	N/A	N/A
XMTRTS		X	N/A	N/A	N/A	N/A
TEMPTS		X	N/A	N/A	N/A	N/A
VIBTS		X	N/A	N/A	N/A	N/A
MGUATS		N/A	N/A	X	X	X
ARATS		N/A	N/A		X	N/A
RATS		N/A	X	N/A	N/A	N/A
B/I ALT		N/A	X	N/A	N/A	N/A

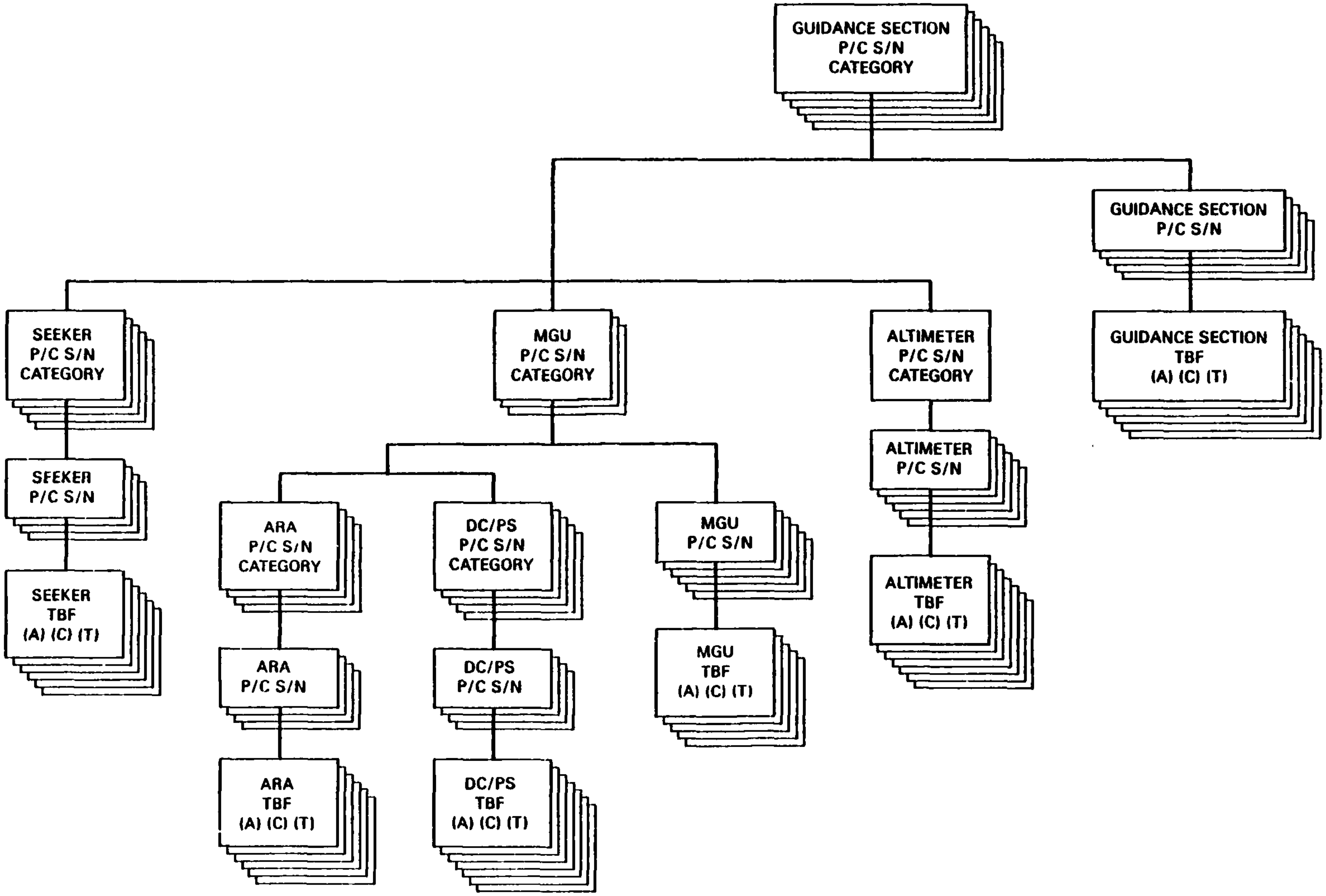

Figure 3-1. Summary Data Tree

TBF periods are illustrated in Figure 3-2 as the calendar time spans between failures designated by X's. The item nomenclature of Figure 3-2 corresponds to the series logic reliability block diagram of Figure 3-3. Assume that the item histories of Figure 3-2 are those of one serialized (S/N) guidance section and its as-built subassemblies, all with the same inservice date. Then the series logic guidance section fails each time any one of its subassemblies fails. The first failure of a subassembly in an item causes the item failure at the same time. Subsequently, however, the item and subassembly failures in the as-built population no longer coincide since failed subassemblies in items are replaced by operable subassemblies. The replaced subassemblies then follow their courses independently of the item.

While the first time span for an item from its inservice date to its first failure does not include a repair or restoration time; while the last time span after the last failure to the data end date is not necessarily terminated by a failure, or while no failure may occur over the item's one time span from inservice to data end, such time spans are also of use in reliability estimation. Their employment is somewhat different from the incorporation of a bona fide TBF data record, but they are also referred to as "TBF records" because the distinction is not significant except in the actual numerical analysis. Including these special records, the number of TBF data records for each serialized population item equals the item's number of failures plus one. The restoration time would be compiled, when applicable, for each TBF record along with the item's age (A), cycles (C), and power-on time (T) for use in employment of these special TBF records.

Figure 2-5 illustrated a general breakdown of an item's TBF record. This general illustration is now made specific for the six missile subassemblies to be analyzed. This specification is shown in Figures 3-4 through 3-9. In each case, the data tree branches analyze the TBF record of calendar time (A), on-off cycles (C), and power-on time (T) accumulated since item inservice and the change (delta) in A, C, and T during the record period into the constituent A's, C's, and T's obtained in the various deployment, storage, and test environments. At each level in any of these trees, both the cumulative and delta A's, C's, and T's in one level of the tree are added to form the respective values at the next

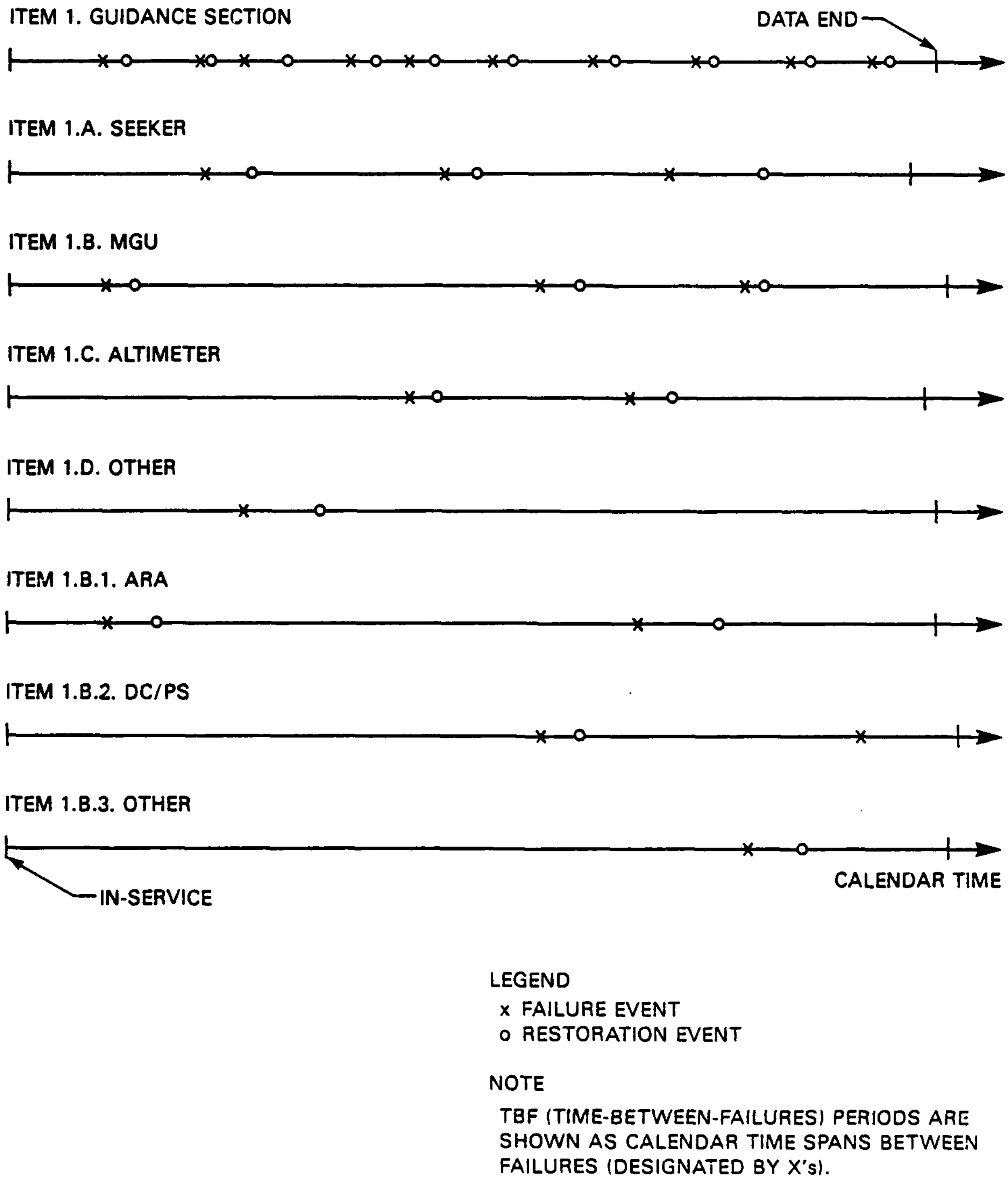

Figure 3-2. Example Item Histories

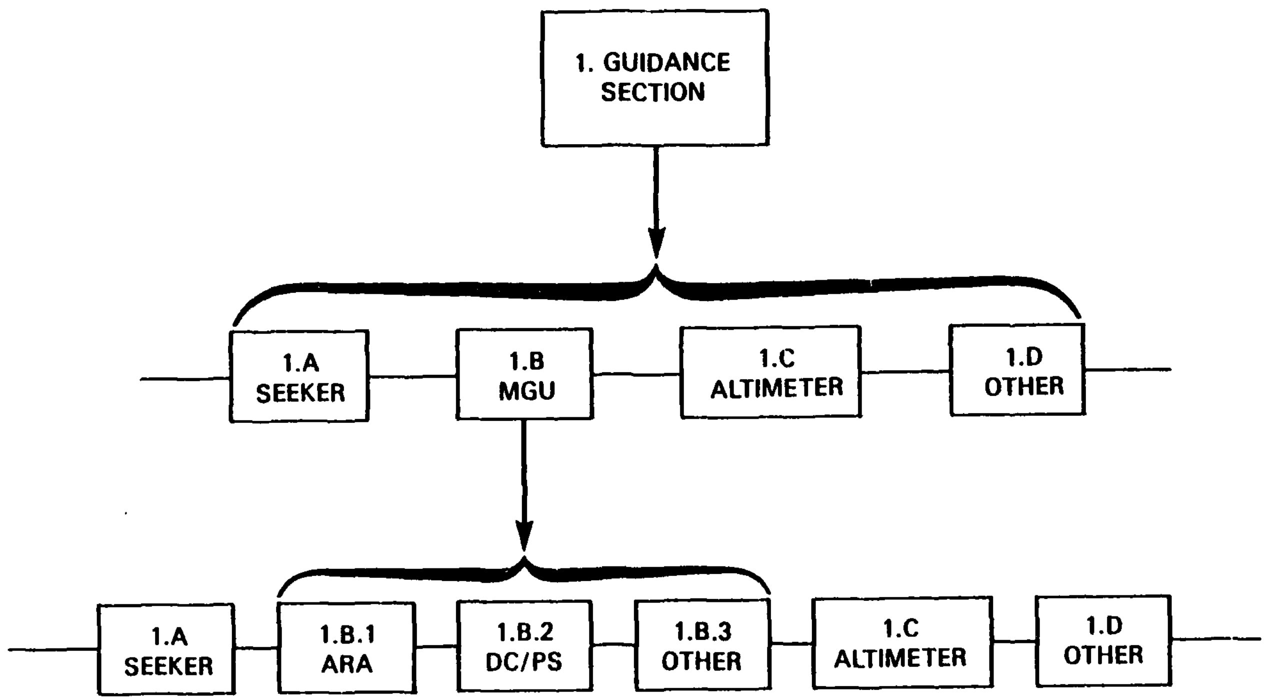

Figure 3-3. Reliability Block Diagram

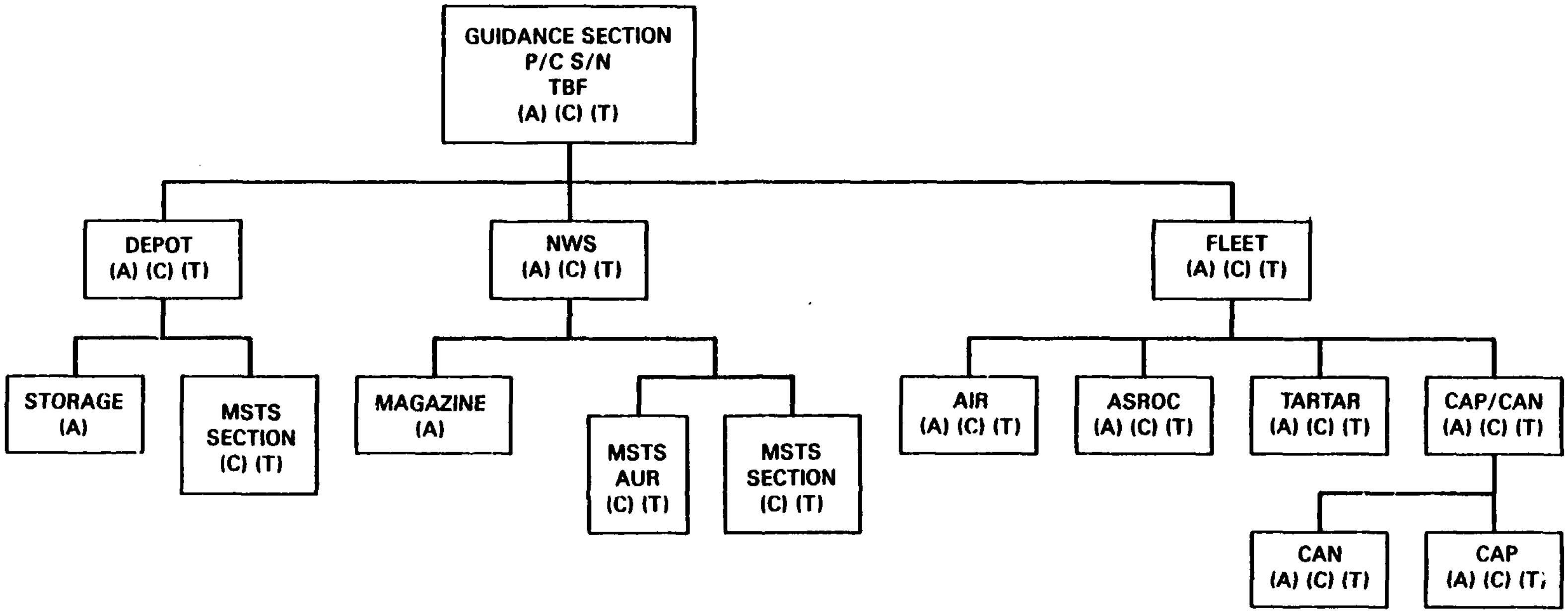

Figure 3-4. Guidance Section Environmental Categories

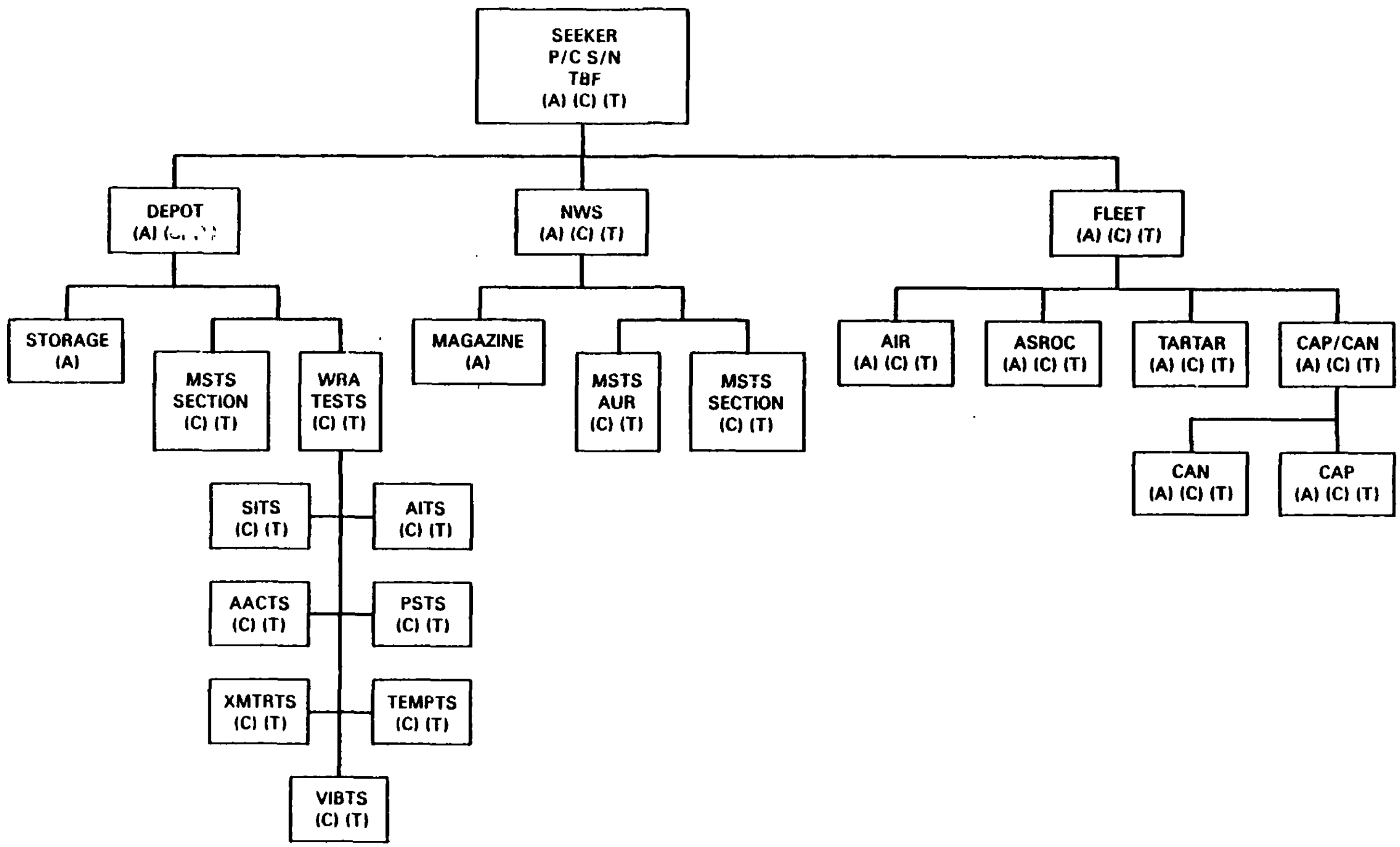

Figure 3-5. Seeker Environmental Categories

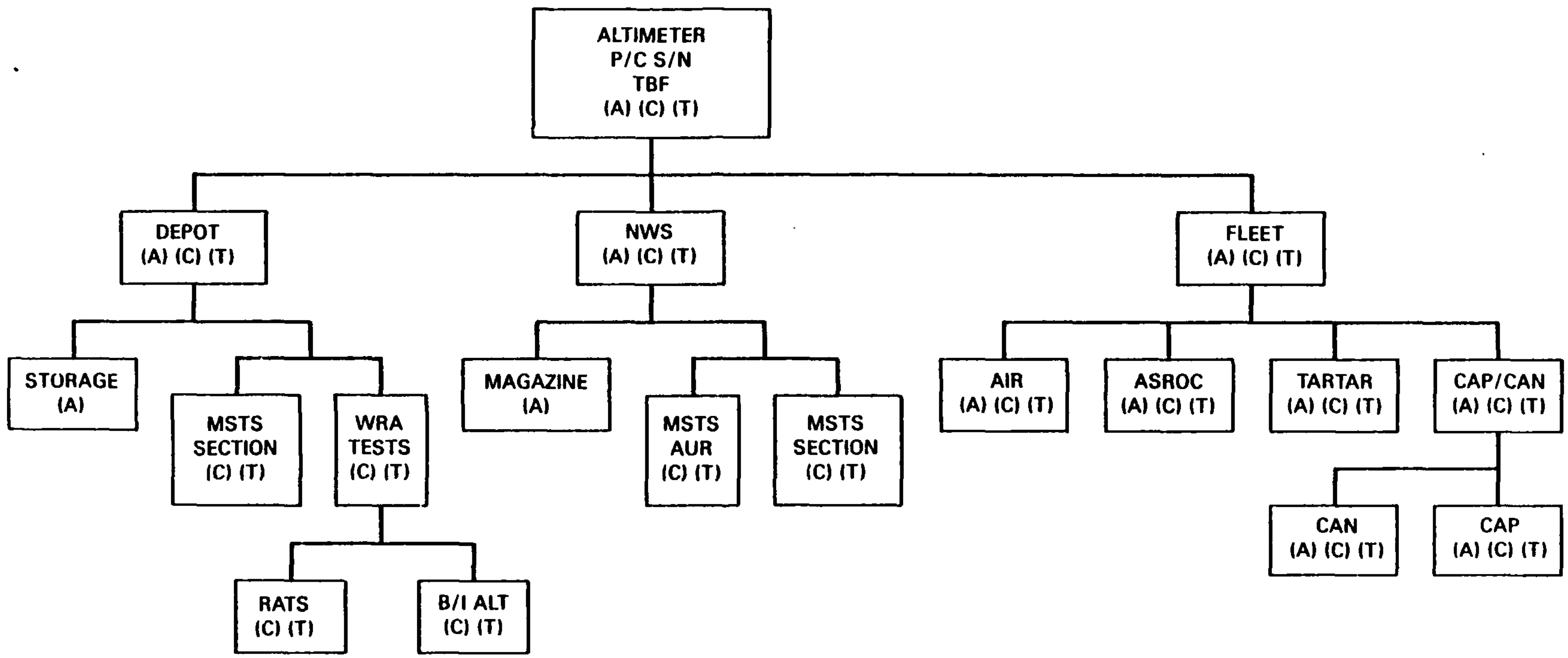

Figure 3-6. Altimeter Environmental Categories

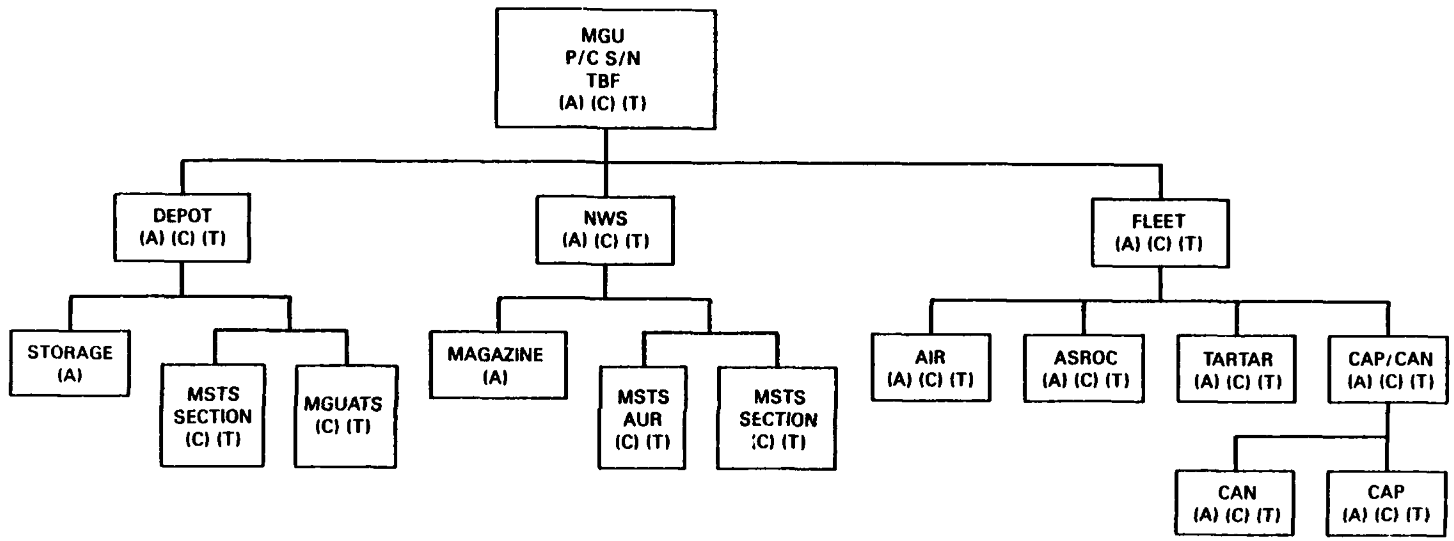

Figure 3-7. MGU Environmental Categories

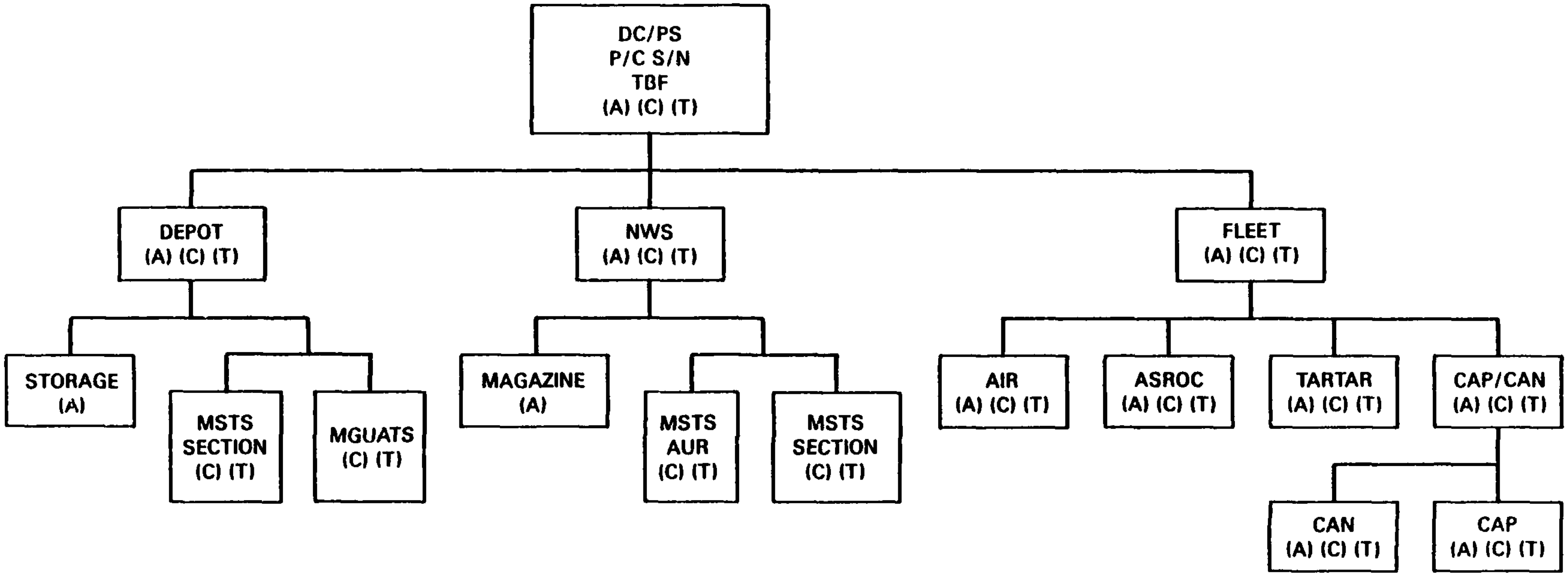

Figure 3-8. DC/PS Environmental Categories

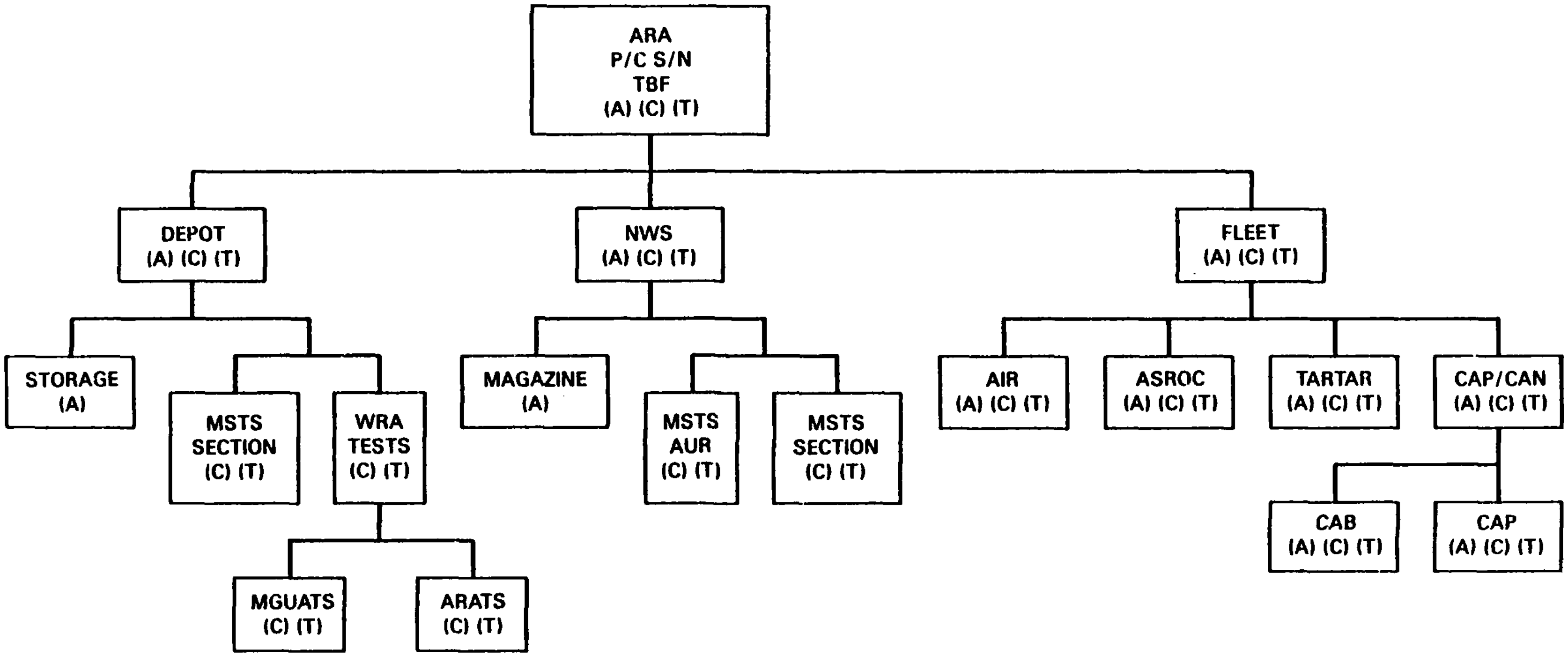

Figure 3-9. ARA Environmental Categories

higher level in the tree. The trees in Figures 3-4 through 3-9 for the six items differ according to the tests applicable to each item. The test environment branches are consistent with the matrix of Table 3-1.

The data organization described above and illustrated in Figures 3-1 and 3-4 through 3-9 would be obtained from the data retrieval described in Section 2. The result of that retrieval would be a flat data file with various data elements arranged with rows corresponding to tests and columns containing test data described in Appendix D. This file would be sorted by item, item P/C S/N design category, S/N, test date, and sequence number. From this, a file of TBF records would be compiled retaining segregation according to design category and including P/C S/N coding on each TBF record. The TBF expressed as calendar time is the change in the item's age since the previous failure. The number of on-off cycles (C) and the power-on time (T) since the previous failure would be computed according to the several models identified in Table 3-1 for the item and the tests it has experienced in the time span. The breakdown by environmental category would be supplied in the TBF record as additional data elements. The data elements that are planned in a TBF record are summarized in Table 3-2.

3.3 Statistical Analysis

The data, when organized as described above, comprises a number of subsets of numerical values of mathematical variables. In the following, the variables are classified for statistical analysis, the purpose and generation of probability distributions in this study are outlined, the use of statistical analysis methods including MTBF estimation, ANOVA, and regression analysis is discussed, and the questions of how much data and when to combine categories are addressed. The result is a methodology to determine the effect, if any, of testing on the Harpoon missile system reliability.

3.3.1 Variables

The data elements, or variables, shown in Table 3-2 are organized to be keyed to time spans during which defined missile subassemblies (items) are operable. For statistical analysis purposes, it is convenient to view the data

TABLE 3-2. TIME-BETWEEN-FAILURES RECORD DATA ELEMENTS

1.	P/C S/N
1.a.	Item
1.b.	Design Category
2.	Restoration Time (When Applicable)
3.	TBF Record Type • Zero Failure Record • First Failure Record • Censored Failure Record • Bona Fide TBF Record
4.	Failure Date
5.	Age, A
5.a.	$\Delta A = a = TBF$
6.	Cycles, C
6.a.	$\Delta C = c$
7.	Power-On Time, T
7.a.	$\Delta T = t$
8.	Additional elements of A, C, T, a, c, and t in accordance with Figures 3-4 through 3-9

as a large matrix in which rows correspond to time-between-failure spans and columns correspond to the several mathematical variables whose numerical values are recorded in the matrix. Then each row represents the numerical value of a multi-element, or multi-variable, "data point."

Certain of the variables are regarded as random variables for which probability distribution functions, or parameters of these distributions, are to be estimated in each of several categories and across regions. The random variables include the change in item age (a), change in on-off cycles (c), and change in power-on time (t) over the item's operable time span. The operable time span is the time-between-failures optionally adjusted for restoration time. The convention has now been adopted of using the lower case letters "a", "c", and "t" to denote the change (delta) in an item's cumulative age "A", cycles "C", and on-time "T". The probability distribution of the change in item age, a, directly relates to the item reliability function (complementary cumulative probability distribution) for a time-based reliability model. An alternative time base is the power-on time, t, and the on-off cycles, c, provide a demand base alternative.

Other of the variables listed in Table 3-2 serve to identify the category or region in which a multi-element data point belongs. These include discrete valued variables such as the item type and design category. The discrete test types and environmental categories referred to in Table 3-2 and identified in Figures 3-4 through 3-9 can be thought of as being provided by a number of additional variables (columns) whose values represent both cumulative and delta age, cycles, and on-time of the item in the category the variable represents. These additional delta variables are the constituent elements of the random variables cited above. The additional cumulative values constitute the item's total A, C, and T. The cumulative values identify the location of the data point in the regions of item age, cycles, and on-time. Thus, a basis is established whereby the character of the random variables can be assessed within various categories, or combined categories, and over positions in regions. The results can be interpreted as changes in reliability as a function of age, cycles, and on-time.

3.3.2 Probability Distribution

The full characterization of a random variable is its probability distribution. In this study, it is planned to form nonparametric estimates of the actual probability distributions for display and for selection of appropriate parametric distribution models. The selected models would then provide verified "assumptions" that will simplify subsequent statistical analysis for effect of testing.

Data representing sample values of the random variable "a" (or TBF), or of other random variables "c" and "t", for an item in a category would be analyzed by a nonparametric method employing the rank distribution (a beta distribution) (Reference 5). In this method, the sample values are ordered from smallest to largest to produce rank numbers, and the effects of suspended (or censored) items where data end date occurred before item failure are included. These effects are included by determining the mean order numbers, j, of the failed items, taking into account all the possibilities of the ranking of the suspended items if the experiment (or data retrieval) had been extended. The mean of the rank distribution is $j/(n + 1)$, and the median is approximated by $(j - 0.3)/(n + 0.4)$ where j is the order number and n is the total number of failed and suspended sample values of the random variable. Most rank distributions are skewed so that the median is considered the better descriptor. Then the set of paired numbers, the median $(j - 0.3)/(n + 0.4)$ and the corresponding value of the jth ranked sample value, x_j, form an estimate of the cumulative probability distribution function, cdf. The cdf could be presented by plotting $(j - 0.3)/(n + 0.4)$ versus x_j. Error bars (confidence intervals) can be calculated and plotted either vertically (Reference 5) or horizontally (Reference 6). Thus, without making assumption of the cdf's parametric mathematical formula, an estimate for the actual cdf can be produced.

It is convenient for use in the statistical method of regression analysis with associated ANOVA to determine a parametric distribution formula, such as the exponential, Weibull, normal, or lognormal, which fits the nonparametric estimate of the actual cdf well. In this manner, verified "assumptions" underlying the subsequent statistical analysis for effect of testing can be produced. A further advantage of finding a formula to describe the actual cdf is that the characterization of the random variable is then accomplished with only one or a few parameter values. The exponential distribution is a one-parameter distribution for which the mean-time-between-failures (MTBF) would fully characterize the distribution. The standard deviation of the exponential is equal to the mean so its coefficient of variation is one. The Weibull, normal, and lognormal are two-parameter distributions where MTBF and the standard deviation of TBF would characterize the random variable. Upon determining a suitable parametric distribution that fits the actual cdf estimate well, this distribution can be transformed to any other parametric distribution form by simple mathematical transformations implemented in computer software libraries. This process is illustrated in Figure 3-10, where a transformation from the exponentially distributed variable x to the normally distributed variable y is sketched.

In summary, probability distributions are to be employed in the task of determining the effect of testing by estimating the actual distribution of a random variable for several benchmark cases. Then suitable parametric models of the actual distributions can be decided. These are more amenable to mathematical manipulations. They provide verified underlying assumptions for the statistical methods of ANOVA and regression, and they reduce the reliability estimation problem to that of estimating one or two parameters.

3.3.3 Statistical Analysis Methods

An abbreviated discussion follows of the application of several statistical methods to the problem of estimating the reliability of an item and deciding whether or not there is a significant change in the reliability of the item with increased item testing. The questions to be answered include: (1) how to estimate MTBF (and possibly standard deviation of TBF); (2) how to detect a change, if any, in the reliability parameter(s) with increasing age, on-off cycles, and power-on time; (3) how to decide when two or more categories of data can be combined to form a larger sample of like data; and (4) how much data is needed.

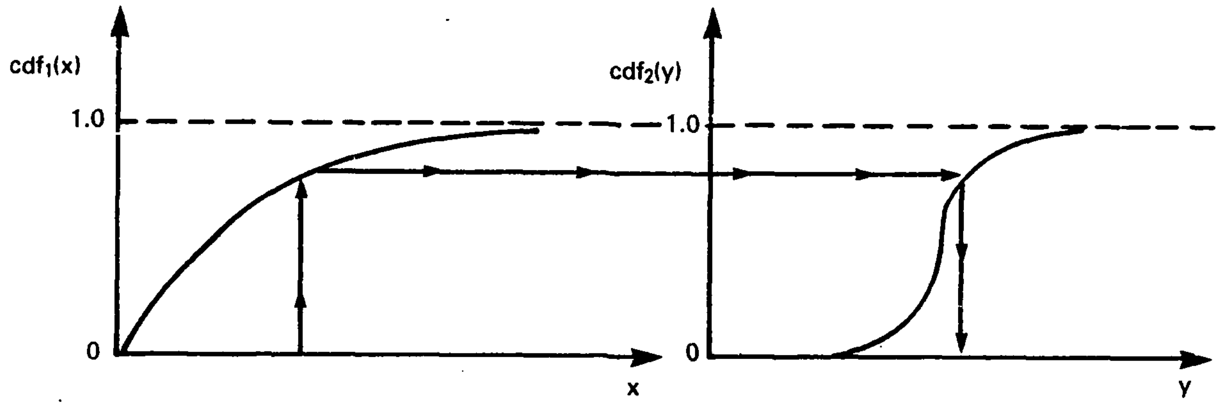

Figure 3-10. Transformation of Random Variables

The key to successfully characterizing item reliability is reasonable assumption of the underlying probability distribution form. The approach to achieving this was outlined in Section 3.3.2. The determined, or transformed, parametric form chosen would be one from a benchmark analysis corresponding as closely as practical to the applicable design, environmental, test, and age category. For an exponential form, the usual chi-squared statistical method (Reference 5, for example) would be used to estimate the one parameter, MTBF. Reference 5 also provides a comprehensive discussion of estimation of the Weibull parameters, and most statistical texts cover estimating means and standard deviations for normal (or lognormal) distributions (References 7 and 8, for example).

In this study, we are looking for dependence, if any, of the distribution of time-between-failure on item cumulative age, cycles, and on-time. With the aid of parametric distribution forms, this becomes mainly the relation between the distribution parameter(s) (MTBF and standard deviation) and the variables A, C, and T. This relationship is referred to as the regression of TBF on A, C, and T. References 7 and 8 provide introductions to regression analysis (method of least squares and fitting of response surfaces) where the regression of a variable named y on a single variable x is discussed. References 9 through 11 provide more advanced guidance on multiple regression integrated with statistical experiment design and ANOVA methodology.

The data input to regression analysis is the set of multi-element data points comprising the dependent variable y [TBF(a), c, or t in our case] and the independent multiple variable X's (A, C, T, and A's, C's, T's in various test and environment categories in our case). The output of the regression analyses in this study would be estimates of the mean TBF (MTBF), mean c, or mean t as functions of total A, C, T, or of the constituent test and environment elements of A, C, and T. The total, or a subtotal, cumulative age, cycles, and on-time in the data trees are linearly dependent on the respective constituent elements at lower levels in the data trees which were presented in Figures 3-4 through 3-9 because the lower level values sum to form the higher level values. Therefore, the regression models finally selected would relate the dependent variable mean to either the constituents or their total (or subtotal) according to the hierarchy established in the data trees. Other potential linear dependencies in the data include the relationship among cumulative age, cycles, and on-time. If two or more of these are highly correlated, then a sufficient model would be obtained using only one, or two, of the three variables. The correlation among A, C, and T would be analyzed as part of the process of deciding regression model forms.

Since the regression analysis output is an estimate of the MTBF as a function of age, cycles, and on-time, it answers how to detect a change, if any, in the primary reliability parameter with an increase in the value of those variables. Analysis of the regression residuals, the deviations between the mean and the data, provides an estimate of the variance of TBF. The methods of Section 3.3.2 above can be applied to the regression residuals as an aggregate, or in various regions, to estimate the distribution about the mean and verify assumptions used in statistical inference related to the regression analysis.

Regression analysis and the associated ANOVA provide the statistical inference tools to answer the remaining three questions posed at the beginning of this section; namely, how to detect a change in MTBF, when to combine categories, and how much data? "Extraneous" environmental and test category effects, while not strictly controlled by statistical experiment design, are observable and have been organized according to the data trees. Two remaining challenges are the measurement error (noise) characteristics of time-between-failure data (coefficient of variation about equal to one), and possible multicollinearity among the variables A, C, T (multicollinearity measured by the correlation coefficients between these variables). To address these questions and challenges, further mathematical detail is required. A summary of the needed mathematics following the conventions and nomenclature generally employed in References 7 through 13 is presented below.

Consider a general regression model of the form

$$y = \sum_{i=0}^{k} b_i X_i, \qquad (1)$$

where y represents a mean response such as MTBF in this study, and the X_i are variables such as cumulative age, on-off cycles, and power-on time. One of the b_i coefficients, say b_o, can represent a constant term in the model if the value of X_o is held constant at one. The coefficients, b_i, in the model are estimated by the least squares procedure from data. Consider a set of N data points,

$$y_j = \sum_{i=0}^{k} b_i X_{ij} + e_j, \; j = 1, 2, \ldots, N, \qquad (2)$$

where y_j = the jth observation of TBF,

X_{ij} = the value of the ith variable for the jth data point, and

e_j = random error, the difference between the model (1) and the actual data (2).

In matrix notation, equation (2) becomes

$$Y = Xb + e \qquad (3)$$

where Y = an Nx1 column matrix with the elements y_j,

X = an Nx(k+1) matrix with elements X_{ij},

b = k+1 column matrix of the b_i elements, and

e = an Nx1 column matrix of the e_j elements.

Corresponding to equation 1, the model becomes

$$\hat{Y} = X\hat{b} \qquad (4)$$

where $\hat{b}$ = a k+1 element column matrix of estimates for the b_i,

$\hat{Y}$ = the Nx1 column matrix of estimates of the mean Y at the corresponding data points represented by the rows of matrix X, and

X is as defined before.

The regression coefficients in the vector $\hat{b}$ are the values that minimize the sum of the squared errors, S_e, between the observed y_j's and the model,

$$S_e = (Y-\hat{Y})'(Y-\hat{Y}). \tag{5}$$

The result is

$$\hat{b} = (X'X)^{-1} X'Y. \tag{6}$$

The usual assumption (which can be checked or practically achieved by transformation) is that the error vector e is a multivariate normal random vector variable with zero mean vector and covariance matrix $I\sigma^2$, where I is the NxN identity matrix and σ^2 is a positive constant. Under this assumption, the covariance of the estimator $\hat{b}$ is $(X'X)^{-1}\sigma^2$.

$$\text{cov}(e) = I\sigma^2 \tag{7}$$

$$\text{cov}(\hat{b}) = (X'X)^{-1}\sigma^2 \tag{8}$$

In a designed experiment, the data points would be controlled to minimize the correlation of the columns of X and thereby minimize the elements in $\text{cov}(\hat{b})$. In this study, control will be achieved by variable selection according to the data trees, and some further control could be achieved by selecting a subset of data with minimum correlation among the X variables. The effect of the correlation (multicollinearity) and the typically large value of σ^2 in reliability problems will influence the number of needed data points, N.

The usual ANOVA procedure used with regression analysis is to partition the sum of squares, Y'Y, form the ratio of certain of the parts, and check the ratio for statistical significance in a probability table of Snedecor's F statistic to test the hypothesis that a subset of the elements of the vector b are all zero versus the alternative that one or more of the elements in the subset are nonzero. This approach would be used in the subsequent data analysis program. However, determining the power (and needed N) of such statistical tests is complicated with correlated multiple variables. A more fruitful approach is to consider the effect of correlation and large σ^2 on the covariance of the subset, and then to select N large enough that the variance of the $\hat{b}$ is small compared to the value of nonzero b which is to be detected.

Consider first the zero correlation, one-dimensional case. If a set of N observations of TBF is retrieved, how large are the "error bars" on the MTBF? If the underlying distribution is exponential (σ = MTBF), then the statistic

$$\chi^2 = \frac{2T}{MTBF} , \qquad (9)$$

where T = total item time, Σ TBF,

follows the chi-squared probability distribution with 2N degrees of freedom. A 95% confidence interval estimate for MTBF is formed by considering the 2.5 and 97.5th percentiles of this distribution,

$$2T/\chi^2(.975,2N) \leq MTBF < 2T/\chi^2(.025,2N). \qquad (10)$$

The resulting percentage error bars as a function of N are presented in Table 3-3.

If the underlying distribution is normal, the applicable statistic is Student's -t statistic,

$$\bar{x} - t(.025,N-1)sN^{-0.5} \leq MTBF < \bar{x} + t(.975,N-1)sN^{-0.5}. \qquad (11)$$

In this study, s is on the order of MTBF estimated by the sample mean $\bar{x}$. Then it follows from equation (11) that the fractional error bars are given by

$$E = \pm\ t(.025,N-1)N^{-0.5} \qquad (12)$$

The values expressed as a percentage are also shown in Table 3-3. The results of a similar formulation for an underlying lognormal distribution are also shown in Table 3-3.

TABLE 3-3. COMPARISON OF PERCENTAGE ERROR BARS CORRESPONDING TO 95% TWO-SIDED CONFIDENCE INTERVAL ON MTBF FOR SEVERAL UNDERLYING DISTRIBUTIONS

No. of Observed Failures in Category	Percentage Error Bars on MTBF		
	Exponential	Normal ($\sigma = \mu$)	Lognormal ($\sigma = \mu$)
5	+210% -45%	±124%	+181% -64%
10	+110% -41%	±72%	+82% -45%
25	+55% -30%	±41%	+41% -29%
50	+36% -23%	±28%	+26% -21%
100	+23% -17%	±20%	+18% -15%
250	+14% -11%	±12%	+11% -10%
500	+9% -8%	±9%	+8% -7%
1000	+7% -6%	±6%	±5%
10,000	±2%	±2%	±2%
20,000	±1%	±1%	±1%

Table 3-3 indicates that the percentage error bars on MTBF become the same regardless of the underlying distribution of TBF as the sample size becomes very large. The table also shows that error bars of practical interest (about ±20% of MTBF) are available with about 100 observations (TBF records).

Now suppose such a data set were divided into two categories--the data with higher than average cycles or power-on time in one set, and lower than average in the other set. How many observations are necessary to detect a difference in the MTBF between the two sets? For the case of normal distributions with unknown but equal standard deviations, the applicable statistic

$$t = (\bar{x}_1-\bar{x}_2)[n_1n_2(n_1+n_2-2)/(n_1+n_2)]^{0.5}/[(n_1-1)s_1^2+(n_2-1)s_2^2]^{0.5}, \quad (13)$$

follows the Student -t distribution with n_1+n_2-2 degrees of freedom. If $n_1 = n_2 = n = N/2$ and s_1 and s_2 are about equal to the mean, then equation (13) can be rearranged into the form (14) expressing the fractional difference between the means of the two data sets which would be considered significant at the 95% *confidence level*,

$$(\bar{x}_1 - \bar{x}_2)/MTBF = \pm 2t(.025,N-2)N^{-0.5}. \quad (14)$$

So, if a total of N data points are divided into two equal groups, a percentage difference between the MTBF's of the two groups as small as that computed by equation (14) could be detected. This relationship is presented in Table 3-4.

Now consider the case of multiple regression with some correlation among the independent variables. Corresponding to a formulation to test the hypothesis that a subset of the b_i are zero against the alternative that at least one is nonzero, partition the vector b into the k_a x 1 vector b_a and the k_b x 1 vector b_b,

$$b' = (b_a', b_b'), \quad (15)$$

$$k = k_a + k_b. \quad (16)$$

TABLE 3-4. TOTAL NUMBER OF TBF RECORDS NEEDED TO DETECT A PERCENTAGE DIFFERENCE IN MTBF BETWEEN TWO EQUAL SIZE GROUPS OF THE DATA RECORDS

N	Percentage Difference
50	±55%
100	±39%
250	±25%
500	±18%
1000	±12%
10,000	±4%
20,000	±3%

The hypothesis to be tested is then

$$H_o : b_a = 0, \tag{17}$$

against the alternative

$$H_1 : \sum_{i=1}^{k_a} \left| b_{a_i} \right| = k_a B \tag{18}$$

where B is a positive number related to the departure from zero of the absolute value of an element of b_a which is to be detected if it exists. In order to detect the departure B, it is necessary that the variances of the estimators of b_{a_i} are sufficiently small so that a statistical test will detect the departure. A practical condition is that the standard deviation of the estimator of each b_{a_i} is equal to about one-half B. The standard deviation is the square root of the variance and the variance is a diagonal element of the covariance matrix given by equation (8).

To quantify the effect of multicollinearity among the columns of X in equation (8), it is convenient to standardize the X_{ij} variable values as follows

$$X^{\circ}_{ij} = (X_{ij} - \bar{X}_i)/s_i, \; i = 1,2,\ldots,k, \tag{19}$$

where $\bar{X}_i$ and s_i are the sample mean and sample standard deviation of the values of X_{ij} in the (i+1)st column of X. Under this transformation, the regression equation (3) becomes

$$Y = X^{\circ} \, b^{\circ} + e \tag{20}$$

where the dimensions of these matrices are as defined in equation (3), the new matrix X° has elements defined by the transformation (19) of the elements of X, and the elements of b° (except the constant term) are simply the corresponding elements of b times the appropriate s_i. The covariance of the estimator $\hat{b}^\circ$ (excluding the constant term) is now

$$\mathrm{cov}(\hat{b}^\circ) = (X^{\circ\prime}X^\circ)^{-1}\sigma^2 \tag{21}$$

where

$$(X^{\circ\prime}X^\circ) = (N-1)\begin{bmatrix} 1 & r_{12} & \cdots & r_{1k} \\ r_{12} & 1 & \cdots & r_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ r_{1k} & r_{2k} & \cdots & 1 \end{bmatrix}. \tag{22}$$

The r_{ij} in equation (22) are the correlation coefficients of the data in columns i+1 and j+1 of the matrix X. To simplify matters, consider the r_{ij} all equal to a value r which can take a value between zero and one. As a guess, the value of r among age, cycles, and power-on time may be between 0.7 and 0.9. With equal correlation coefficients, it can be verified that the inverse of the matrix given by equation (22) is

$$(X^{\circ\prime}\ X^\circ)^{-1} = [I - rJ/(1 - r + rk)]/[(1 - r)(N - 1)] \tag{23}$$

where I = the kxk identity matrix, and

J = the kxk matrix with every element equal to one.

Now, the variance of the estimator $\hat{b}_i^\circ$ is the ith diagonal element in the matrix of equation (21), and using equation (23), we obtain

$$V(\hat{b}_i^\circ) = [\sigma^2/(N-1)][1 - r/(1-r+rk)]/(1-r) \tag{24}$$

The standard deviation of $\hat{b}_i^\circ$ is the square root of $V(\hat{b}_i^\circ)$ and this result is to be about one-half the departure of b_i° from zero for which detection capability is desired. Therefore,

$$[V(\hat{b}_i^\circ)]^{0.5} = 0.5B. \tag{25}$$

Upon rearranging and using σ = MTBF, equation (26) is obtained. This expresses the departure, B, of b_i from zero expressed as a percentage of MTBF. This value of B could be detected if the number of data points N are analyzed, in a multiple regression with k variables, where the variables are collinear with correlation coefficient r.

$$\frac{B}{MTBF} \times 100\% = 2(V(\hat{b}_i^o)/\sigma^2)^{0.5} \times 100 \qquad (26)$$

Using equations (24) and (26) together, the results in Table 3-5 are obtained.

Table 3-5 indicates, for example, that if the correlation among the regression independent variables is r = 0.7, and the number of variables is k = 3, the case for item total age, cycles, and on-time, and if 1000 time-between-failure records for the item were retrieved, then a nonzero effect of age, cycles, or on-time on MTBF as small as 10% would be detectable. Since the regression variables were standardized for the presentation of Table 3-5, the 10% value would correspond to a 20% of MTBF departure over two standard deviations of age, cycles, or on-time. This corresponds roughly to dividing the data into two groups—one with above and one with below average testing, as was done for Table 3-4. In Table 3-4, about 20% (18%) detectable difference was obtained with 500 data points. So the effect of multiple (k = 3) regression and a degree of multicollinearity (r = 0.7) is to approximately double the number of required data points to obtain the same sensitivity as in the simple two-group analysis (k = 1, r = 0).

As in the example above, the percentage change in MTBF over two standard deviations in age, cycles, or on-time that could be detected with statistical significance would be twice the percentage B values presented in Table 3-5. This is illustrated in Figure 3-11. Thus, on doubling the values in Table 3-5, it is concluded that with correlation among the regression variables on the order of 0.7 to 0.9, changes in MTBF on the order of 30% to 50% could be detected in an analysis program employing a population of 500 item histories. It has been assumed that an average of only one failure record per item history would be obtained.

TABLE 3-5. DETECTABLE PERCENTAGE DEPARTURE FROM ZERO OF THE STANDARDIZED REGRESSION COEFFICIENTS

		(B/MTBF) x 100%	
	N	k = 3	k = 10
	50	44%	50%
	100	31%	35%
	250	19%	22%
r = 0.7	500	14%	16%
	1000	10%	11%
	10000	3%	3%
	20000	2%	2%
	50	74%	86%
	100	52%	60%
	250	33%	38%
r = 0.9	500	23%	27%
	1000	16%	19%
	10000	5%	6%
	20000	4%	4%

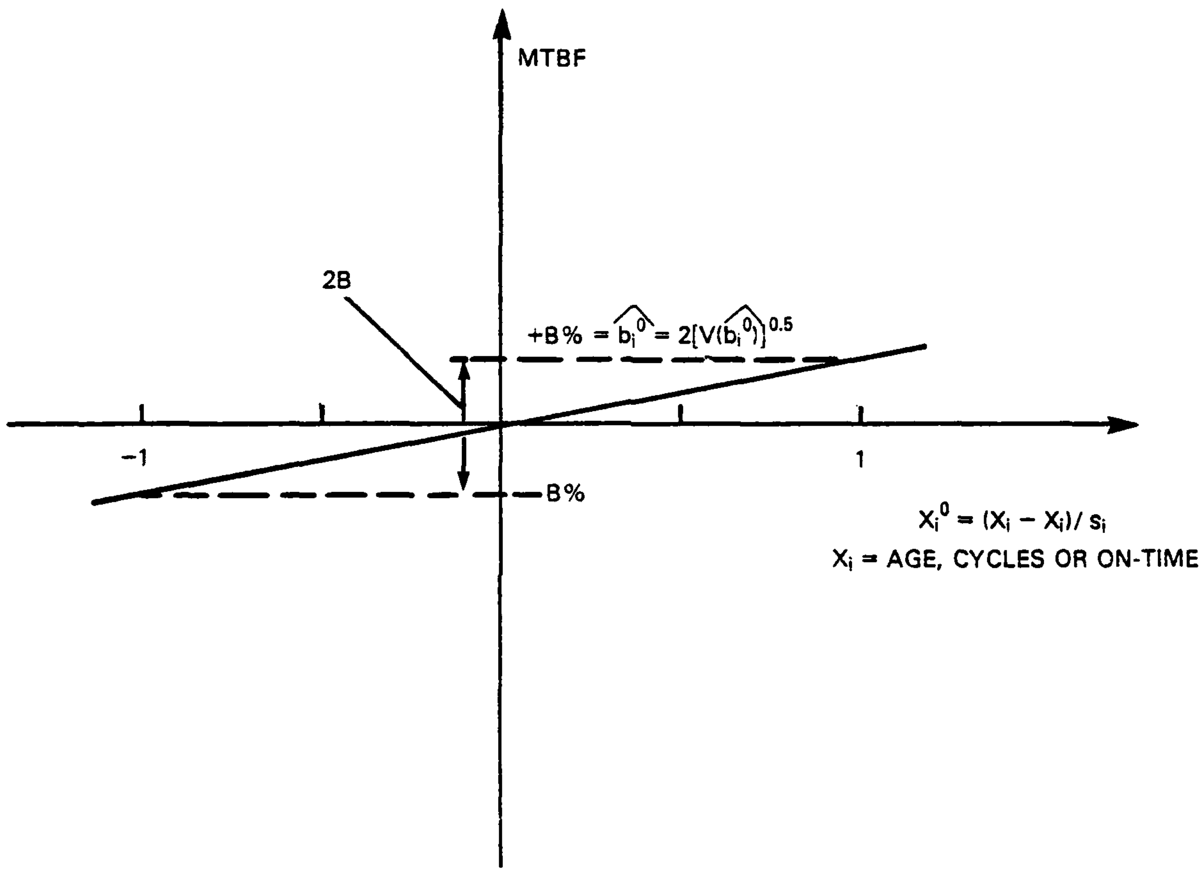

Figure 3-11. Relationship Between Coefficient Estimator and Detectable Change in MTBF

Tables 3-3 through 3-5 answer the questions of detecting changes and how much data is needed. Of course, the correlation, the number of TBF data points per item history, and the number of variables in the final regression models will not be known until after data analysis. However, review of the tables indicates that a population of 500 item histories is a reasonable pilot program goal.

The other question that needed answering was how to decide when two categories of data could be combined. This is accomplished in effect by comparing the regression coefficients from two models, one fit to one data set, and the other fit to the second data set. Analogous to the statistical approach used above to test a regression coefficient equal to zero, an approach would be used to test the difference, or contrast, between regression coefficients. The foregoing tables would then be interpreted as the percentage MTBF differences detectable between the categories for N total data points in the categories.

The above discussions have centered on the least squares estimator, the minimum variance unbiased estimator. For data analyses where there is significant correlation among the variables, sometimes a smaller variance estimator can be obtained if a bias is acceptable. One such approach is named "ridge regression." It is expected that when the combined effects of variance and nonzero bias are unraveled, practically the same number of required data points would result. It could be of interest to analyze the Harpoon data set with both usual least squares and ridge regression and compare the results.

3.4 Methodology Summary and Conclusion

In Section 3, considerations of statistical experiment design, data organization, statistical analysis including estimation of distributions and distribution parameters, regression analysis, and associated ANOVA applicable to the study of the effect of testing on the Harpoon missile system inherent reliability have been presented. Limited control of the experiment design can be achieved through organization of the data primarily subsequent to data retrieval. Control during retrieval is practically limited to uniform selection of design categories, and selection of item population to produce a broad range of item age, power on-off cycles, and power-on time. A hierarchy of test and environmental categories described by data trees presented in Section 3.2 provides the data organization that would be generated from the retrieved data. Descriptions of the models needed to compute cycles and power-on time from the retrieved data were provided in Section 3.2.

The statistical analysis methodology discussion centered on the number of data records needed to detect changes in the inherent reliability characterized by MTBF with increased age, cycles, and on-time. The expected multicollinearity among age, cycles, and on-time, and the usual problem of high variance in reliability estimation were addressed. It was concluded that a practically sized initial data retrieval of 500 item population histories per missile subassembly to be analyzed would probably be sufficient. This would correspond, roughly, to the capability to detect a 20% change in item MTBF between items with lower than average testing and items with higher than average testing. The exact capability would not be known until the correlations between age, cycles, and on-time are calculated, until the number of time-between-failure records per item history is finalized, and until final decisions are made on combinations of design and environmental categories of the data.

The results of the statistical analyses would be presented in tabular and graphical form showing correlations between age, cycles, and on-time in the several test and environmental categories, and showing the relationship of interval estimates of MTBF (MTBF with error bars) to cumulative item age, cycles, and on-time. The results of the feasible analysis would be useful inputs to decisions on the Harpoon missile system test equipment or procedure changes. The testing dependent inherent MTBF results are needed for reliability optimization where tradeoffs are decided among reduced testing, higher inherent reliability, and higher or lower missile availability (dependent on functional test frequency and inherent MTBF). The methodology provides the tools to identify stronger and weaker reliability areas among the missile subassemblies.

4. COST

It is estimated that the statistical analyses described in Section 3 can be accomplished on 500 histories of the five subassemblies of the Harpoon missile system as described in Section 2, with preparation of a summary results report, for a direct labor cost of about 640 manhours. A computer usage cost estimate based on similar recent experience amounts to $2,000. Cost of the data retrieval described in Section 2 by McDonnell-Douglas Corporation is not included in this estimate, nor is any travel expense included.

5. CONCLUSIONS

In the foregoing sections, an introduction and approach to data retrieval, manipulation, and analysis was presented. The data needed to estimate the effect of testing on the Harpoon missile system reliability was defined in terms of several of the missile subassemblies. Work with McDonnell-Douglas Astronautics, St. Louis, indicated that this data is retrievable, and a feasible data retrieval plan was prepared. A number of potential extraneous effects on reliability were identified including the effects of several design and test evolution categories, environmental categories, and differences among the several test types and levels. An organization of these measurable variables in a hierarchical relationship called "data trees" assigns the missile subassembly accumulating age, power on-off cycles, and power-on time to the several environmental and test categories at the depot, intermediate, and organizational levels.

The raw data from the planned retrieval can be manipulated to directly obtain time-(change in item age) without-failure and between-failure data records. Further manipulation with models of on-off cycles and power-on time as a function of retrieved values would produce the other variables. These models can be synthesized from information which is available at McDonnell-Douglas. The information would be applicable and specific to the several test types and missile subassemblies to be analyzed.

A combined approach of "limited" statistical experiment design, organization of measurable variables, and statistical analysis is sufficient to analyze for changes in item MTBF with changes in item age, cycles, and on-time. Impractically retrievable information or nonmeasurable effects such as the variation in BIT testing are expected to be covered by the assumption of a time-between-failures probability distribution with about unity coefficient of variation, the usual situation in reliability analysis. The expected degree of multicollinearity among age, cycles, and on-time increases the number of time-between-failure records necessary to detect a given change in MTBF with age or testing. A combination of statistical analysis methodology including estimation of probability distributions and distribution parameters, correlation analysis, regression analysis, and associated ANOVA is capable of detecting a 20% to 40% change in MTBF between groups of items in a sample of 1000 data records dichotomized according to above and below average age or testing if such a change exists. The methodology would, in any case, produce an estimate (with error bars) of the relation between item MTBF and age and testing. The above percentage change that would be detectable with statistical significance is expected to be between 30% and 50% for a data retrieval which generates 500 time-between-failure records. The relation between the detectable percentage change in MTBF and the number of data points depends on the degree of multicollinearity between item age and testing. The percentage ranges stated above correspond to age and testing correlation of 0.7 to 0.9.

Considering that percentage errors (standard deviations) on the order of 10% to 25% of MTBF are relatively small compared to the usual goals of reliability demonstrations, a trial, or pilot, data retrieval and analysis of 500 item histories would be a worthwhile and feasible goal. The analyses would produce estimates of item MTBF with error bars over the region of item age and testing in the data set. This result would be useful input to decisions on certain Harpoon missile system design and test equipment or procedure changes. Such a pilot program would demonstrate the methodology defined in this feasibility study, and would indicate the usefulness of extending the scope to further Harpoon missile subassemblies.

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APPENDIX A

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

TERM	MEANING
AACTS	AUTOMATED ANECHOIC CHAMBER TEST SYSTEM
AC	ALTERNATING CURRENT
ADMIN	ADMINISTRATIVE
AFC	AUTOMATIC FREQUENCY CONTROL
AITS	AUTOMATED INTEGRATION TEST SYSTEM
ANOVA	ANALYSIS OF VARIANCE
ARA	ATTITUDE REFERENCE ASSEMBLY
ARATS	ATTITUDE REFERENCE ASSEMBLY TEST SET
ASSC	AVIONICS SOFTWARE SUPPORT CENTER
ASSY	ASSEMBLY
ASU	APPROVAL FOR SERVICE USE
ATTEN	ATTENUATION
AUR	ALL UP ROUND
AUR/EX	ALL UP ROUND WITH EXERCISE SECTION
AURT	ALL UP ROUND TEST
AUX	AUXILIARY
AV	AVIONICS
AVE	AVERAGE
AZ	AZIMUTH
B/I	BURN-IN
B/I ALT	ALTIMETER BURN-IN TEST STATION
BIT	BUILT-IN-TEST
BOA	BASIC ORDERING AGREEMENT
BSTR	BOOSTER
C	CONCORD, CALIFORNIA
C/B	CIRCUIT BREAKER
CA	CALIFORNIA
CAN	CANISTER
CAP	CAPSULE
CBL	COMMERCIAL BILL OF LADING
CCW	COUNTER-CLOCKWISE
CDTR	CONTROLLED DEVELOPMENT TEST ROUND
CGSE	COMMON GROUND SUPPORT EQUIPMENT
CKT	CIRCUIT
CLS	COMMAND AND LAUNCH SUBSYSTEM
CMD	COMMAND
CMRS	CALIBRATION/MEASUREMENT REQUIREMENTS SUMMARY
CND	CANNOT DUPLICATE FAILURE
CNTL	CONTROL
CONT	CONTINUITY
CONV	CONVERTER
CRT	CATHODE RAY TUBE (MSTS DISPLAY CONSOLE)
CRT	CATHODE RAY TUBE

CW	CLOCKWISE
CY	CALENDAR YEAR
D	DEPOT REPAIR STATUS
D	DEPOT (ST. CHARLES - MDC)
D/A	DIGITAL TO ANALOG
DB	DECIBEL
DC	DIRECT CURRENT
DC/PS	DIGITAL COMPUTER/POWER SUPPLY
DEMOD	DEMODULATION
DF	DIRECTION FINDING
DF	DIRECTION FINDER
DIG	DIGITAL
DISC	DISCRETE
DM	DEPOT MAINTENANCE
DOP	DESIGNATED OVERHAUL POINT
DR	DYNAMIC RESULTS
DRF	DERATE FACTOR
DRT	A CLASSIFIED TESTING AREA
DVM	DIGITAL VOLTMETER
DVM	DIGITAL VOLTMETER
ECA	ELECTRONIC CONTROL AMPLIFIER
ECA	ELECTRONIC CONTROL AMPLIFIER
ECP	ENGINEERING CHANGE PROPOSAL
EGT	EXHAUST GAS TEMPERATURE
EL	ELEVATION
EM	ELECTROMECHANICAL
ENG	ENGINE
ETI	ETM INDICATION
ETM	*ELAPSED TIME METER, OR ETM READING*
EXT	EXTEND
FAT	FINAL ACCEPTANCE TEST
FCE	FUEL CONTROL ELECTRONICS
FLTAC	FLEET ANALYSIS CENTER
FM	FREQUENCY MODULATED
FMS	FOREIGN MILITARY SALES
FMS	FOREIGN MISSILE SALES
FOT&E	FOLLOW ON TEST AND EVALUATION
FWD	FORWARD
FY	FISCAL YEAR
G	GRAVITY
GBL	GOVERNMENT BILL OF LADING
GPSS	GENERAL PURPOSE SIMULATION SYSTEM
GQN	GUIDANCE SECTION SERIAL NUMBER PREFIX
GQN	SEEKER UNIT IDENTIFICATION NUMBER CATEGORY
GSE	GROUND SUPPORT EQUIPMENT
GUID	GUIDANCE (SECTION)
H/O	HOLD OFF
HELPC	FORTRAN SUBROUTINE
HMB	HARPOON MISSILE BODY
HPP	HARPOON PRODUCTION PHASE
HSD	HAMILTON STANDARD DIVISION

HYST	HYSTERESIS
HZ	HERTZ
I	INTERMEDIATE
I-LEVEL	INTERMEDIATE LEVEL (MAINTENANCE)
I/O	INPUT/OUTPUT
IBM	INTERNATIONAL BUSINESS MACHINES, INC.
IF	INTERMEDIATE FREQUENCY
INSP	INSPECTION
ITL	INTENT TO LAUNCH
L	LEFT
LO	LOCAL OSCILLATOR
LO, L/O	LOCK ON
LORA	LEVEL OF REPAIR ANALYSIS
MALT	MANUFACTURING ALIGNMENT TEST
MAX	MAXIMUM
MC	MAINTENANCE CYCLE
MCV	MODE CONTROL VECTOR
MDAC	MCDONNELL DOUGLAS ASTRONAUTICS COMPANY (ST. LOUIS)
MDC	MCDONNELL DOUGLAS CORPORATION
MDD	MAINTENANCE DUE DATE
MEM	MEMORY
MGU	MIDCOURSE GUIDANCE UNIT
MGUATS	MIDCOURSE GUIDANCE UNIT AUTOMATIC TEST SYSTEM
MIN	MINIMUM
MO	MONTH OR MISSOURI
MRF	MAINTENANCE REPLACEMENT FACTOR
MSEC	MILLISECOND
MSL	MISSILE
MSTS	MISSILE SUBSYSTEM TEST SET
MT	MASTER TRIGGER
MTBF	MEAN TIME BETWEEN FAILURES
MTM	MISSILE TEST MODULE
MTS	MISSILE TEST STAND
MTTR	MEAN TIME TO REPAIR
N	NONWARRANTY
N/C	NORMALLY CLOSED
N/O	NORMALLY OPEN
N/R	NEAR RANGE
NAVAIR	NAVAL AIR SYSTEMS COMMAND
NEUT	NEUTRAL
NO	NUMBER
NWS	NAVAL WEAPONS STATION
NWS-C	NAVAL WEAPONS STATION, CONCORD, CALIFORNIA
NWS-Y	NAVAL WEAPONS STATION, YORKTOWN, VIRGINIA
O	ORGANIZATIONAL
O/B	OUTBOUND
OMB	OFFICE OF MANAGEMENT AND BUDGET
P CODE	PERFORMANCE CODE
PC	PRIME CSF FLTAC
PCB	PRINTED CIRCUIT BOARD

PGSE	PECULIAR GROUND SUPPORT EQUIPMENT
PHI (SYMBOL)	PHASE ANGLE
PM	PRIME MAIN FLTAC
PMTC	PACIFIC MISSILE TEST CENTER
PREFAT	PRE-FINAL ACCEPTANCE TEST
PRF	PULSE REPETITION FREQUENCY
PROG	PROGRAMMER
PROX	PROXIMITY
PRP	PYRO RELAY PANEL
PS	POWER SUPPLY
PSTS	POWER SUPPLY TEST STATION
PT2	ENGINE INLET PRESSURE
PWA	PRINTED WIRING ASSEMBLY
PWR	POWER
RATS	RADAR ALTIMETER TEST STATION
RCT	REPAIR CYCLE TIME
RES	RESISTANCE
RF	RADIO FREQUENCY
RF/IF	RADIO FREQUENCY/INTERMEDIATE FREQUENCY
RFI	READY FOR ISSUE
RPF	REPORTABLE POOL FACTOR
RPM	REVOLUTIONS PER MINUTE
RT	RIGHT
S	SLITS
S&A/CF	SAFE AND ARM/CONTACT FUZE
S/F	SCALE FACTOR
S/L	SECTION LEVEL
S/N	SERIAL NUMBER
SCO	SIGNAL CONTROLLED OSCILLATOR
SECT	SECTION
SEL	SELECT
SEN	SENSITIVITY
SEP	SEPARATE
SHF	SUPER HIGH FREQUENCY
SIGMA (SYMBOL)	STANDARD DEVIATION
SIM	SIMULATION
SITS	SYSTEM INTEGRATION TEST STATION
SKR	SEEKER
SM&R	SOURCE, MAINTENANCE AND RECOVERABILITY
SOW	STATEMENT OF WORK
SPF	STOCK POOL FACTOR
SRA	SHOP REPLACEABLE ASSEMBLY
SSAT	SWEEP STOP ALARM TARGET
STA	SEEKER TEST ASSEMBLY
STC	ST. CHARLES, MISSOURI
STC	SENSITIVITY TIME CONTROL
STD DEV	STANDARD DEVIATION
STE	SPECIAL TEST EQUIPMENT
SW	SWITCH

T/S	TROUBLESHOOT, THERMAL SCREENING
TAT	TURNAROUND TIME, ALSO SEE TT
TBF	TIME-BETWEEN-FAILURES
TEMPTS	TEMPERATURE TEST STATION
TGT SENS	TARGET SENSING
THR	THRESHOLD
THRES	THRESHOLD
TI	TEXAS INSTRUMENTS
TM	TELEMETRY
TR	TRANSACTION REPORT SLITS
TS	TROUBLESHOOT (FAULT ISOLATION)
TT	TURNAROUND TIME, ALSO SEE TAT
TT2	ENGINE INLET AMBIENT TEMPERATURE
TVT	TARGET VERIFICATION TEST
TWT	TRAVELING WAVE TUBE
UK	UNITED KINGDOM
US	UNITED STATES
USN	UNITED STATES NAVY
UUT	UNIT UNDER TEST
V	VOLT
VA	VIRGINIA
VHF	VERY HIGH FREQUENCY
VIBTS	VIBRATION TEST STATION
W	WARRANTY
WG	WAVEGUIDE
WRA	WEAPON REPLACEABLE ASSEMBLY
X/BAR	CROSS BAR
XMTR	TRANSMITTER
XMTRTS	TRANSMITTER TEST STATION
Y	YORKTOWN, VIRGINIA

APPENDIX B

TEST SET DESCRIPTIONS

(Notes from McDonnell-Douglas Astronautics Company,
December, 1983)

APPENDIX B

TEST SET DESCRIPTIONS

(Notes from McDonnell-Douglas Astronautics Company, December, 1983)

AACTS (Automated Anechoic Chamber Test System) - An automatic or manually operated test system designed to test the Harpoon Seeker in a far-field environment. It is utilized for troubleshooting, detailed alignment, and selloff testing of Harpoon Radar Seekers.

AITS (Automated Integration Test System) - An automatic or manually operated test system designed to test the Harpoon Seeker in a transitional zone environment. It is utilized for troubleshooting and for detailed alignment before entering AACTS testing.

ARATS (Attitude Reference Assembly Test Set) - Used for troubleshooting, alignment, and selloff.

DRT - "Classified testing area."

FAT (Final Acceptance Test) - Primarily used to designate selloff testing for Seekers on AACTS. May also be used for an acronym to describe other repair item selloff testing.

MALT (Manufacturing Alignment Test) - Detailed alignment testing of Seekers, prior to selloff testing, utilizing either the AACTS or AITS.

MGUATS (Midcourse Guidance Unit Automatic Test Station) - An automatic or manually operated test system designed to test the Harpoon MGU. It is utilized for troubleshooting, temperature/vibration tests, detailed alignment, and selloff testing of Harpoon MGUs and their component Attitude Reference Assemblies (ARA) and Digital Computer/Power Supplies (DCPS).

PREFAT (Pre-Final Acceptance Test) - A trial run of Final Acceptance Test for Harpoon Radar Seekers on AACTS prior to going into failure-free testing (Temperature Cycling and FAT).

PSTS (Power Supply Test Station) - A test set for the Power Supply subassembly of the Harpoon Seeker.

RATS (Radar Altimeter Test Station) - A manual test set designed to test Harpoon altimeters. It is utilized for troubleshooting, detailed alignment, random vibration test monitoring, and selloff testing of the Harpoon Altimeter.

Altimeter B/I (Burn-In) Test Station - A manual test set used to monitor altimeter functions during temperature/vibration testing.

SITS (System Integration Test Station) - A manually or automatic operated test station used to evaluate, troubleshoot, and perform rough alignments on Harpoon Seekers in a transitional zone environment.

TEMPTS (Temperature Test Station) - A manually or automatic operated test station used for testing Harpoon Seekers under varying temperature environments.

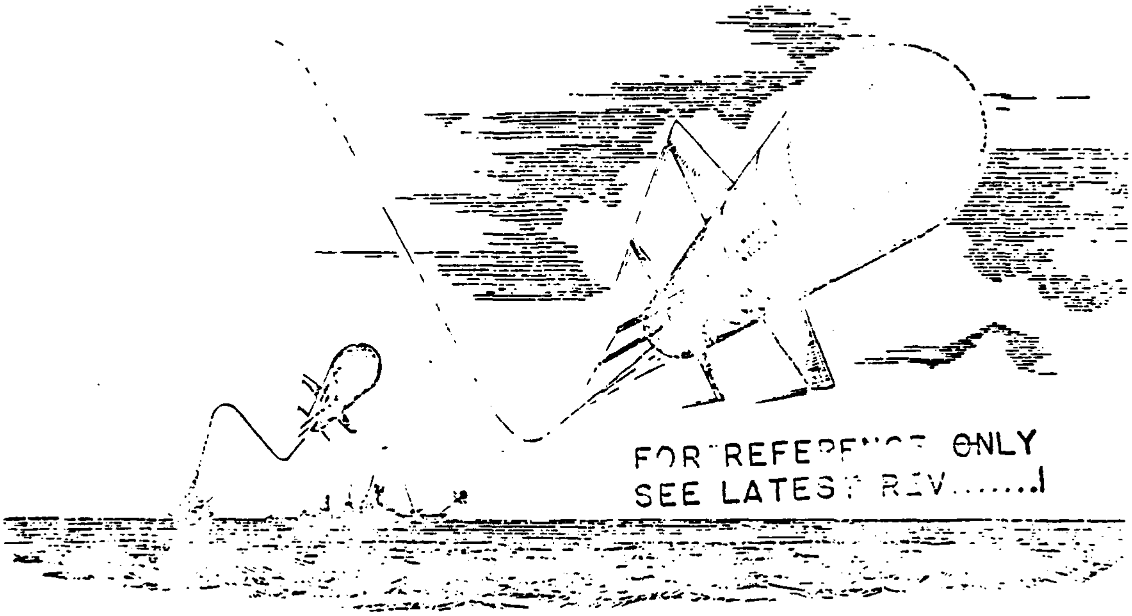
VIBTS (Vibration Test Station) - A manually operated test station utilized to monitor Harpoon Seeker operation under random vibration conditions.

XMTRTS (Transmitter Test Station) - A manually operated test station utilized to test Harpoon Seeker transmitters and to match their component magnetrons and modulators.

P-Codes (Performance Codes) - Coding of functional Seeker tests on SITS.

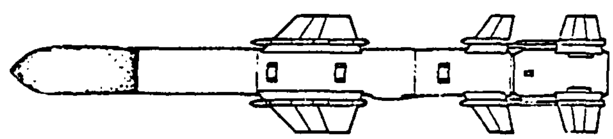
APPENDIX C

SAMPLE AS-BUILT CONFIGURATION LIST



FOR REFERENCE ONLY
SEE LATEST REV.......

As Built Configuration List



Guidance Section

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY · ST. LOUI
Box 516, Saint Louis, Missouri 63166 (314) 232-02

Serial Number GQN-0512

MCDONNELL DOUGLAS

END ITEM NOMENCLATURE	END ITEM NUMBER	SERIAL NUMBER	FACTORY ACCEPTANCE (MONTH/YEAR)
GUIDANCE SECTION	P/C 642AS1250-1	P/N GQN-0512	May 78

COMPONENT NOMENCLATURE	COMPONENT NUMBER	SERIAL NUMBER	MANUFACTURER
RADAR ALTIMETER, ANTENNA	642AS4200	GQN- 1006	BALL BROTHERS
POWER CONVERTER	642AS0753	GQN- 0568	ELDEC
TARGET SEEKER	642AS3400	GQN- 0334	TEXAS INSTRUMENTS
MIDCOURSE GUIDANCE UNIT	642AS1214	GQN- 0428	MDAC-ST. LOUIS
RADAR ALTIMETER	642AS4100	GQN- 0477	HONEYWELL

APPLICABLE WAIVERS, DEVIATIONS

THE FOLLOWING DEVIATIONS ARE APPLICABLE TO THIS GUIDANCE SECTION:

D0083, D0109R1, D0039, D0082, D0035, D0052, D0023R1, D0027, D0028, D0095.

FOR REFERENCE ONLY
SEE LATEST REV.......

QPIS 72-00-113

"AS BUILT"

CONFIGURATION DEFINITION LISTING

MGU
S/N 88N 0428

PART NO.	REV.	ITEM	S/N	REMARKS
67735-301	A	ARA Installation	—	
101874-301	E	Attitude Reference Assembly	4100	
67678-301	D	Accelerometer AP-G6-202A U1 (X)	9828	
67678-301	D	Accelerometer AP-G6-202A U2 (Y)	9830	
67678-301	D	Accelerometer AP-G6-202A U3 (Z)	9851	
67663-304/ ~~or 303~~	E	Gyro, Integrating GI-G6-344B (MP1) (X) Roll	11597	
67663-~~304/~~ or 303	E	Gyro, Integrating GI-G6-344B (MP2) (Y) Pitch	10479	
67663-303	E	Gyro, Integrating GI-G6-344A (MP3) (Z) Yaw	10476	
69802-304	P	Countdown PWB Assembly	627	
69803-301	H	Interface PWB Assembly	679	
69804-302	L	Wheel Supply PWB Assembly	745	
69809-307	U	DRE PWB Assembly (Roll)	799	
69809-308	U	DRE PWB Assembly (Pitch)	1350	
69809-308	V	DRE PWB Assembly (Yaw)	522	
101640-301	E	Temp Monitor PWB Assembly	405	
101888-302	C	S.S. Heater Controller Assy.	837	

Date 6-13-77

MDAC-E
MGU
S/N GQN 0428

AS BUILT LIST

DC/PS

IBM Corporation
Owego, NY 13827

MDAC S/N GQN-0033

EQUIPMENT NOMENCLATURE	PART NUMBER	PART S/N	SUBASSEMBLY EC LEVEL	MRB
Digital Computer/Power Supply			66273LT	
Digital Computer/Power Supply	642AS7789	185	EO 55782	
Page Assembly, Analog IO	642AS7652	208	KM	
A MIB	642AS7670-51	28		ARB 1607
B MIB	642AS7680-51	52		
Connector, Jumper Assembly	642AS7653	286	KM	
Frame, DCPS	642AS7654	359		
Connector Assembly, Back Panel	642AS7655	201	KM	
MIB	642AS7730-50	50006		
Power Supply	642AS7656	217	KM	
MIB	642AS7763-50	210		
Page Assembly, Digital IO	642AS7657	247	KM	
A MIB	642AS7690-51	66		
B MIB	642AS7700-51	57		MRB 66
Page Assembly, CPU	642AS7659	413	KM	
A MIB	642AS7710-51	132		MRB 660
B MIB	642AS7720-51	111		MRB 660
Page Assembly, ROM - 2 oz.	542AS7790	195	LT	
MIB	642AS7702-50	287		

Waivers and Deviations

Seller's Date 6-14-77
Q.C. Approval R.A. Wood

Date 6-13-77
CM Approval [illegible]

512

AS-BUILT CONFIGURATION (FY77 MAINLINE)
DATA DESCRIPTION

MDAC-E P.O. Y6G112R

HARPOON PROGRAM, CONTRACT NO. N00019-76-C-0573

NAVY P/N 642AS3400, (TI P/N 762121-1)
SEEKER, TARGET RADAR, SERIAL NO. GQN-0334, MANUF. SEQ. NO. 2330

PART NUMBER NAVY	(TI)	DESCRIPTION	(M)SN	DRAWING REVISION
642AS2753	(761838-1)	MAGNETRON	1201	R
642AS2502	(761944-2)	RADOME ASSY.	1498	K
642AS2995	(849202-1)	BIT/ANGLE PWB ASSY.	2316	AW
642AS3368	(836451-1)	RECEIVER PWB ASSY.	5006	T
642AS3002	(849232-1)	AZIMUTH SERVO PWB ASSY.	5009	AM
642AS3002	(849232-2)	ELEVATION SERVO PWB ASSY.	5034	AM
642AS3005	(849235-1)	RANGE SEARCH PWB ASSY.	2338	BB
642AS3008	(849238-1)	RANGE TRACKER PWB ASSY.	2302	BE
642AS3011	(349241-1)	DETECTION PROC PWB ASSY.	2342	AM
642AS3014	(849244-1)	CFAR PWB ASSY.	5064	AY
642AS3239	(849925-1)	J4 FLEX CABLE	3122	P
642AS3251	(349985-1)	SYNCHRONIZER PWB ASSY.	5107	AE
642AS3254	(850004-1)	BULKHEAD ASSY.	5021	AV
642AS3255	(850005-2)	A3 ELECTRONICS ASSY.	5040	AK
642AS3256	(850006-1)	POWER SUPPLY ASSY.	5053	Y
642AS3257	(850007-1)	MODULATOR ASSY.	5066	AC
642AS3261	(850015-1)	MODE CONTROL PWB ASSY.	2382	AB
642AS3263	(850017-1)	PROGRAM STORAGE PWB ASSY.	2312	U
642AS3186	(850033-1)	CARRIER PWB ASSY #2	5100	M
642AS3183	(850034-1)	CARRIER PWB ASSY #1	5047	J
642AS3266	(850055-1)	TARGET CHAR PWB ASSY.	2407	Y

ETM 31 HOURS

Document Control Number	Revision Letter
R1027- C-007A-HGON-0477	

Date 12 · 14 · 77

PURCHASE ORDER NUMBER Y6G041

SYSTEM HARPOON RADAR ALTIMETER

PROCUREMENT SPECIFICATION AS-2422

MANUFACTURER HONEYWELL INC. Minneapolis, MN 55416

SUPPLIER DATA REQUIREMENTS LIST NUMBER (SDRL) SDRL AS-2422

PART NUMBER 642AS4100

SUPPLIER DATA ITEM DESCRIPTION NUMBER (SDID) C-007A

TITLE: AS-BUILT CONFIGURATION LIST

Prepared By: R Heise
R. A. Heise
Principal Development Engineer

Approved By: J. E. Baas
J. E. Baas
Project Engineer

GQN 0477

ASSEMBLY CONFIGURATION LIST

MFG-5263

Page 1 of 1

PART/ASSEMBLY NUMBER 1-16	REV. 18-19	LOT NO. 20-25	SERIAL NO. 26-31	ISS. 32-33	WAIVER DOC. NO.	PART/ASSEMBLY NAME	*	SECTION CODE
2AS4100	BC 3		CCNC177					

PART NAME	USE 34-36	*	LOC. CODE 37-41	PART NUMBER 42-57	REV. 58-60	SERIAL NO. 67-72	WAIVER DOC. NO. 73-79	OPERATOR CODE	INSP. STAMP
Reciever				642AS4103 A	C 1	375	✓	2005	
Amp IF				642AS4104 B	C 1	400	✓ DCC82		
RF Head				642AS4220 -	-	1707	✓		
Modulator				642AS4107					
Altr Card 1				642AS4109 A	C 1	371	✓ DCC12		
Altr Card 2				642AS4316 -	-	183	✓		
Cavity				642AS4116 A	C 1	849	✓		
Range Computer				642AS4117					
Tracker 1				642AS4119 A	C 3	388	✓ …92		
Tracker 2				642AS4122 B	O 1	355	✓		
Tracker 3				642AS4125 A	C 1	379	✓		
Digital				642AS4128 B	C 1	361	ECP-629		
Power Supply Assy				642AS4131					
Power Supply 1				642AS4133 B	C 1	351	✓		
Power Supply 2				642AS4136 B	C 1	354	✓ CNR-92		
Chassis				642AS4139 A	O 1	376	✓		
Flex, PS				642AS4140 A	O 1	382	✓		
Flex. Altr				642AS4142 A	C 1	379	✓		
Flex, Track				642AS4144 A	O 1	406	✓		

* CONFIGURATION ACCOUNTING CODE

A. STD. PART NO. IDENT. D. REV. LTR. + SERIAL NO.

B. REV. LTR. IDENT. E. REV. LTR. + SERIAL NO. AND LOC. CODE

1-3-77

APPENDIX D

DATA RETRIEVAL STATEMENT OF WORK

JUN 13 '84 8:43 PO

FACSIMILE LEAD SHEET

PLEASE CHECK ONE:

- ☐ DESTROY COPY
- ☒ MAIL BACK TO SENDER
- ☐ CALL SENDER FOR PICK UP

DATE 6-13-8..

NO. OF PAGES ______ TIME SENT ______

TO: EDGAR OELKERS

COMPANY South West Research Institute

CITY San Antonio STATE Texas

BLDG ______ DEPT ______

(512) 684-5111

EXT 2807 FACSIMILE EXT ______

TELEFAX
CHECK PHONE 512-684-4822

FROM: ROD SCHULTZ

BLDG 98 DEPT ESC

EXT 5724

SPECIAL INSTR ______

SENT FROM BLDG ______ FACSIMILE EXT ______ CHECK PHONE ______

MAC 1527C (REV 18 NOV 82)

MCDONNELL DOUGLAS CORPORATION
P.O. Box 516 Saint Louis, Missouri 63166

STATEMENT OF WORK
FOR
SUPPORT OF SW RESEARCH INSTITUTE STUDY

1.0 SCOPE

This Statement of Work defines the effort to be performed by the Contractor, McDonnell Douglas Corporation, through its McDonnell Douglas Astronautics Company-St. Louis Division (MDAC-STL) to support the feasibility study on the effects of testing on the Harpoon missile system reliability being performed by Southwest Research Institute. The effort will consist of the detailed review and research of 500 USN Harpoon Guidance Section and associated subassemblies test history.

2.0 DETAILED REQUIREMENTS

The Guidance Section test history will include both section level and missile level MSTS tests performed at either MDAC-STL or Naval Weapon Station. The test history will begin at the final acceptance test of the Guidance Section performed at MDAC-STL. The Guidance Section/Missile Test History will not include other non-MSTS tests such as BIT test, CAP/CAN test, pyro interface test, etc.

The Guidance Section subassemblies will include the Target Seeker Radar, Midcourse Guidance Unit (MGU), Attitude Reference Assembly (ARA), Digital Computer/Power Supply (DC/PS) and the Altimeter. The testing will be limited to the MDAC-STL Depot WRA level tests. It will not include any vendor or SRA level testing.

The Guidance Section and its original as built subassemblies will be traced through their respective test cycles. As subassembly replacements occur, only the original subassemblies will be traced. The HMB/Section Level testing will always include a complete listing of its associated subassembly configurations.

3.0 DATA CONTENT

Each individual test result will include the following information (when applicable):

Missile Type - Code to identify missile configuration (i.e. A = Air, B = Asroc, etc.).

Missile Serial Number - The serial number of the warhead associated with the missile.

Guidance Section Part Code - Code to identify Guidance Section part number (i.e. A = 642AS1250-1, etc.).

Guidance Section Serial Number - Serial number of Guidance Section.

Seeker Part Code - Code to identify seeker part number (i.e. A = 642AS2500, etc.).

Seeker Serial Number - Serial number of seeker.

MGU Part Code - Code to identify MGU part number (i.e. A = 642AS1214, etc.).

MGU Serial Number - Serial number of MGU.

ARA Part Code - Code to identify ARA part number (i.e. A = 642AS1213, etc.).

ARA Serial Number - Serial number of ARA.

DC/PS Part Code - Code to identify DC/PS part number (i.e. A = 642AS7789, etc.).

DC/PS Serial Number - Serial number of DC/PS.

Altimeter Part Code - Code to identify Altimeter part number (i.e. A = 642AS4100, etc.).

Altimeter Serial Number - Serial number of Altimeter

End Item Test Level - Level of unit under test (i.e. A = Missile Level, B = Section Level, etc.).

Test Type - Type of test performed (i.e. Acceptance, Fault Isolation, etc.).

Support Equipment Used - Major test equipment used to test unit (i.e. MSTS, AACTS, etc.).

Date - Date test performed

Location - Where test performed (i.e. NWS-Concord, MDAC, etc.).

ETM - Reading of elapsed time meter (ETM) at end of test (when available).

Test Time - Minutes of actual test time.

Test Results - Results of test performed (i.e. Pass, Fail, Troubleshoot, etc.).

Replacement Part - Failed part replaced.

Sequence No. - A sequence number to indicate multiple repairs/ replacements.

4.0 DATA FORMAT

The data will be provided via magnetic tape and a listing of the data will be included. The tape will be structured in fixed length records.

5.0 SCHEDULE

The data will be submitted once no later than 4 months after authorization.

APPENDIX E

SAMPLE GUIDANCE SECTION DEPLOYMENT LOGS

TR: TRANSACTION REPORT SLITS
S = SLITS
PM: PRIME MAIN FLTAC
PC = PRIME CSF FLTAC
D: DEPOT REPAIR STATUS
DM = DEPOT MAINTAINENCE

GUID GQN-0512

DATE	ACTION	COMMENT	LOCATION	DATA SOURCE
5-8-79	IN	INSTALLED (NP) IN L0590	C	PM
5-11-79	CONFIG	HARP/84A CONFIGURATION L0590	C	PC
5-11-79	CONFIG	HARP-RGM/84A/3B L0590	C	PC
11-14-79	TR	DEPLOYED - WAINWRIGHT CG28	52703	S
11-20-80	TR	DEPLOYED - WAINWRIGHT CG28	52703	S
12-17-80	TR	NWS REPORT	Y	S
1-8-81	MTSTS	L0590 (F) 5160-0	Y	PM
1-8-81	RM	REMOVED FRM L0590	Y	PM
1-12-81	TR	L0590	Y	S
1-18-81	F	FAILED PREPWR RES (MTM5160)	Y	NWS
2-13-81	DEPOT MAINT.	REC MDAC FOR DM	MDC	D
2-25-81	DEPOT MAINT.	START DM (F 5160 CONFIRMED)	MDC	D
10-30-81	DEPOT MAINT.	FINISH DM RM-SKR 0334 IN-SKR 0129	MDC	D
12-4-81	SHIPPED	FRM MDC TO Y ON 8150073	MDC	D
12-18-81	IN	INSTALLED (NP) IN L0685	Y	PM
12-21-81	CONFIG	HARP-GM/84A/1B L0685 (CAN.)	Y	PC
12-28-81	TR	COND. CODE CHANGE	Y	S
1-6-82	TR	DEPLOYED - SPURANCE DD963	20574	S
4-14-82	TR	DEPLOYED - SPURANCE DD963	20574	S

TR: TRANSACTION REPORT SLITS
S: SLITS
PM: PRIME MAIN FLTAC
PC: PRIME CSF FLTAC
D: DEPOT REPAIR STATUS
DM: DEPOT MAINTAINENCE

GUID GQN-0122

DATE	ACT	COMMENT	LOC	DATA SOURCE
2-9-79	IN	INSTALLED (NP) L0607	C	PM
2-11-79	RM	REMOVE (F)(NFR) L0607	C	PM
1-8-80	CONFIG	HARP-GM/84A/1 L0924	MDA	PC
4-15-80	TR	AT C	C	S
5-9-80	TR.	XFR C TO Y	C	S
5-25-80	TR	DEPLOYED MOUSE BRUGGER DD980	V20612	S
8-14-81	TR	AT CHARLESTON	00193	S
9-14-81	TR	AT YORKTWN	Y	S
10-30-81	TEST	L0924 (F) PWR UP 5210 ALT COMM 5510 TRANS CHAN 5320 ALT HW 5520	Y	NWS
10-30-81	RM	REMOVE FRM L0924 (F) MTM 5216	Y	PM
12-1-81	DEPOT MAINT	REC MDAC FOR DM	MDC	D
12-17-81	DEPOT MAINT	START DM 5510 5520 CONFIRMED	MDC	D
3-22-82	DEPOT MAINT	FINISH DM RI SKR 0009 — 0100	MDC	D
		RI RDRACT 0159 — 0407	MDC	RRO
		RI MGU 0111 — 0076		
6-16-82	IN	INSTALLED (NP) L1042	Y	PM
6-18-82	CONFIG	HARP-GM/84A/1B L1042	Y	PC
7-7-82	TR	AT YORKTWN (COND A)	Y	S
7-22-82	TR	TXR Y TO V52690 (AS A CAN. RGM 94A-4)	Y	S
7-26-82	TR	DEPLOYED DALE CG19	V52690	S
2-4-83	TR	DEPLOYED DALE CG19	V52690	S

APPENDIX F

TEST HISTORY OF GUIDANCE SECTION 512

TEST HISTORY FOR ITEMS SELECTED IN PATH105

```
12:48 JAN 04,'84
********************************************************************************************************************
GU  0512  0509780101    49 SAMA   050978                   XAL  0477  MG  0428  SE  0334
GU  0512  0510780101    50 SAMA   051078                   XAL  0477  MG  0428  SE  0334
GU  0512  0509790101     0 AACN2 050879          0497      AL  0477  MG  0428  SE  0334
GU  0512  0509790201    44 AACA2 050879          0497      AL  0477  MG  0428  SE  0334
GU  0512  0108810101     0 AAYA5         010881  0497     XAL  0477  MG  0428  SE  0334        0000  RRO WN10155 5160*5
                PRE PWR RESIST*MGU/SKR HTR ISOL           DEFECTIVE SKR S/N 0334(RRO WN10275)23   NEW SEEKER S/N 0129
                X SE  0334   RRO WN10155
GU  0512  0305810101    50 SASA3         030581  0000     XAL  0477  MG  0428  SE  0334        0000  RRO WN10155 6600*21
                PRE PWR * SKR HTR ISOL                     CONFIRMED YORKTOWN HMB FAILURE            DEFECTIVE SEEKER S/N 0334
                X SE  0334   RRO WN10275
GU  0512  1027810101    47 SRSA3 102781                    XAL  0477  MG  0428  SE  0129
GU  0512  1218810101    44 AAYA5 121781          0562     XAL  0477  MG  0428  SE  0129
********************************************************************************************************************
   234
```

END
DATE
FILMED
9-88
DTIC