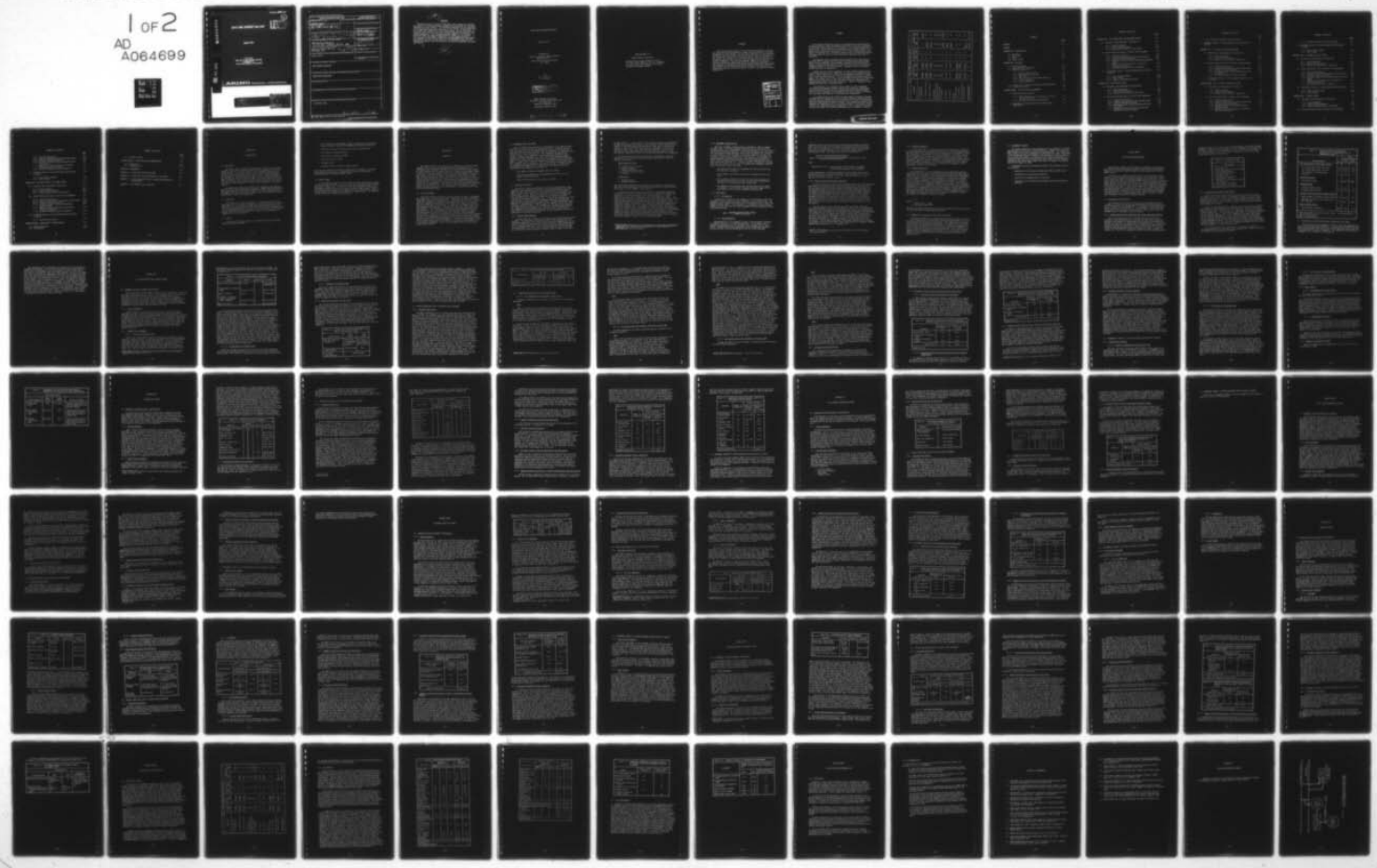
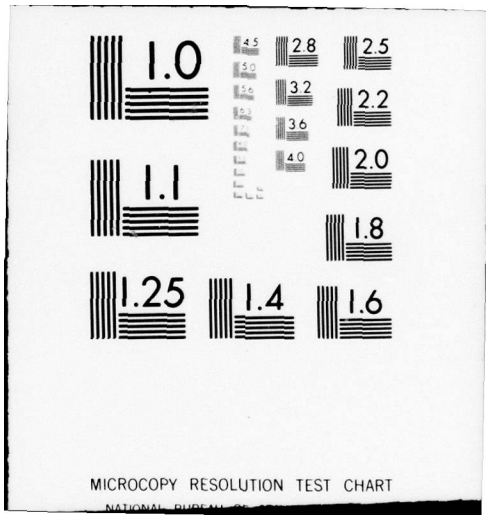
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January 1979

Prepared for
NAVAL SEA SYSTEMS COMMAND, PMS-400C
WASHINGTON, D.C.
under Contract N00140-77-D-0417-0020

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ABSTRACT

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January 1979

Prepared for

Naval Sea Systems Command, PMS-400C
Washington, D.C.

under Contract N00140-77-D-0417
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by

E. J. Lutz, Jr.
B. W. Averyt

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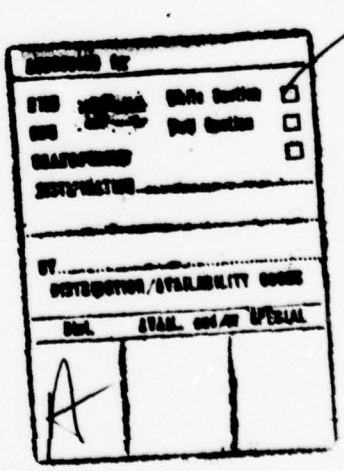
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ABSTRACT

Seven distributive systems of the CGN-42 were analyzed to evaluate the Reliability and Maintainability (R&M) values specified for the major equipments of these systems. The evaluation addressed the reasonableness of the specified values from the point of view of the critical nature of the system, the reliability of the system design, and the likelihood of achieving these values in the light of Fleet operational experience with similar equipments. This report recommends changes to the existing specified values and suggests R&M values for additional equipments. It also presents a discussion of potential equipment R&M design improvements and compares the total projected corrective maintenance man-hours for manning calculations with the historical corrective maintenance man-hours experienced.



SUMMARY

This report presents the results of the analyses of the Reliability and Maintainability (R&M) requirements specified for the major equipments of seven distributive systems as configured by the contract designs for the CGN-42 Class. The objective of the analyses was to evaluate whether the specified R&M values were reasonable in view of the critical nature of the system, the reliability of the system design, and the likelihood of achieving these values in light of Fleet operational experience with similar equipments.

The approach used in performing these analyses was to identify the projected CGN-42 equipment and the associated R&M specification requirements; select comparable Fleet equipment; determine the historical R&M indices; compare the specification values with the historical values; and recommend changes to the specifications, equipment design, or equipment support functions as appropriate.

Analysis of the 32 major equipments of these systems indicated that a mean time between failure (MTBF) for one additional equipment and mean times to repair (MTTR) for two additional equipments should also be specified in the Ship Specification. It also indicated that changes should be made to the values of five of the specified MTBFs and three of the specified MTTRs to bring them more in line with state-of-the-art improvements as demonstrated by Fleet operational experience. Table S-1 summarizes these changes and additions to the R&M values.

Investigation of the dominant failure modes of these equipments identified six equipments in which significant reliability improvements could be realized if the failures could be reduced by improved designs. Four of the six equipments are recommended for further study to determine the life-cycle cost benefits of these potential improvements.

An investigation of the effects of higher MTTRs on potential manning problems led to a comparison of the projected corrective maintenance man-hours for manning calculations with the operational corrective maintenance man-hours experienced for similar systems. This comparison identified the possibility of manning-level or skill-mix problems for individual systems; however, the comparison should be expanded to cover a complete work center so that the impact of the system differences can be adequately assessed.

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Table S-1. SUMMARY OF RECOMMENDED CHANGES TO SPECIFIED R&M VALUES

System/Equipment	Specification Values		Operational Values		Recommended Changes	
	MTBF (Hours)	MTTR (Hours)	MTBF (Hours)	MTTR (Hours)	MTBF (Hours)	MTTR (Hours)
A/C Chilled Water System						
A/C Chilled Water Plant	6600 goal 3300 minimum	24.6 goal 49.2 maximum	6,407	7.8	None	Change to: 12.5 goal
A/C Chilled Water Circulating Pump	4200 goal 2100 minimum	10.8 goal 21.6 maximum	15,957	31.1	Change to: 8000 goal	None
A/C Sea Water Circulating Pump	6600 goal 3300 minimum	7.1 goal 14.2 maximum	10,923	23.2	Change to: 8000 goal	None
Ventilation System	None	None			None	None
60 Hz Power Distribution System	None	None			None	None
400 Hz Power Distribution System	None	None			None	None
Electronic Dry Air System	None	None			None	None
L.P. Air Compressor	1000 minimum	None	4,359	17.1	Change to: 2820 goal	Add values: 4.0 goal
Type I Dehydrator	1000 minimum	5.0 maximum	5,071	35.6	Change to: 2000 goal	None
Type II Dehydrator	1000 minimum	5.0 maximum	6,300	7.5	Change to: 2000 goal	None
Firemain System						
Turbine Driven Firepump	2750 goal 1375 minimum	5.4 goal 10.8 maximum	1,927	20.0	None	None
Motor Driven Firepump	3000 goal 1500 minimum	4.0 goal 8.0 maximum	3,495	33.4	None	None
Sea Water Cooling for Combat System						
AEGIS Radar Cooling Pump	8500 goal 4250 minimum	8.1 goal 16.2 maximum	5,720	26.6	Add Demonstration Test	None
Cooling Coil and Miscellaneous Machinery Sea Water Pump	None	None			Add values: 8500 goal	Add values: 8.1 goal

CONTENTS

	Page
ABSTRACT	iii
SUMMARY	v
CHAPTER ONE: INTRODUCTION	1-1
1.1 Background	1-1
1.2 Objectives	1-1
1.3 Scope	1-1
1.4 Report Format	1-2
CHAPTER TWO: APPROACH	
2.1 CGN-42 Equipment	2-1
2.2 Comparable Fleet Equipment	2-2
2.3 Historical R&M Data	2-2
2.3.1 Failure Identification	2-2
2.3.2 Equipment Operating Time	2-4
2.3.3 R&M Indices	2-4
2.3.4 Total Corrective Maintenance Man-Hours	2-5
2.3.5 Failure Categories	2-6
2.3.6 System Reliability	2-6
2.4 Comparision of Historical and Specified R&M Values	2-6
2.5 Recommended Change	2-7
CHAPTER THREE: SPECIFICATION REQUIREMENTS	3-1
3.1 Applicable Specifications	
3.1.1 CGN-42 AEGIS Nuclear Guided Missile Cruiser Ship Specification	3-1
3.1.2 Military Specifications (MIL-SPECs)	3-2
3.2 Discussion of Specification Versus Operational MTTR Values	3-3

CONTENTS (Continued)

	Page
CHAPTER FOUR: AIR CONDITIONING CHILLED WATER SYSTEM	4-1
4.1 Determine System Equipment Configuration	4-1
4.1.1 CGN-42 Equipments	4-1
4.1.2 Similar Fleet Equipment	4-1
4.1.3 Review Specifications for R&M Values	4-3
4.2 Review Operational Data on Similar Fleet Equipment	4-4
4.2.1 Calculate R&M Indices	4-4
4.2.2 Compare Operational and Specified R&M Values	4-5
4.2.3 Calculate System Reliability	4-8
4.2.4 Determine System Corrective Maintenance Man-Hour Burden	4-9
4.2.5 Compare Projected and Historic Corrective Maintenance Man-Hours	4-10
4.2.6 Determine Equipment Failure Categories	4-11
4.3 Recommended Changes to System Equipment Specification or Design	4-11
4.3.1 Specification Changes	4-11
4.3.2 Other Changes	4-13
4.3.3 Summary of Recommended Changes	4-13
CHAPTER FIVE: VENTILATION SYSTEM	5-1
5.1 Determine System Equipment Configurations	5-1
5.1.1 CGN-42 Equipments	5-1
5.1.2 Similar Fleet Equipment	5-1
5.1.3 Review Specifications for R&M Values	5-2
5.2 Review Operational Data on Similar Fleet Equipments	5-3
5.2.1 Calculate R&M Indices	5-3
5.2.2 Compare Operational and Specified R&M Values	5-5
5.2.3 Calculate System Reliability	5-5
5.2.4 Determine System Corrective-Maintenance Man-Hour Burden	5-5
5.2.5 Compare Projected and Historic Corrective-Maintenance Man-Hour Burdens	5-5

CONTENTS (Continued)

	Page
5.2.6 Determine Equipment Failure Categories	5-6
5.3 Recommend Changes to System Equipment Specifications or Design	5-7
CHAPTER SIX: 60 HZ POWER DISTRIBUTION SYSTEM	6-1
6.1 Determine System Equipment Configurations	6-1
6.1.1 CGN-42 Equipments	6-1
6.1.2 Similar Fleet Equipment	6-1
6.1.3 Review Specifications for R&M Values	6-2
6.2 Review Operational Data on Similar Fleet Equipments	6-2
6.2.1 Calculate R&M Indices	6-2
6.2.2 Compare Operational and Specified R&M Values	6-3
6.2.3 Calculate System Reliability	6-3
6.2.4 Determine System Corrective-Maintenance Man-Hour Burden	6-4
6.2.5 Determine Equipment Failure Categories	6-4
6.3 Recommend Changes to System Equipment Specifications or Design	6-5
CHAPTER SEVEN: 400 HZ POWER DISTRIBUTION SYSTEM	7-1
7.1 Determine System Equipment Configuration	7-1
7.1.1 CGN-42 Equipment	7-1
7.1.2 Similar Fleet Equipment	7-1
7.1.3 Review Specifications for R&M Values	7-2
7.2 Review Operating Data on Similar Fleet Equipments	7-2
7.2.1 Calculate R&M Indices	7-2
7.2.2 Compare Operational and Specified R&M Values	7-3
7.2.3 Calculate System Reliability	7-3
7.2.4 Determine System Corrective-Maintenance Man-Hour Burden	7-3
7.2.5 Compare Projected and Historic Corrective-Maintenance Man-Hours	7-4

CONTENTS (Continued)

	Page
7.2.6 Determine Equipment Failure Categories	7-4
7.3 Recommend Changes to System Equipment Specifications or Design	7-4
7.3.1 Specification Changes	7-4
7.3.2 Other Changes	7-4
CHAPTER EIGHT: ELECTRONIC DRY AIR SYSTEM	8-1
8.1 Determine System Equipment Configuration	8-1
8.1.1 CGN-42 Equipment	8-1
8.1.2 Similar Fleet Equipment	8-2
8.1.3 Review Specifications for R&M Values	8-3
8.2 Review Operational Data on Similar Fleet Equipments	8-3
8.2.1 Calculate R&M Indices	8-3
8.2.2 Compare Operational and Specification R&M Values	8-5
8.2.3 Calculate System Reliability	8-6
8.2.4 Determine System Corrective-Maintenance Man-Hour Burden	8-6
8.2.5 Compare Projected and Historic Corrective-Maintenance Man-Hours	8-7
8.2.6 Review Equipment Failure Categories	8-8
8.3 Recommended Changes to System Equipment Specifications	8-8
8.3.1 Specification Changes	8-8
8.3.2 Other Changes	8-9
CHAPTER NINE: FIREMAIN SYSTEM	9-1
9.1 Determine System Equipment Configurations	9-1
9.1.1 CGN-42 Equipment	9-1
9.1.2 Similar Fleet Equipment	9-1
9.1.3 Review Specifications for R&M Values	9-3
9.2 Review Operational Data on Similar Fleet Equipment	9-3

CONTENTS (Continued)

		Page
9.2.1	Calculate R&M Indices	9-3
9.2.2	Compare Operational and Specified R&M Values	9-5
9.2.3	Calculate System Reliability	9-5
9.2.4	Determine System Corrective Maintenance Man-Hour Burden	9-6
9.2.5	Compare Projected and Historic Corrective Maintenance Man-Hour Burdens	9-6
9.2.6	Determine Equipment Failure Categories	9-7
9.3	Recommend Changes to System Equipment Specification or Design	9-8
9.3.1	Specification Changes	9-8
9.3.2	Other Changes	9-8
CHAPTER TEN:	SEA WATER COOLING FOR COMBAT SYSTEM	10-1
10.1	Determine System Equipment Configuration	10-1
10.1.1	CGN-42 Equipment	10-1
10.1.2	Similar Fleet Equipment	10-1
10.1.3	Review Specifications for R&M Values	10-2
10.2	Review Operational Data on Similar Fleet Equipment	10-3
10.2.1	Calculate R&M Indices	10-3
10.2.2	Compare Operational and Specification R&M Values	10-4
10.2.3	Calculate System Reliability	10-5
10.2.4	Determine System Corrective Maintenance Man-Hour Burden	10-5
10.2.5	Compare Projected and Historic Corrective-Maintenance Man-Hours	10-6
10.2.6	Determine Equipment Failure Categories	10-7
10.3	Recommend Changes to System Equipment Specification or Design	10-7
10.3.1	Specification Changes	10-7
CHAPTER ELEVEN:	COMPILATION OF SYSTEM RESULTS	11-1
11.1	R&M Specification	11-1
11.2	Ship Manning	11-3

CONTENTS (Continued)

	Page
11.3 R&M Improvements	11-6
CHAPTER TWELVE: CONCLUSIONS AND RECOMMENDATIONS	12-1
12.1 Conclusions	12-1
12.2 Recommendations	12-2
SOURCES OF INFORMATION	13-1
APPENDIX A - SYSTEM CONFIGURATION DIAGRAMS	A-1
APPENDIX B - RELIABILITY AND MAINTAINABILITY DATA SHEETS	B-1
APPENDIX C - SYSTEM RELIABILITY BLOCK DIAGRAMS AND RELIABILITY CALCULATIONS	C-1
APPENDIX D - EQUIPMENT FAILURE CATEGORIES	D-1

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The CGN-42 Class of Nuclear Guided Missile Cruisers is one of two new ship classes being designed specifically as platforms for the AEGIS Combat System. In a design review of the preliminary designs of the CGN-42 Distributive Systems, questions were raised concerning whether the Reliability and Maintainability (R&M) of these systems' equipments were adequate to support the AEGIS Combat System. Concern was expressed about the extent to which R&M requirements were being specified, whether the specifications were reasonable when compared with Fleet experience, and, if not, what changes were required to the equipment or the specifications.

To answer these questions concerning the reliability and maintainability of the various HM&E system equipments, ARINC Research Corporation was tasked under Contract N00140-77-D-0417, D.O. 0020 to analyze seven distributive systems and to assist NAVSEC 6112B by providing R&M information for use in their CGN-42 RMA study.

1.2 OBJECTIVES

The objectives of this study were (1) to identify the R&M values being specified for the major equipments of seven distributive systems of the CGN-42; (2) to determine the R&M values being experienced in the Fleet by investigating historical data for similar system equipments; and (3) to recommend appropriate changes to specifications or to the system design if the specified R&M values were found to be unreasonable as compared with Fleet experience.

1.3 SCOPE

The project objectives were to be accomplished for the following seven distributive systems:

- Air Conditioning Chilled Water System (including the Chilled Water Plant, the Mains, and the Chilled Water for Electronic Cooling)
- Ventilation System (including electrostatic precipitators)
- 60 Hz Power Distribution System
- 400 Hz Power Distribution System
- Electronic Dry Air System
- Firemain System
- Sea Water Cooling System for Combat Systems

The scope was limited by the CGN-42 Program Office, PMS-400C, to exclude those systems and portions of systems which are part of the Nuclear Propulsion Plant or the AEGIS Combat System.

1.4 REPORT FORMAT

In the remaining chapters of this report the seven distributive systems will be discussed in detail, each in the same general format as the approach presented in Chapter Two. In order to assess the cumulative effect of the information being developed on the ship as a whole, Chapter Eleven compiles the separate system results into a summary for all seven systems. Chapter Twelve presents the specific conclusions and recommendations. The appendixes provide supporting information and analyses.

CHAPTER TWO

APPROACH

The approach used in this study was to identify the projected CGN-42 equipment and the associated R&M specification requirements; select comparable Fleet equipment; determine the historical R&M indices; compare the specification values with the historical values; and recommend changes to the specifications, equipment design, or equipment support functions as appropriate. For the purposes of this analysis, reliability in terms of mean time between failures (MTBF) and maintainability in terms of mean time to repair (MTTR) were the indices used in the comparison of specification and historical R&M values. Another aspect of maintainability, that which results in the total corrective maintenance man-hours expended on a system, was also examined for its impact on the projected manning levels and skills for the CGN-42 Class. The following sections address in greater detail the steps leading up to the development of these R&M indices from historical maintenance data.

2.1 CGN-42 EQUIPMENT

For each system of this study, three principal sources of information were researched: specifications, Master Equipment List (MEL), and NAVSEA and NAVSEC system design documentation. Each source was studied to identify system and equipment configuration and characteristics, i.e., the equipments and components that made up each system, their quantities, and how they were configured in the system. In addition, the characteristics of each equipment and component -- rating, size, capacity, type, style, R&M requirements -- were identified, together with the appropriate military specifications. The specifications to be reviewed included the CGN-42 Ship Specification, various military specifications, and procurement specifications. Because no procurement specifications had yet been prepared, the review was limited to the Ship Specification and the military specifications. The NAVSEA/NAVSEC documentation consisted of engineering studies and preliminary issues of system drawings. Conflicting requirements in any of the sources were presented to NAVSEC for resolution and validation as to the latest information. Much of the information was revised as each system design evolved.

2.2 COMPARABLE FLEET EQUIPMENT

Fleet equipments were selected for R&M analysis on the basis of their similarity to projected CGN-42 equipment and service. Wherever possible, Fleet equipment that was the same as that projected for the CGN-42 was analyzed; otherwise, selections were based on equivalent or similar designs, characteristics, and configurations. The comparable equipments were selected from the Type Commander's Consolidated Ships Allowance Lists (COSALs), Standard Components List (SCL), and Fleet Equipment/Component Application Listing, and were identified by the Allowance Parts List (APL) number. In most cases, multiple equipment APL numbers were selected for each equipment type to provide as large a data base as possible for analysis of the R&M data and development of the desired indices. In addition to the equipment APL numbers, the following types of identification were required for proper analysis of the data:

- The number of identical equipment APLs per system
- Associated equipment APLs (subequipment-level APLs, e.g., oil pumps, coolers, governors)
- APLs of related units (e.g., motor or turbine)

2.3 HISTORICAL R&M DATA

As the first step in determining the historical R&M indices of the comparable Fleet equipments, the Fleet corrective maintenance data (MDS data) for these system equipments were obtained from the Maintenance Support Office (MSO), where the current data are stored on magnetic tape. The MDS labor actions, parts, and narrative records for the comparable Fleet equipments were obtained on tapes for the three-year period 1 January 1975 through 31 December 1977. A tape of the steaming-hour data that is used in the calculation of equipment operating time was also obtained for the same period for Fleet units. The data tapes were copied, audited for completeness, and merged into one complete file by APL, JCN, Card Type, and Action Date. The steaming-hour tape was copied, audited for completeness, and printed out in hard copy. The APLs identified for the comparable Fleet equipments were used to create an analysis file consisting of all corrective maintenance records reported on those equipments during the three-year period.

2.3.1 Failure Identification

Failure events are a subset of the total corrective maintenance events reported. The definition of "failure" used for this analysis was "any corrective maintenance event that occurred while the equipment was in an operational mode and that resulted in the equipment's being nonoperational or in a reduced capability." This definition has been used by the Navy for approximately five years and is currently used to identify failures for the Detection Action Response Technique (DART) Program in MSO Report

No. 4790.S5711-01. It is similar to the definition used in the computation of MTBFs from pre-1970 MDCS data*, which represent a large portion of the indices in the NAVSEC RMA Design Data Bank, except that it includes the category "reduced capability," which was not available in the pre-1970 Generation I MDCS data. The additional codes available in the pre-1970 data did allow the determination of reduced-capability events, so that the failures identified for both sets of data are believed to be comparable.

The initial-failure event screening was accomplished by using any combination of the following "When Discovered" and "Status" codes** to identify the failures:

When Discovered Codes:

1 = Lighting off or starting
2 = Normal operation
3 = During operability tests
5 = Shifting operational modes
7 = Securing

Status Codes:

2 = Nonoperational
3 = Reduced capability

The resulting maintenance actions identified as "failures" were printed out fully (with narratives) for review by the analyst to ensure that the events were, in his judgment, truly failures.

By direction** only those actions which are considered "maintenance significant" or need to be deferred for parts or outside assistance are required to be reported by means of the 4790-2K Form (i.e., "fully reported" actions, which include When Discovered and Status codes). All other actions need not be reported or need only a NAVSUP Form 1250 or 1348 if parts are required; these forms contain none of the desired codes. These maintenance actions were called "part only" maintenance events; they contained a number of "failures" not previously identified because they lacked the required codes. The number of failures in the "part only" events was estimated for each equipment by using the ratio of identified failures to fully reported maintenance actions to indicate the corresponding number of failures from the total "part only" events reported. This number was added to the failures previously identified from the review of the proper combinations of "When Discovered" and "Status" codes to achieve the total equipment failures for the corresponding APLs.

*_Establishment of Reliability and Maintainability Data Bank for Shipboard Machinery_, ARINC Research Publication 0E13-01-1-1224, March 1973.
**From OPNAVINST 4790.4, Enclosure 5.

2.3.2 Equipment Operating Time

The total equipment operating time is required in order to compute the MTBF index. The total equipment operating time is the sum of the operating times for all equipments of the desired APL(s) on all the ships in the selected population data base. Most of the equipments that constitute the distributive systems generally do not have time meters or logs kept on their operation; thus estimates of operating time as a function of a time base, such as ship steaming hours, are required. The estimates are called Equipment Utilization Factors or Duty Cycles and represent the ratio of the equipment operating time to the ship steaming hours for the three categories reported, i.e., steaming underway, steaming not underway, and cold iron (boilers not lit-off). To obtain total equipment operating time, the following steps were taken:

- The ships and the number of equipments per ship were identified for each APL of interest.
- The equipment utilization factors were estimated for each ship type.
- The equipment utilization factors for the proper APL and ship type were multiplied by the total hours for each steaming-hour category for all applicable ships of that type.
- The product of the preceding step was multiplied by the number of equipments on the various ship types and then summed for all ship types to give the total equipment operating time.

2.3.3 R&M Indices

2.3.3.1 Reliability

Reliability is defined as the probability of performing a specified function or mission under specified conditions for a specified time. The parameter used to describe reliability at the equipment level is mean time between failures (MTBF). This parameter is calculated by using the data elements of operating time and total equipment failures experienced during that operating time:

$$\text{MTBF} = \frac{\text{Equipment Operating Time (Hours)}}{\text{Number of Failures}}$$

2.3.3.2 Maintainability

Maintainability is the probability that a failed system is restored to operable condition in a specified downtime. The parameter used to describe maintainability at the equipment level is mean time to repair (MTTR). The MTTR index was calculated by first determining the mean of the Ship's Force (SF) and IMA man-hours from the "fully reported"

completed* failure events and then by multiplying this mean by a maintenance factor to account for the number of men working on the job at one time. The SF and IMA hours constitute the "active repair" time required to repair an equipment failure; i.e., it does not include logistics or administrative time. The formula used for this calculation is

$$\text{MTTR} = \frac{\text{Total SF and IMA Maintenance Man-Hours for All Fully Reported Failure Events}}{\text{Total Fully Reported Failures}} \times \text{Maintenance Factor}$$

where

$$\text{Maintenance Factor} = \frac{1}{\text{Average number of men normally performing corrective maintenance on the equipment}}$$

It was assumed that an average of between one and two men work on each maintenance event, so that the maintenance factor became 1/1.5, or 0.67, for all calculations of MTTR -- i.e., for 1 man the factor is 1; for 2 men it is 0.5; for 1.5 men it is 0.67.

2.3.4 Total Corrective Maintenance Man-Hours

To project the effect that higher operational MTTRs than those projected might have on the manning level or skills projected for a new ship class, the procedures used to calculate manning requirements were reviewed. It was determined from this review that the corrective maintenance man-hours for manning projections were the result of an empirical formula based on the number of planned maintenance man-hours and had no direct relation to the maintainability measure of MTTR. Because the MTTRs of the system equipments do affect the magnitude of the total corrective maintenance man-hours experienced in the Fleet, both the projected corrective maintenance man-hours and the historical corrective maintenance man-hours were calculated for all systems to assess the impact of the difference in the two methods.

For the purpose of this analysis the total historical corrective maintenance man-hour burden for an equipment is the sum of the SF man-hours from all corrective maintenance actions reported against the selected APLs. This number was calculated for the comparable Fleet equipments and aggregated to the system level to compare the historical burden with the projected man-hours for corrective maintenance used to calculate ship manning level and skill requirements. The number of corrective maintenance man-hours was easily obtained from a summary printout of the MDS data on the APLs of interest. The projected corrective maintenance man-hours were obtained by equipment from the CGN-42 AEGIS Cruiser Preliminary Ship Manpower Document, NAVSEC Report 6112F-022-78 of 1 September 1978.

That is, the maintenance action has been closed out and all man-hours have been reported.

2.3.5 Failure Categories

As a possible means of identifying corrective measures for achieving desired improvements in equipment reliability or in corrective maintenance man-hour burdens, the failure events were categorized to determine if there were predominant failure modes for these equipments. If certain failure modes accounted for a significant percentage of the failure events, they are considered candidates for reliability or corrective maintenance design-improvement analyses. Before performing a design analysis, other factors, such as equipment redundancy, cost of new procurements and their support, and overall system reliability must be considered to determine if the improvements would be cost-effective.

2.3.6 System Reliability

The reliability (i.e., the probability that a system will perform satisfactorily for at least a given period of time when used under stated conditions) was calculated for the most demanding operational requirements of each system to provide a relative measure of the worst-case reliability of the systems in their proposed configurations, using historical MTBF values for their equipments. Block diagrams were prepared to illustrate the relationships of the system equipments to each other. The formulas used to calculate the system value approximated the effect of the standby redundancy but not the repairable nature of a majority of these equipments. By ignoring the repairability of the components the resulting system reliability is very conservative and should be considered a lower limit. It was assumed for these calculations that the times of component failure are distributed exponentially and the failure rates are therefore constant. The formula for component reliability becomes:

$$R = e^{-\lambda t}$$

where

λ = failure rate = 1/MTBF
t = designated time period

The time period designated for all system calculations was a mission period of 1500 hours which is approximately 60 days.

2.4 COMPARISON OF HISTORIC AND SPECIFIED R&M VALUES

The MTBF and MTTR indices computed by the method described in Section 2.3.3 were compared with the R&M values determined from review of the Ship Specifications and military specifications. This comparison was intended to show where the specification values were too stringent to be achieved without either state-of-the-art improvements or special R&M program attention, or where the values or lack of specified values were inadequate to ensure the desired reliability and maintainability. The results of these comparison were recommendations for changes to the specification values, addition of specification values where required, and retention of the existing values.

2.5 RECOMMENDED CHANGES

The primary emphasis of this analysis was on the adequacy of the R&M specifications for the major system equipments. Changes to the specified MTBF and MTTR values were the principal recommendations. The reasons for these changes are better performance or lower life-cycle costs. The extent of the recommended changes is based on the confidence in the accuracy of the historical R&M values, an evaluation of the logical differences to be expected between specification and operational values, and the expected performance gain versus the probable cost effect of adding or increasing specification MTBFs or MTTRs.

Recommendations were anticipated from any of the following steps of this analysis:

- Comparison of the historic and specified MTBF and MTTR values
- Determination of the system reliability
- Review of the equipment failure categories
- Comparison of the historical and planned corrective maintenance man-hours

CHAPTER THREE

SPECIFICATION REQUIREMENTS

The principal purpose of this study is to determine the adequacy of the reliability and maintainability specifications for the major equipments of the seven distributive systems to ensure support of the AEGIS Weapon System.

In contrast to a totally new ship concept such as the FFG-7 Class, wherein all major systems are being integrated, with compromises allowed in all areas, the CGN-42 is design-constrained in several areas. The three controlling areas are the AEGIS Combat System, the nuclear propulsion plant, and the CGN-38 Class hull design. As a fourth consideration, the system designs of the CGN-42 are to provide as much commonality as possible with those of the DDG-47. Within these constraints it would be difficult to allow R&M trade-off considerations to alter the systems significantly from those designs of the DDG-47 and CGN-38 Classes which have preceded the CGN-42 design. Therefore, this analysis concentrated on evaluating the R&M aspects of the system designs within these constraints, rather than considering the merits of different designs.

3.1 APPLICABLE SPECIFICATIONS

The 20 January 1978 issue of the Top Level Requirements and the 1 October 1977 issue of the Ship Specifications were initially reviewed for any reliability, maintainability, or availability requirements at the ship or system level of the CGN-42. No requirements of this type were found, and it was concluded for the purpose of this analysis that only equipment-level requirements would be analyzed.

3.1.1 CGN-42 AEGIS Nuclear Guided Missile Cruiser Ship Specification

The 5 July 1978 issue of the Ship Specification, Section 076 (Reliability and Maintainability), requires the contractor to develop, maintain, and implement a comprehensive R&M program in accordance with MIL-STD-785 (Reliability) and MIL-STD-470 (Maintainability). Section 076 further specifies the requirements for R&M analyses, the preparation of FMEAs for certain systems listed in Table II (see Table 3-1), and the conduct of R&M demonstration tests for equipments listed in Table I of Section 076. The list of equipments in Table I has been changed from the

original 1 October 1977 issue of the Ship Specification to include different equipments; however, the total number for which R&M demonstration tests will be required remains at nine equipments. Eight of these, listed in Table 3-2 with their R&M goals, represent the major equipments in four of the seven distributive systems of this study.

Table 3-1. SYSTEMS FOR FMEAs

	SHIP SYSTEM
1	Machinery Plant
1	60 Hz Ship Service Electric Plant
1	400 Hz Power System
1	Air Conditioning System
1	Firemain System
1	Sea Water Cooling System
1	Chilled Water System
1	Electronics Cooling Water System
1	Fuel System
1	High Pressure Air System
1	Ship Service Air System

3.1.2 Military Specifications (MIL-SPECs)

Except for the Ship Specification discussed in Section 3.1.1, the only specifications that contain requirements relating to reliability and maintainability at this time are the individual equipment military specifications (MIL-SPECs). The procurement specifications could also contain R&M requirements when they are written; however, there were none prepared at the time of this study.

Of the 26 individual MIL-SPECs reviewed, only two called for an MTBF -- MIL-D-23523C for the dehydrator and MIL-R-24085A for the Air Conditioning Chilled Water Plant -- and only one, the dehydrator, referred to a requirement for repair time. Of the remaining 24 MIL-SPECs, 12 contained statements of the intended "design life" of the equipments and normal wearing parts such as bearings and pump wear rings. Endurance tests were also called for in 14 of the specifications, but neither the design life statements nor the endurance tests can be construed to be the same as R&M requirements or R&M Demonstration Tests. Only the dehydrator specification MIL-D-23523C, revised 19 August 1975, has what can be considered adequate R&M requirements for any equipment of a fairly complex nature.

It is suggested by this review that if a specific reliability or maintainability value is required to meet system needs, it must be specified in the ship or procurement specification.

Table 3-2. SYSTEM EQUIPMENTS DESIGNATED FOR RELIABILITY (R) OR MAINTAINABILITY (M) DEMONSTRATION TESTS

System/Equipment	Test	Goal* MTBF (Hours)	Goal* MTTR (Hours)
Air Conditioning Chilled Water System			
A/C Chilled Water Plant (200 tons)	M	6,600	24.6
A/C Chilled Water Pump (720 gpm)	M	4,200	10.8
A/C Sea Water Circulating Pump (800 gpm)	M	6,600	7.1
Ventilation System			
Ventilation Blowers	M	(TBD)**	(TBD)
Firemain System			
Firepump (Turbine Driven)	M	2,750	5.4
Firepump (Motor Driven)	M	3,000	4.0
Sea Water Cooling System for Combat Systems			
AEGIS Sea Water Circulating Pump (300 gpm)	M	8,500	8.1
Sea Water A/C Cooling Coil Circulating Pump (650 gpm)	M	(TBD)	(TBD)
Prairie Masker System			
Prairie Masker Compressor	R&M	4,250	9.5

**The minimum MTBF is one-half the goal value. The maximum MTTR is twice the goal value.*
***TBD - to be determined.*

3.2 DISCUSSION OF SPECIFICATION VERSUS OPERATIONAL MTTR VALUES

In the analysis of the equipments of these systems and comparison of their historical operating experience, it appears that the MTTRs developed from the Fleet operational data are an order of magnitude larger than the values specified for similar equipments. The explanation that follows is a judgment of the reasons for this disparity.

The operational and specification test values are for two distinctly different environments. In the case of the specification value used in a vendor test, the equipment is new; the mechanic is well trained and is specifically knowledgeable about the tested equipment; tools are available; and, even if the space and temperature conditions are the same as on board ship, the equipment has not operated in the real ship environment for any period of time. The operational situation varies significantly from that of the vendor in that the mechanic (i.e., sailor) is probably not familiar with the exact design on which he is working, tools and technical documentation are not always available, the equipment is often "frozen" (either corroded or crystallized) in place, and the real failure has affected other parts besides the one part designated in a test simulation. It is concluded, therefore, that the comparison of specified and operational values should logically show a larger operational value. The magnitude of this value will vary from one equipment type to another, and no rule for determining a reasonable difference is known at this time.

CHAPTER FOUR

AIR CONDITIONING CHILLED WATER SYSTEM

4.1 DETERMINE SYSTEM EQUIPMENT CONFIGURATION

The Chilled Water Service Mains on CGN-42 will be separated -- one on the port side, second deck; and the other on the starboard side, first platform. Both mains will be fed from all five A/C Chilled Water Plants cross-connected as shown by the typical arrangement in Figure A-1 of Appendix A. The various sections of the mains will be capable of being isolated in case of damage, such that chilled water can be provided to the various combat system and air conditioning heat exchangers from another of the two separate segregated sections of main that will serve each unit.

4.1.1 CGN-42 Equipments

Initial reviews of Section 516 of the 1 October 1977 issue of the Ship Specification, the original design studies* for CGN-42, the Master Equipment List (MEL), and the preliminary NAVSEC system drawings all resulted in identification of the requirements for five 175-ton R-114 Air Conditioning Chilled Water (ACCW) Plants; five 630-gpm, 60-psi Chilled Water Circulating Pumps and Motors; and five 700-gpm, 25-psi Sea Water Circulating Pumps and Motors. The ACCW system design was subsequently updated (5 July 1978 issue of the Ship Specification), and the ratings of the Chilled Water Plants and the associated pump motor units have been increased to the values shown in Table 4-1.

4.1.2 Similar Fleet Equipment

4.1.2.1 R-114 Chilled Water Plant

Freon R-114 Chilled Water Plants are significantly different from the Freon R-11 and R-12 plants. The following properties of R-114 have allowed significant changes in plant design and operation: R-114 is less toxic; it operates at a lower pressure, which allows use of a much quieter, more efficient centrifugal (rather than reciprocating) compressor; and it is less corrosive than the other refrigerants. With these kinds of improvements, it is valid to expect a significant improvement in reliability and

**AEGIS Impact on CGN-38 Nonpropulsion Piping Systems for CGN-42 Contract Design, M. Rosenblatt & Sons, Inc.*

maintainability of the R-114 plants over the R-11 and R-12 systems. The selection of similar equipments was therefore restricted to R-114 plants of similar size.

Table 4-1. A/C CHILLED WATER SYSTEM COMPONENTS

Component	Rating	Quantity	MIL-SPEC
R-114 Chilled Water Plant	200 tons	5	MIL-R-24085A (Amendment 1)
Chilled Water Circulating Pump	720 gpm, 60 psi	5	MIL-P-17639D
Motor, AC, 440 V	40 hp	5	MIL-M-17060E
Sea Water Circulating Pump, Chilled Water Plant Condenser	800 gpm, 25 psi	5	MIL-P-17639D
Motor, AC, 440 V	25 hp	5	MIL-M-17060E

Four classes of ships have the R-114 Air Conditioning Chilled Water Plants: LHA-1 (300-ton units), CGN-38 (200-ton units), SSBN-640 (175-ton units), and DD-963 Class (150-ton units), as shown on the Equipment Reliability and Maintainability Data Sheets of Appendix B (pages B-4 through B-11) for all four units. These equipments are all made by the same manufacturer, York Division of Borg-Warner. As with all new equipments, the early reported data can reflect many different factors in addition to the intrinsic reliability and maintainability that are being sought. Infant mortality, warranty repairs, and unfamiliarity with the equipment design are some of the influencing factors that prevent the data from being viewed as data on "mature" equipment. To best represent the R&M characteristics of this type of equipment, the data on APL 325010380 for a 175-ton plant on the SSBN-640 Class were chosen, for three reasons. First, all of the equipments had been on the ships through the entire period for which maintenance data were available, making them the most "mature" equipments; second, they were the exact size units initially projected for the CGN-42; and third, they represent 22 units, providing an adequate data base for reasonable confidence in the R&M estimates. All of the other similar equipments had less than 18 months of operating data since commissioning of the ships on which they are installed.

4.1.2.2 Chilled Water Circulating Pumps

Selection of pumps for analysis was restricted to those pumps which could be positively identified as being used in the Fleet for circulating chilled water. Restricting the data base to only those pumps and associated

motors whose capacity was approximately that of the CGN-42 resulted in too small a population. Therefore, it was decided to expand the data base to all chilled water circulating pumps and motors, regardless of size, as listed on the R&M Data Sheets in Appendix B, pages B-12 through B-14. This group of equipments was used to represent the average experience of centrifugal pumps in this type of service application. The total population obtained by this process was 255 units on 69 different ships, and it included 17 equipment APLs with capacities ranging from 80 to 900 gpm and pressures from 50 to 85 psi.

4.1.2.3 Sea Water Circulating Pump

Selection of pumps for analysis was again restricted to those Fleet equipments identified as being used for only ACCW Plant Sea Water Circulation. This restriction resulted in pumps with a capacity range from 250 to 1100 gpm, with output pressures from 25 to 50 psi. Fourteen different equipment APLs are included in the total data base of 140 units on 64 different ships that make up this generic group, as listed on the R&M Data Sheets in Appendix B, pages B-16 and B-17.

4.1.3 Review Specifications for R&M Values

The two specifications that apply to the ACCW System at this time are the Ship Specification and the MIL-SPECs for the components of the system. The ACCW System requirements are specified in two places in the Ship Specification -- Section 516 and 532 for A/C Plant and system design information, and Section 076 for equipment R&M requirements. There are no procurement specifications at this point in the acquisition process, but they should also contain R&M requirements when written. Since the ACCW System is one of the systems that has major equipments listed in Table I of Section 076 of the Ship Specification, the shipbuilder or equipment vendor will be required to perform specific R&M analyses and testing on these equipments. Currently, only a maintainability Demonstration Test is required for the ACCW Plant and Pumps. The MTTR test values are listed in Table 4-2.

Table 4-2. EXISTING SPECIFICATION REQUIREMENTS FOR THE A/C CHILLED WATER PLANTS

Specification	MTBF (Hours)	MTTR (Hours)
Ship Specification Section 076	6,600 goal 3,300 minimum No Demonstration Test	24.6 goal 49.2 maximum Demonstration Test required
Military Specification MIL-R-24085A	15,000 minimum	None
Procurement Specifications	None available	

Military Specification MIL-R-24085A (SHIPS), Amendment 1, contains a rather stringent reliability requirement consisting of a demonstrated MTBF of 15,000 hours, together with a comprehensive reliability program to assure that the MTBF is met. A maintainability demonstration is also called for; however, no specific MTTR is imposed, only that the repairs be made in accordance with instructions in the technical manual. Both the ACCW Circulating Pump and the A/C Condenser Sea Water Circulating Pump are to be manufactured in accordance with MIL-P-17639D. This specification is for centrifugal pumps of miscellaneous service generally larger than 600 gpm. It contains a section entitled "Reliability," in which both the philosophy and desire for reliable and easily maintainable equipment is expressed, but there are no requirements to demonstrate either MTBF or MTTR. The endurance tests call for a 500-hour test with 100 starts if for propulsion use, and a 100-hour test with 25 starts for nonpropulsion use. These tests are not of sufficient duration to be considered adequate for R&M Demonstration Tests. The motors for both pumps are to be manufactured in accordance with MIL-M-17060E, which also addresses reliability in "design to" terms such as "designed to last 40,000 hours over 20 years with bearings to last 10,000 operating hours." These are valid goals, but they cannot be considered R&M requirements in the sense of a demonstrated MTBF and MTTR.

4.2 REVIEW OPERATIONAL DATA ON SIMILAR FLEET EQUIPMENT

4.2.1 Calculate R&M Indices

The MTBF and MTTR for the A/C Chilled Water Plant and associated pump were calculated in accordance with the procedures described in Chapter Two, Section 2.3.3. The failures identified from the data, properly coded to allow determination of a failure event, were: 20 for the A/C Chilled Water Plant, 99 for the Chilled Water Circulating Pump Motor Unit, and 107 for the Sea Water Circulating Pump Motor Unit. All of these values were increased by the addition of a percentage of the part-only actions that were estimated to have also been failures. This percentage was approximately equal to the ratio of the identified failures to the fully reported corrective maintenance actions. The resulting failure counts for each of the major components of this system are: 30 for the A/C Chilled Water Plant, 177 for the Chilled Water Circulating Pump Motor Unit, and 188 for the Sea Water Circulating Pump Motor Unit. Operating time for the ACCW Plant and Pumps was computed by applying to the ship steaming hours in each of the three steaming conditions, for each ship in the data base, the following equipment utilization factors: A - each plant operates 35 percent of the time the ship is underway; B - each plant operates 50 percent of the time in port with the engineering plant operating; and C - each plant operates 50 percent of the time in port when the engineering plant is not operating. The resulting MTBFs obtained by dividing the total equipment operating time by the total number of failures are shown in Table 4-3 under operational values. The specification values for the same equipment are also shown in the table. It is noted from the Data Sheets in Appendix B for these equipments that of the failure events used to calculate the MTBFs, a smaller number of events had the fully reported man-hours required for computation of the MTTRs.

Table 4-3. AIR CONDITIONING CHILLED WATER SYSTEM R&M VALUES						
System Equipment	MTBF (Hours)			MTTR (Hours)		
	Specification		Operational	Specification		Operational
	Goal	Minimum		Goal	Maximum	
Chilled Water Plant	6,600	3,300	6,407	24.6	49.2	7.8
Chilled Water Circulating Pump	4,200	2,100	15,957	10.8	21.6	31.1
Sea Water Circulating Pump	6,600	3,300	10,923	7.1	14.2	23.2

4.2.2 Compare Operational and Specified R&M Values

4.2.2.1 Air Conditioning Chilled Water (ACCW) Plant

The MTBF and MTTR for the ACCW Plant are discussed in the following paragraphs.

MTBF

Table 4-3 shows a 6,407 hour MTBF for the ACCW Plant which is the highest of the four different-sized R-114 units examined. This value is not so much higher than the next highest (5,360 hours shown in Appendix B) that any question is raised about its being unrepresentative. The lower 90-percent confidence limit for the 6,407-hour MTBF is 4,485 hours based on 30 failures, which is reasonably close to the estimated value of 6,407 hours, and it indicates a 90-percent confidence that the actual MTBF is equal to or above the 4,485-hour value.

As can be seen in Table 4-3, the MTBF of 6,407 hours for the R-114 ACCW Plant is very close to the specification value of 6,600 hours used as a goal value in Table I, Section 076 (R&M) of the Ship Specification. The operational value of 6,407 is approximately three times better than the MTBFs for comparable R-11 and R-12 Plants calculated from 1967-1969 MDS data*. This supports the expectations of the NAVSEC engineers that a significant improvement in the reliability of these systems would be obtained as a result of changing to the R-114 Plants. However, the MTBF of 6,407 hours is less than half the 15,000-hour MTBF required by the MIL-SPEC (MIL-R-24085A), as discussed in Section 4.1.3. Because of the consistency of the calculated ACCW Plant MTBFs, all in a range considerably lower than

*NAVSEC RMA Design Bank Report, June 1975, Revision A.

the MIL-SPEC requirement, it is concluded that the 15,000 hours cannot be achieved in an operational environment. The Ship Specification goal value of 6,600 hours with a minimum of 3,300 hours appears reasonable in light of the operational value.

It is noted from the R&M Data Sheets in Appendix B that the MTBFs of the larger-sized R-114 Plants decrease as the units become larger. The data base from which these MTBFs were calculated is not as extensive as that of the value representing the 175-ton units shown in Table 4-3; and the effect of "infant mortality" may also be present, so that less confidence is held in the values for these larger units. The trend of lower MTBFs for the larger units suggests caution in procurement of these sizes if the higher MTBF represented by the specification goal is desired or required. This caution could be expressed in the requirement for a Reliability Demonstration Test in the procurement specifications.

MTTR

The operational MTTR of 7.8 hours is the second lowest of the four values calculated for the R-114 ACCW Plants. It is based on 18 failure events and the standard maintenance factor of 0.67 used throughout this report, as discussed in Section 2.3.3.2. The standard deviation of 5.7 hours for this particular sample indicates a relatively tight grouping of the data about the 7.8-hour value. All four MTTR values for the R-114 Plants are relatively low in comparison with the specification goal of 24.6 hours and the maximum allowable value of 49.2 hours, which indicates that the specification goal value can be easily met by the vendor. As with these plants' better MTBFs when compared to the R-11 or R-12 Plants, their MTTRs are attributed primarily to the significantly improved centrifugal compressor design made possible by the use of R-114 refrigerant. Because of the newness of these equipments in the Fleet, it is expected that their MTTR will increase over the next three to five years as they begin to experience wear-out type failures not reflected in the current data.

4.2.2.2 Air Conditioning Chilled Water (ACCW) Circulating Pump

The MTBF and MTTR for the ACCW Circulating Pump are discussed in the following paragraphs.

MTBF

The 15,957-hour MTBF for the ACCW Circulating Pump is based on a very large population base of 255 pump-motor units and a large data base statistically speaking (177 failures), so that the upper and lower 90-percent confidence intervals are 13,563 and 18,351 hours. This value represents slightly less than two years of continuous operation between failures, or approximately one failure every 3.7 years if operating 50 percent of the time, which is the same time interval required by the PMS for opening these pumps to inspect for worn parts. Therefore, with the accomplishment of normal preventive maintenance, an MTBF of approximately 16,000 hours can be accepted from an operational

engineering point of view. A comparison of the operational value with that being specified (as listed in Table 4-3) shows a significant difference in the two values: the operational value is four times better than that specified. The specification value was derived by combining R&M indices from the NAVSEC R&M Design Data Bank Report for a pump and a motor of approximately the size required. In view of the large quantity of data analyzed for these pumps, it is concluded that the 16,000-hour MTBF is more representative of that which can be expected from centrifugal pumps used to circulate chilled water than the current specification value.

MTTR

The MTTR for the ACCW Circulating Pump Motor Unit is 31.1 hours, which is based on the mean of 82 "failure" maintenance actions. In considering this value, it must be kept in mind that more than half of these events involved the motor and the time to repair is significantly influenced by the motor repair time; the largest percentage of motor failures were due to bearing failures and grounded motor windings (see Table D-2 of Appendix D). The operational MTTR is three times the specification goal value of 10.8 hours and one and one-half times the maximum allowable value as shown in Table 4-3. As discussed in Section 3.2, the operational MTTR is expected to be larger than the specification value that will be imposed on a vendor to demonstrate the inherent maintainability of his equipment. The magnitude of the difference is dependent on many unknowns, including the type of vendor test imposed and the shipboard environmental factors under which the equipment will be operated and maintained. Therefore, the reasonableness of the specification MTTR cannot be assessed solely on the basis of a comparison with operational values. In this particular case there are two other pumps of similar size and type (i.e., centrifugal) for which the specification values have been verified by vendor demonstrations. These are the Turbine and Motor Driven 1,000 gpm Firepumps discussed in Chapter Ten under the Firemain System. The specification MTTR goal values for these units are 5.4 hours and 4.0 hours, respectively, which indicates that the specification value for the ACCW Circulating Pump is too lenient to ensure state-of-the-art manufacturing achievements in pump maintainability. The service application of this pump is less critical than that of the Firepumps; and with the plant redundancy, which facilitates maintenance, it is not considered necessary to specify a more stringent MTTR than the current 10.8-hour value. A review of previously calculated MTTR values* for similar-sized pumps and motors indicated that the value of 31.1 hours for the ACCW Circulating Pump is within the range of these historical values.

4.2.2.3 Air Conditioning (A/C) Sea Water Circulating Pump

The MTBF and MTTR of the A/C Sea Water Circulating Pump are discussed in the following paragraphs.

**NAVSEC RMA Design Data Bank Report, June 1975, Revision A.*

MTBF

The A/C Sea Water Circulating Pump operational MTBF is 10,923 hours, which (like that of the ACCW Circulating Pump) is based on a large population of 140 units and a very large sample of 188 failures, with more than 2 million total equipment operating hours. The 90-percent confidence interval about the mean is approximately ±1600 hours. This is a relatively narrow band, indicating a high probability that the mean of the sample is within the interval of 9,285 to 12,560 hours. The operational value for these pumps is lower than the Chilled (Fresh) Water Circulating Pumps, which is to be expected since the salt water is more corrosive and erosive than the fresh water. The temperature of the sea water will also be higher on the average than the chilled water, which will affect the bearing operating temperature of the Sea Water Pumps and Motors.

The 3,495-hour MTBF of the Motor Driven Firepumps discussed in Chapter Ten is significantly less than the value of the Air Conditioning Sea Water Circulating Pumps. This appears to be the correct relationship from an engineering viewpoint since the Firepump pressure, and therefore wear, is approximately three times that of the A/C Sea Water Circulating Pump. It is concluded from these data that the operational MTBF of the A/C Sea Water Circulating Pumps is a reasonable value to expect from a centrifugal pump in this application. The specification goal of 6,600 hours was derived from the NAVSEC RMA Design Data Bank Report by combining similar pump and motor units and therefore may not be as representative of the equipment projected for the CGN-42 as the value developed in this analysis, and it appears to be too lenient a value to result in any assurance of procuring state-of-the-art equipments.

MTTR

The 23.2-hour operational MTTR value for the A/C Sea Water Circulating Pump was based on the mean of 91 failure events. As with the ACCW Circulating Pump MTTR, it is three times the specification goal value shown in Table 4-3. As discussed in subsection 4.2.2.2 and Section 3.2, the magnitude of this difference is dependent on unknown factors not contained in the data used in these analyses; however, the specification MTTR value for this pump should have a direct relationship to MTTR of the Motor Driven Firepump since they are both centrifugal pumps of similar capacity operating with sea water as the fluid medium. On this basis, the specified MTTR value of 7.1 hours for the A/C Sea Water Circulating Pump is less stringent than the 4.0-hour Firepump MTTR that has been vendor-demonstrated and should be easily achieved by the prospective vendors.

4.2.3 Calculate System Reliability

The reliability block diagram and calculations to show the most demanding reliability situation for the ACCW System are presented in Appendix C, Figure C-1. For this system this is the "Cruise" condition, in which four of the five ACCW Plants are required to meet the cooling load.

It was assumed for the calculations that the failures were distributed exponentiallv and therefore the failure rates of the components were constant. The reliability approximation is based on the standby redundancy and interchangeability of all units. This gives the probability that the unit in standby can complete the mission successfully if one of the starting units fails. On the basis of these assumptions, there is a 62-percent probability that the ACCW System will be able to accomplish this worst-case mission goal successfully over a 1500 hour period (≈60 days), which is equivalent to the system's having an MTBF of 2,223 hours. These calculations are conservative in that they do not take into account the repairability of the components and as such they should be viewed as lower limit values.

4.2.4 Determine System Corrective Maintenance Man-Hour Burden

4.2.4.1 Operational Corrective Maintenance Man-Hours

In the previous section only the failure events which are a subset of the total corrective maintenance events were considered for calculation of MTBF and MTTR. To calculate the total corrective maintenance man-hour burden for this system, the Ship's Force man-hours were summed from all the corrective maintenance events. The man-hour burden for the A/C Chilled Water System is the sum of the reported burdens for the three major components plus an estimated amount from the part-only maintenance events. This estimate is made by taking the number of part-only actions and multiplying it by the average of the man-hours from the actions that were fully reported. Table 4-4 shows the annualized component and system corrective maintenance man-hour burden for the A/C Chilled Water System.

Table 4-4. ANNUALIZED OPERATIONAL CORRECTIVE MAINTENANCE MAN-HOUR BURDEN FOR THE A/C CHILLED WATER SYSTEM

Component	Man-Hours per Equipment per Year	Man-Hours per Ship per Year (5 Plants)
Chilled Water Plant	45.7	228.5
Chilled Water Circulating Pump*	8.7	43.5
Sea Water Circulating Pump*	29.3	146.5
System Total	83.7	418.5

**Pump end only.*

4.2.4.2 Projected Corrective Maintenance Man-Hours for Manning Requirements

As explained in Chapter Two, Section 2.3.4, an estimate is made of the projected corrective maintenance man-hours, which are added to the man-hours projected for other ship functions to develop the manning

requirements of Ratings, Special Skills, and Numbers of Personnel for a new class of ships. The method of calculating the projected corrective maintenance man-hours required is to sum the Planned Maintenance man-hours from the Maintenance Requirements Card (MRC) for a similar piece of equipment and to project one hour of corrective maintenance for every two hours of planned maintenance*. Table 4-5 shows the annualized projected corrective maintenance man-hours for the A/C Chilled Water System. These figures were obtained from the CGN-42 AEGIS Cruiser *Preliminary Ship Manpower Document*, Report No. 6112-F-022-78, 1 September 1978. The hours projected for the pumps are for the pump end only and do not include any hours for the motor because all motors on the ship are summarized under one entry in the report.

Table 4-5. ANNUALIZED PROJECTED CORRECTIVE MAINTENANCE MAN-HOURS FOR THE A/C CHILLED WATER SYSTEM

Component	Man-Hours per Equipment per Year	Man-Hours per Ship per Year (5 Plants)
Chilled Water Plant	15.3	76.5
Chilled Water Circulating Pump*	7.3	36.5
Sea Water Circulating Pump*	17.0	85.0
System Total	39.6	198.0

**Pump end only.*

4.2.5 Compare Projected and Historic Corrective Maintenance Man-Hours

The effect on ship manning levels or skills of high operational MTTR values based on a significant number of failures was studied. It was found that the planned manning requirements are developed in accordance with the *Guide to the Preparation of Ship Manning Documents* (OPNAV OP-23) and that MTTRs, either Specification or Operational, are not considered in the empirical formula used to calculate manning requirements for corrective maintenance. However, operationally higher MTTRs (based on a large sample) and the associated high total corrective maintenance man-hour burden do have a significant effect on the required level of manning and the skill mix necessary to perform the required maintenance.

For the A/C Chilled Water System, both the operational and the projected corrective maintenance man-hour burdens were calculated; these are shown in Tables 4-4 and 4-5, respectively. The annual man-hours per plant per year are 83.7 hours experienced operationally and 39.6 hours

**"Guide to the Preparation of Ship Manning Documents" (OPNAV 1OP-23).*

projected for manning calculations. The percentage difference is approximately 50 percent fewer man-hours being projected than are being experienced for similar units in the Fleet. The difference amounts to five times the annual hours per plant since there will be five units on the CGN-42 Class. This difference is 418.5 minus 198.0 hours, or 220.5 hours of corrective maintenance per year. This deficit, by itself, is only 4.5 man-weeks (based on a 50-hour work week) and is not significant unless there is a similar deficit in other systems. It appears that an analysis on a ship or work center basis is needed to determine the actual impact on the manning level of both the rates and skill mix required to perform the corrective maintenance indicated by operational experience for this system.

4.2.6 Determine Equipment Failure Categories

To determine if any particular component failure modes were having a significant effect on reliability or the total corrective maintenance man-hours of the ACCW System, the failure events were reviewed for each component of the system. The results of these reviews are listed by system and component in the tables of Appendix D. For the Chilled Water Plant itself, the failures categorized in Table D-1 do not show a definite trend or single significant contributing category. Instead, there are a number of different failure categories.

For the Chilled Water Circulating and Sea Water Circulating Pumps, there are significant failure categories for both equipments, as shown by Tables D-2 and D-3, respectively. For both units, the pump wearing rings and motor bearings contribute between 20 percent and 30 percent each to the number of failures of these units. Two other failure categories, pump gland leak-off and grounded motor windings, each accounted for another 10 to 15 percent of the unit failures. Elimination of these categories, although highly unlikely, would reduce the number of failures on these units from 50 to 80 percent. This means that even a 50-percent reduction in the number of these types of failures would have the effect of increasing the MTBF of these pump-motor units from 30 to 65 percent. The same 50-percent reduction in these failure types would have the effect of reducing the total corrective maintenance man-hour burden by 37 percent for the Sea Water Circulating Pump and 15 percent for the Chilled Water Circulating Pump.

4.3 RECOMMENDED CHANGES TO SYSTEM EQUIPMENT SPECIFICATION OR DESIGN

4.3.1 Specification Changes

4.3.1.1 R-114 Air Conditioning Chilled Water Plant

With the 6,407-hour operational MTBF providing strong support for a specification goal value of 6,600 hours, no change is recommended in the specification value. However, since the operational value was developed for a smaller, 175-ton plant and the projected equipments for CGN-42 are 200-ton units, the lower operational MTBFs for the 200- and 300-ton units

(although from smaller data bases in which there is less confidence) must be taken as possible indications that less reliable equipment is being procured. It is recommended that the MTBF goal be left at 6,600 hours, but that a Reliability Demonstration Test also be required.

Three of the four R-114 ACCW Plant MTTRs were considerably lower than the specification value of 24.6 hours. This was to be expected because of the difference between the R-114 Plants and the R-11 and R-12 type plants on which the 24.6-hour MTTR was based. It follows that the specification value should be reduced to ensure that these state-of-the-art maintainability improvements are realized in future procurements. The operational MTTR value of 7.8 hours, even though it is based on a sizable data base, is considered too drastic a reduction of the requirement for these relatively new equipments to be used as the new specification value, since it could cause the manufacturer to raise the price of the equipment to cover what may be an unacceptable risk. Half of the current MTTR goal value, or 12.5 hours, is recommended as a compromise for the ship specification MTTR goal. This will tighten the requirements in order to preserve the state-of-the-art maintainability achievements for this type of equipment, but it should not cause unacceptable risks for the manufacturers.

4.3.1.2 Chilled Water Circulating Pump

The difference between the specification MTBF goal value (4,200 hours) and the operational value (15,957 hours) for a large number of pumps in this service application indicates that the specification value is much too low. Comparison of the specification MTBF for the ACCW Circulating Pump with the A/C Sea Water Circulating Pump also suggests that the ACCW Circulating Pump value is too low since it is lower than the Sea Water Pump, which is pumping a more corrosive and erosive fluid and should logically have the lower MTBF. The decision to raise the specification MTBF value is somewhat academic in that the mean of the pumps in the Fleet -- most of which were probably procured without an MTBF requirement -- is already four times the specification value. Even though it may seem unnecessary to raise the specification value or to have one at all, the fact that these pumps may be procured on a low-bid basis makes it wise to use a specification value that will ensure the higher quality available from responsible manufacturers. It is recommended that an MTBF value of 8,000 hours be specified for these pumps.

The operational MTTR for this type of pump-motor combination appears to be reasonably well established in the 20- to 35-hour range. Again, as compared with the Firepump MTTR specification goal of 4.0 hours met by the pump vendor for the FFG-7 program, the MTTR specification value of 10.8 hours for the ACCW Circulating Pump should easily be met by most vendors. With the relatively high MTBF that can be expected for these pumps and the redundancy of the ACCW Plants in this system, it does not appear necessary to make the MTTR requirements any more stringent. It is recommended, therefore, that no change be made in the MTTR specification goal value of 10.8 hours.

4.3.1.3 A/C Sea Water Circulating Pump

The discussions presented in the previous section for the ACCW Pump MTBF and MTTR also apply to the A/C Sea Water Circulating Pump. To prevent a manufacturer from providing a pump to the existing specification MTBF value of 6,600 hours, which is lower than the state-of-the-art in the Fleet, it is recommended that this value be increased to 8,000 hours. It is also recommended that MTTR specification value of 7.1 hours not be changed.

4.3.2 Other Changes

4.3.2.1 System/Equipment Design Changes

No design changes were indicated from the review of failure categories for the Chilled Water Plants.

The review of failure categories for both the Chilled Water and Sea Water Circulating Pump-Motor Units indicated a potential for improving the reliability and total corrective maintenance man-hour burden by improving the design or materials of the pump wearing rings and the motor bearings. From a reliability point of view, the system design for the A/C Chilled Water System of the CGN-42 Class has sufficient redundancy that increased pump reliability is not warranted. However, a further cost-benefit analysis should be performed by the Navy to evaluate the potential cost savings by improvements in the pump wearing rings and motor bearings.

4.3.2.2 Support/Manning Changes

The potential deficit in the manning level to support the corrective maintenance load anticipated from review of Fleet operational experience and the appropriate skill mix to properly handle the A/C Chilled Water System repairs was discussed in Section 4.2.5. The difference between the projected and the experienced man-hours is a 220-hour deficit, which in itself is not significant.

Because of the lack of knowledge of the total ship manning and skill mix needs as derived from operational experience, it is recommended that the required system/equipments be analyzed to determine whether or not there is a manning or skill mix problem at the ship or work center level.

4.3.3 Summary of Recommended Changes

Table 4-6 summarizes the recommendations for the Air Conditioning Chilled Water System.

Table 4-6. RECOMMENDED SPECIFICATION AND DESIGN/SUPPORT CHANGES FOR AIR CONDITIONING CHILLED WATER SYSTEM

Ship Specification			
System Equipment	MTBF (Hours)	MTTR (Hours)	Design or Support
Chilled Water Plant	None	12.5 goal	Consider modification or manning change due to CM man-hour burden.
Chilled Water Circulating Pump	8000 goal	None	Consider modification of pump wearing rings and motor bearing design to improve R&M.
Sea Water Circulating Pump	8000 goal	None	Consider modification of pump wearing rings and motor bearing design to improve R&M.

CHAPTER FIVE

VENTILATION SYSTEM

5.1 DETERMINE SYSTEM EQUIPMENT CONFIGURATIONS

The Ventilation System consists of many small independent systems, each comprising many small components such as fans, cooling coils, and electrostatic precipitators, rather than a large unit like the A/C Chilled Water Plant, which dominates its system. Another aspect that tends to hinder a clear view of the system, especially from an R&M standpoint, is that the final sizing, duct routing, and equipment selection are determined by the detailed calculations of the shipbuilder.

5.1.1 CGN-42 Equipments

From a review of the MEL* for CGN-42, a list of all the components applicable to the Ventilation System was obtained, including estimated quantities of each component. This list is presented in Table 5-1. Examination of the diagrams for the Heating, Ventilation, and Air Conditioning Systems, NAVSEA Dwg. No. 5170954, revised 14 June 1978, and related documents from NAVSEC Code 6154 indicated that there was a difference in the way air conditioning and ventilation was provided to combat spaces as compared with the other office-habitability areas. The difference is that the combat spaces are served by built-up systems consisting of two fans, two cooling coils, and two electrostatic precipitator filters generally contained in a fan room, whereas the other areas are served by modular fan coil units in the spaces. Figure A-2 of Appendix A is a simplified diagram of a typical built-up ventilation system as it serves a combat space. Each such section is designed so that in the event of a failure or casualty, either component of the fan, cooling coil, and electrostatic precipitator filter pairs can maintain the space at a temperature not greater than 120°F.

5.1.2 Similar Fleet Equipment

The selection of similar Fleet equipment for analysis of this system was significantly different from the process used for the A/C Chilled Water System discussed in Chapter Four. The process started by reviewing the equipments on the CGN-38 Class to determine if there was an adequate data base

**AEGIS Guided Missile Nuclear Cruiser CGN-42 Class Master Equipment List, Issue 4, 24 April 1978.*

from which to make the R&M estimates. For most components there was no such base. For one group, including the Tubeaxial Fan, Sea Water Cooling Coil, and Gravity Type Cooling Coil, the APLs from the CGN-38 Class provide the only data base. A second group of APLs was selected on the basis that the APLs of these components on the CGN-38 Class were used on a sufficient number of other ships to make an adequate data base for analysis. These components include the Fan Coil Units and Unit Coolers. The third group of APLs was selected from those equipments/components which were represented in the Standard Component List (SCL) by many different APLs for the same type of component. In this case, APLs that represented the largest Fleet populations for a given size were selected for analysis. These included the Vaneaxial Fans, Convection Heaters, Electric Vent Type Heaters, and Air Duct Type Cooling Coils. In the case of the Electrostatic Precipitators, all APLs in the Fleet were included in the data base for analysis. The resulting equipment selections are contained in the R&M Data Sheets of Appendix B. In general, the populations of most of the components are very large, including as many as several thousand units on hundreds of individual ships.

Table 5-1. VENTILATION SYSTEM COMPONENTS

Component	Rating/ Capacity	Quantity	MIL-SPEC
Electrostatic Precipitator Air Filters	Various	43	MIL-F-22963
Duct Cooling Coils		48	MIL-C-2939
Vaneaxial Fans		75	MIL-F-18953
Fan Coil Units		42	MIL-A-23798 Type I
Gravity Cooling Coils		2	MIL-C-2939
Unit Coolers		8	MIL-C-2939
Tubeaxial Fans		4	MIL-F-18953
Sea Water Cooling Coils		8	---
Preheaters/Reheaters		13/18	MIL-H-16235 MIL-H-22594
Convection Heaters		33	MIL-H-3117

5.1.3 Review Specifications for R&M Values

The Ventilation System Equipments are addressed in Section 512 of the Ship Specification for detailed design requirements and again in Section 076 (R&M) as one of the systems to be included in the Shipbuilders R&M Program Plan. There are no quantitative R&M requirements in either section for any component or the system as a whole.

The MIL-SPECs listed in Table 5-1 were identified from Section 512 of the Ship Specification. A review of these documents also produced no quantitative R&M requirements for any of the system equipments. It is concluded that there are no applicable specification values for MTBF or MTTR on these system equipments.

5.2 REVIEW OPERATIONAL DATA ON SIMILAR FLEET EQUIPMENTS

5.2.1 Calculate R&M Indices

Even though the data base for most of the Ventilation System components encompasses very large equipment populations, there are few failures of these components in comparison with the equipment operating time, making the MTBF value very large. Table 5-2 lists the MTBFs and MTTRs for all components of the Ventilation System, although only the values for the first three -- Electrostatic Precipitator Filter, Duct Cooling Coils, and Vaneaxial Fans -- are of interest from the aspect of support to the AEGIS Combat System.

For all components except the fans, the utilization factor was assumed to be 1.0 -- i.e., the equipment operating time is the same as calendar time. For these components, the total operating time was the total equipment population times 26,280 hours (3 years x 8760 hours per year). Where the MTBF exceeded 30 years, the designation of >300,000 hours was used, since this is approximately the maximum life expectancy of the ship. (The exact value in all cases can be calculated from the information in the data sheets in Appendix B.) Of the three components of primary interest to this analysis, only the Cooling Coil MTBF was designated as >300,000.

The Cooling Coil MTBF calculated from the data is not considered to be within a believable range on the basis of the following explanation. The cooling coils are designed to last at least 20 years (approximately 175,000 hours*). There are no moving parts, so that a failure must occur from a metal defect, a manufacturing defect, or erosion usually caused by a higher-velocity fluid flow than called for in the original design. These failures result in leaks, which are not "maintenance significant" items according to the MDS reporting criteria and, since they require no repair parts, are never entered into the MDS data system. These same coils can also be subjected to hydrostatic testing during ROH periods, which may prevent an impending failure, but these actions will also go unreported in the MDS. These two reasons are typical of why fewer failures are reported for this type of equipment and, consequently, why the MTBFs are out of the logical range suggested by operational engineering experience. There is no question that the cooling coils are inherently reliable, a fact supported by the lack of reporting of any corrective maintenance actions.

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*MIL-A-23798B.

The figure of >300,000 hours (approximately 34 years) has been used in this report as the maximum MTBF that can logically be expected for these components.

Table 5-2. VENTILATION SYSTEM R&M VALUES

System Equipment	MTBF (Hours)			MTTR (Hours)		
	Specification		Operational	Specification		Operational
	Goal	Minimum		Goal	Maximum	
Combat System-Related						
Electrostatic Precipitator Air Filters	None		17,000	None		18.6
Duct Cooling Coils			>300,000			22.0
Vaneaxial Fans			93,000			35.4
Habitability-Related						
Fan Coil Units			93,000			35.4
Gravity Cooling Coils			>300,000			10.1
Vent Heaters			100,000			6.7
Unit Coolers			135,000			20.2
Tubeaxial Fans			95,000			8.6
Sea Water Cooling Coils			97,000			--
Steam Heaters/Preheaters			>300,000			8.3
Convection Heaters			>300,000			8.3

The MTBF of 93,000 hours for the Vaneaxial Fans is almost totally the result of the motor failures. It represents 1 failure every 15 years if the fan is operated 60 percent of the time. This value seems high from an intuitive engineering viewpoint because certain fans will fall far short of this MTBF depending primarily on their specific environmental conditions; however, for the population of the Ventilation Fans as a whole, it is quite probably the average MTBF being experienced in the Fleet.

The MTBF of the Electrostatic Precipitator is a special case inasmuch as a "failure" of this component has no immediate effect on the Ventilation System and therefore is not normally discovered until PMS inspection. The problem this situation created in analyzing the data was that the majority of corrective maintenance events were discovered during inspection or PMS and, by our criteria (see Section 2.3.1), would not be considered "failure" events even though the equipment was not operable. This had the effect of exaggerating the MTBF. To correct for this anomaly, a manual review of every reported maintenance action and a determination of whether or not the equipment was inoperable at the time of the event was made; if it was inoperable it was counted as a "failure" event. The failures (570) obtained by this review are listed on Data Sheet B-18 of Appendix B.

The MTTR of 18.6 hours for the Electrostatic Precipitator is based on the mean of the man-hours reported for 213 failure corrective maintenance actions and is considered highly representative of the Fleet operational experience for these units.

In a similar manner, the MTTR of 35.4 hours based on 238 failure corrective maintenance actions of the Vaneaxial Fans is considered representative of Fleet experience. Although this value also seems high, it is believed to result from the significant effort involved in removing and reinstalling the units in the ventilation ducts or fan rooms, where there is often little room to maneuver.

The MTTR of 22 hours for the Duct Cooling Coils is based on only 6 failure events and thus does not have the same level of confidence as that of equipment experiencing a greater number of failures. This will have little effect on any availability calculations because of the magnitude of the MTBF, which indicates that repairs are made very infrequently.

5.2.2 Compare Operational and Specified R&M Values

Since there are no specification R&M values for any components of the Ventilation System, no comparison can be made.

5.2.3 Calculate System Reliability

The reliability diagram and calculations for a typical section of the system designed to serve a combat space are presented in Appendix C, Figure C-2. It was assumed for the calculations that the component failure rates were constant; the resulting reliability is that of the worst case, wherein either one of the two components (of the Fan, Precipitator, and Cooling Coil) must be operating during a 1500-hour (approximately 60-day) mission. On this basis, the probability that the system will meet the mission goal is approximately 99 percent, which is equivalent to the system's having an MTBF of 23,000 hours. For the worst-case situation, this system has a high probability of success.

5.2.4 Determine System Corrective-Maintenance Man-Hour Burden

Tables 5-3 and 5-4 present the operational and projected corrective-maintenance man-hour burdens for the Ventilation System. Not all of the identified components are represented on both tables, since some had no reported corrective-maintenance man-hour burden, and others were not considered for the projection of corrective maintenance. A majority of components are covered in both cases, and the resulting totals show the magnitude of the difference between empirical calculation for manning purposes and the corrective-maintenance burden as determined from operational data on similar components in the Fleet.

5.2.5 Compare Projected and Historic Corrective-Maintenance Man-Hour Burdens

For this system, although the projected annual system total is 453 hours greater than the operational annual system total of 799 hours, it should be

noted that 717.5 hours of the annual projected corrective maintenance man-hours used for manning calculations are attributable to two components, the Duct Cooling Coils (315.7 hours) and the Vent Duct Steam Heaters (401.8 hours). This is significant because these components utilize lower-rated personnel with different skills from those used to repair the Electrostatic Precipitators, for which there is a deficit of 335 hours. This comparison indicates potential problems with the Electrician Mate ratings associated with this difference.

Table 5-3. VENTILATION SYSTEM OPERATIONAL CORRECTIVE-MAINTENANCE MAN-HOUR BURDEN

Component	Number of Components	Annual Man-Hours	
		Hours per Component per Year	Component Total per System
Electrostatic Precipitators	45	10.8	486.0
Duct Cooling Coils	48	.1	4.8
Vaneaxial Fans	75	2.5	187.5
Fan Coil Units	42	2.5	105.0
Gravity Cooling Coils	20	.1	2.0
Unit Coolers	8	1.0	8.0
Tubeaxial Fans	4	.6	2.4
Convection Heaters	33	.1	3.3
Annual System Total			799.0

5.2.6 Determine Equipment Failure Categories

Only two of the three components of the Ventilation System that serve the combat spaces had sufficient failures to warrant categorization -- the Electrostatic Precipitators and the Vaneaxial Fans, which are presented in Tables D-4 and D-5 of Appendix D. Table D-4 shows that failures of the ionizing cell account for about 29 percent of the total failures of the Electrostatic Precipitators. An additional 12 percent were the result of dirty cells. It appears that improvement of both the elements and cleaning maintenance schedule offers the potential for reducing the failure rate and the corrective-maintenance burden of these components up to 40 percent. Table D-5 lists the failures of the Vaneaxial Fans, with the motor accounting for the majority of failures. Since the failure rate of the fans is already

very low, it does not appear that an effort to improve these bearings would be cost-effective unless it became part of an effort to improve pump motor bearings, as discussed in Chapter Four.

Table 5-4. VENTILATION SYSTEM PROJECTED CORRECTIVE-MAINTENANCE MAN-HOUR BURDEN

Component	Number of Components	Annual Man-Hours	
		Hours per Component per Year	Component Total per System
Electrostatic Precipitators	45	3.36 (EM3)	151.3
Duct Cooling Coils	48	6.58 (FN)	315.7
Vaneaxial Fans	75	2.80	210.0
Fan Coil Units	42	2.80	117.6
Gravity Cooling Coils	20	.99	19.8
Unit Coolers	8	2.80	22.4
Convection Heaters	83	.10	8.6
Vent Duct Heaters (Steam)	124	3.24 (FN)	401.8
Vent Duct Heaters (Electric)	10	.49	4.9
Annual System Total			1,252.1

5.3 RECOMMEND CHANGES TO SYSTEM EQUIPMENT SPECIFICATIONS OR DESIGN

In view of the high component MTBFs and the resulting high reliability of the system in support of the combat-related spaces, it is concluded that R&M values are not required for the components of the Ventilation System in the Ship Specification or equipment MIL-SPECs. Therefore, no specification changes are recommended.

From the comparison of the projected and operational corrective-maintenance man-hours, it is concluded that there is a potential problem associated with the Electrician Mate rating and that further study should be made to determine whether or not this is a problem shipwide or at the work center level. Studies of improvements to the ionizing cell of the Electrostatic Precipitators might be cost-effective on a Navy-wide basis.

CHAPTER SIX

60 Hz POWER DISTRIBUTION SYSTEM

6.1 DETERMINE SYSTEM EQUIPMENT CONFIGURATIONS

This analysis is restricted to the switchboards and various distribution panels and components of the distribution network. The major components of the 60 Hz System, the SSTGs and associated equipment, are under the cognizance of NAVSEA Code 08 and were not addressed in this analysis, as directed by PMS 400 C.

6.1.1 CGN-42 Equipments

As identified from the MEL, there are three load-center ship service switchboards -- LC 31, LC 32, and LC 33 -- for distribution of power outside the machinery spaces. To ensure maximum continuity of service, each load center will be provided with normal and emergency sources of power from ship service and emergency switchboards (1 and 2 AS, 1 and 2 BS, and 1 and 2 BSA). A review of Sections 300 through 324 of the Ship Specification and the Ship's Service and Emergency 60 Hz Power System Diagram, NAVSEA Dwg. No. 5170965, dated 6/12/78, showed dual sources of power to the major combat systems such as the AN/SPY-1A Radar and Fire Control System. Figure A-3 of Appendix A is a simplified diagram of the distribution arrangement for a typical combat system's component load.

6.1.2 Similar Fleet Equipment

There are power distribution switchboards on the CGN-38 Class ships designated as load centers 31, 32, and 33 that should be similar to those on the CGN-42; however, an initial review of the data for their associated APLs did not identify any failure events over a maximum of 18 months of ship MDS data reporting. This is not considered an adequate or suitable data base, and the components of the distribution system were investigated further. The switchboards and various distribution panels are made up primarily of the following components:

- Circuit Breakers
- Fuse Unit Assemblies
- Fuse Boxes
- Terminal Boxes

All of these components have their own APLs and are in wide use in the Fleet. From the potential sizes and ratings of these units to be used on the CGN-42, a selection was made of corresponding APLs from the Standard Components List (SCL). These components are listed on Data Sheets B-38 through B-45 (Appendix B), with their associated population information.

6.1.3 Review Specifications for R&M Values

Sections 300 through 423 of the Ship Specification, covering electric power generation and distribution, both 60 Hz and 400 Hz, were reviewed for R&M requirements. Section 320d does address design for maximum continuity of services, but there are no quantified R&M values for either the system or the components of the system. Table 6-1 lists the MIL-SPECs pertaining to the system components, which were also reviewed. These MIL-SPECs require testing for various numbers of cycles and load conditions, but these represent endurance rather than R&M requirements.

Table 6-1. APPLICABLE COMPONENT MIL-SPECs FOR 60 Hz POWER DISTRIBUTION SYSTEM

Component	Military Specification
Power Distribution Switchboards	MIL-S-16036/P-23928B
Circuit Breakers	MIL-C-17587/17361
Fuse Unit Assemblies	MIL-S-17000L
Fuse Boxes	MIL-S-15001
Terminal Boxes	MIL-S-17000

6.2 REVIEW OPERATIONAL DATA ON SIMILAR FLEET EQUIPMENTS

6.2.1 Calculate R&M Indices

Even though the total equipment populations of these system components are in the thousands and the corresponding ship populations in the hundreds, there were few failure events, and the operational MTBF values are very high, as can be seen from Table 6-2. The total equipment operating time used for these MTBFs was calculated on the basis that the utilization factors were all 1.0 -- i.e., the operating time for each component was equal to the sum of the three calendar years in the data base times 8,760 hours per year. This results in a total equipment operating time for the Circuit Breakers in the millions of hours and only 27 failures in more than 19,000 units. Although the Circuit Breakers are very reliable, an MTBF in the millions of hours is not realistic. The failure reporting for the Circuit Breakers and

other components of the Distribution System is thought to be reduced because the repair of a Circuit Breaker is not considered "maintenance significant" for reporting purposes. In addition, circuit breakers are the type of equipment that can fail but have no effect on the system unless there is a second "failure" of another piece of equipment that causes a circuit overload from which the circuit breaker does not trip properly. This unknown failure may also be found and repaired during normal PMS, requiring nothing more than an adjustment, and never be reported in the MDS.

In the foregoing example, the equipments have high inherent reliability, as supported by the lack of reporting of any type of corrective maintenance actions. The figure of >300,000 hours (approximately 34 years) has been used in this report as the maximum logical MTBF that can be expected for these components. As shown in the table, all MTBFs for components of this system are represented as greater than 300,000 hours.

Even though the MTTRs were calculated from a limited data base, the values do not appear unreasonable from a subjective engineering judgment of the time it would take to repair these components on board ship.

Table 6-2. 60 Hz POWER DISTRIBUTION SYSTEM R&M VALUES

System Equipment	MTBF (Hours)			MTTR (Hours)		
	Specification		Operational	Specification		Operational
	Goal	Minimum		Goal	Maximum	
Power Distribution Switchboards	None		>300,000	None		5.0
Circuit Breakers			>300,000			5.1
Fuse Unit Assemblies			>300,000			2.5
Fuse Boxes			>300,000			8.2
Terminal Boxes			>300,000			2.0

6.2.2 Compare Operational and Specified R&M Values

Since there are no specification R&M values for any components of the 60 Hz Power Distribution System, no comparison with the operational values can be made.

6.2.3 Calculate System Reliability

The reliability of the 60 Hz Power Distribution System was calculated for the worst case -- the case in which only one power source is available to the load. The reliability block diagram and the calculations are presented in Figure C-3 of Appendix C. The reliability of this system for

a worst-case situation is a 96 percent probability of completing a mission of 1500 hours (>60 days) without a failure, which is equivalent to a system MTBF of 33,300 hours. This is a conservative estimate in that the maximum probable number of Circuit Breakers was used in the block diagram. In view of the conservative nature of the estimate, the system reliability appears adequate to support the Combat Systems.

6.2.4 Determine System Corrective-Maintenance Man-Hour Burden

The number of corrective-maintenance man-hours reported against the system components, as seen in the Data Sheets in Appendix B, is so small that it totals less than 10 man-hours per year even if the quantity of components on the CGN-42 is assumed to be 1,000. Therefore, the operational corrective-maintenance man-hour burden will be ignored for this system. The lack of reported man-hours suggests that the actual CM burden is not significant.

The projected corrective-maintenance man-hours for use in manning calculations are tabulated in Table 6-3. For this system, the number of hours projected for corrective maintenance exceeds the operational data by approximately 436 hours per year. This imbalance in projected man-hours for the Electrician Mate ratings appears to counteract the shortage identified for that rating for the Ventilation System. The actual impact of these comparisons cannot be properly assessed until the ship or work center level is studied further.

Table 6-3. 60 Hz POWER DISTRIBUTION SYSTEM PROJECTED CORRECTIVE-MAINTENANCE MAN-HOURS FOR MANNING CALCULATIONS

Component	Number of Components	Annual Man-Hours	
		Hours per Component per Year	Component Total per System per Year
Electrical Distribution	7	25.7	179.9
Distribution Panels	82	3.1	255.8
Annual System Total (Hours)			435.7

6.2.5 Determine Equipment Failure Categories

Because of the very few failures and the corresponding high MTBFs, there was no benefit to be gained from categorizing failures for these system components.

6.3 RECOMMEND CHANGES TO SYSTEM EQUIPMENT SPECIFICATIONS OR DESIGN

There are no recommended changes to either equipment specifications or design as a result of this analysis.

CHAPTER SEVEN

400 Hz POWER DISTRIBUTION SYSTEM

7.1 DETERMINE SYSTEM EQUIPMENT CONFIGURATION

The 400 Hz Power Distribution System is one of the systems to which new state-of-the-art technology is being applied to reduce the problems of providing reliable high-quality 400 Hz power to the combat systems. The Motor-Generator Sets represent the primary problem with this system, as demonstrated by the selection of these equipments for high-level management attention as part of the DART Program and the resulting 400 Hz M-G Set Improvement Program. The Navy's solution to this problem has been to develop Solid-State Frequency Changers (SSFC) to replace the M-G Sets. It is the intention of PMS 400 that a totally new SSFC be developed for the CGN-42 and that it be GFE, so that only the remaining distribution network is the responsibility of the shipbuilders. Although this analysis will concentrate on the distribution aspects of the system, a brief discussion of the Fleet experience with the only operational SSFCs will also be presented for information on these components.

7.1.1 CGN-42 Equipment

Six 250 kW, 450 volt, 400 Hz Solid-State Frequency Changers and three Distribution Switchboards are identified for this system in Sections 314 and 320 of the CGN-42 Ship Specification, dated 5 July 1978. The MEL dated 24 April 1978, Issue 4, calls for six 300 kW Mk 84 Solid-State Frequency Changers (SSFC). The Mk 84 is a specific model of frequency changer built by the ALS Company under contract to the Naval Ship Weapon Systems Engineering Station (NSWSES), which is the development and testing activity for this unit. NAVSEC engineers confirmed the 300 kW size; however, they indicated that the MEL is in error concerning the Mk 84 designation since it refers to a specific unit that may or may not be the unit selected for the CGN-42. The Ship Service 400 Hz Power System One-Line Diagram NAVSEA Dwg. No. 5170966, does not clarify the output power question; however, it does provide sufficient information to permit preparing a simplified diagram of the system, which is presented in Figure A-4 of Appendix A.

7.1.2 Similar Fleet Equipment

Although in many cases switchboards have their own APL numbers, a switchboard is primarily a frame, bus bar, and facing for connection of

the standard circuit breakers, which are the primary components of the switchboards. As discussed in Chapter Six with respect to the 60 Hz Power Distribution System, the maintenance actions are more often reported for the circuit breaker, which has its own APL number, than for the switchboard. For this reason, in the 400 Hz Power Distribution System the circuit breakers and the Solid-State Frequency Changers were the primary components selected to represent the system as a whole.

Since the TYCOM COSAL uses circuit breakers interchangeably between the 60 Hz and the 400 Hz Distribution Systems, it was appropriate to use the same information gathered for the 60 Hz System to represent the operational perience of circuit breakers for the 400 Hz System. The selection of the APLs for the circuit breakers is discussed in Section 6.1.2. The APLs used in the data base for this component are shown on pages B-40 and B-41 of Appendix B.

There is only one SSFC of the 250 kW size range on which operational data are being reported from the Fleet -- the Teledyne 250 kW unit APL 112700002, which is used on the DD-963 Class ships and the FFG-7. The population data for the Teledyne units are presented on pages B-46 and B-47 of Appendix B.

Another equipment, the ALS Company's 300 kW Mk 84 SSFC, has been under test and development by NSWSES and was installed on the USS NORTON SOUND, AVM-1, for the tests of the AEGIS Combat System. This unit has since been moved to the RCA CSED site, where it continues to provide power for the development and test of the AEGIS Combat System components. It is noted that this is a prototype unit and may or may not represent the type of experience that would result from a production model in the general Fleet environment.

7.1.3 Review Specifications for R&M Values

A review of both the Ship Specification and the MIL-SPEC for the SSFC, MIL-F-24122A, identified no quantitative R&M requirements for the 400 Hz Power Distribution System or for any component of the system. The extensive R&M program required by MIL-F-24122A lacks the quantitative MTBF and MTTR values that would make the requirements for the R&M programs meaningful.

7.2 REVIEW OPERATING DATA ON SIMILAR FLEET EQUIPMENTS

7.2.1 Calculate R&M Indices

The MTBF and MTTR for the circuit breakers are >300,000 hours and 5.1 hours, respectively, as shown in Table 6-2. The value of 300,000 hours (~34 years), which is about the maximum life of a ship and is the lower limit of the maximum useful MTBF of a component, has been used as the best estimate of the MTBF for these circuit breakers.

The Teledyne 250 kW SSFC units have accumulated 65,000 hours of operating time on 8 ships and have experienced 101 failures, for an MTBF of 645 hours. The data for these units were normalized to time after commissioning and the number of ships in commission to determine if there had been any reliability growth since the units were first installed. The difference between the failure rates during the first six months and that of the subsequent year was not appreciable (less than 5 percent). It was concluded that there has been no apparent reliability growth. The procurement specification required a 4000-hour MTBF for these units.

The ALS Mk 84 SSFC has performed somewhat better than the Teledyne units in its prototype phase, with an MTBF of 1400 hours*. However, the latest status report from NSWSES on the Mk 84 program* indicates that, with the modifications to the unit made as a result of the early failures, it is predicted that the unit is now capable of achieving its design MTBF for Major/Critical Equipment Events of 1400 hours. According to the report, continued testing and monitoring of the Mk 84 at the CSED site will be required until a total of 9000 operating hours are accumulated, in order to demonstrate that the 4000-hour MTBF can in fact be realized.

This discussion about the achieved reliability of these two units emphasizes that the state-of-the-art for these equipments currently provides MTBFs ranging from 645 to 1400 hours. Even though the unit developed for the CGN-42 may be totally different from the other two, it is necessary to consider the possibility that the eventual design will have a similar MTBF.

7.2.2 Compare Operational and Specified R&M Values

Since there are no specification R&M values for the components of the 400 Hz Power Distribution System, no comparison with the operational values can be made.

7.2.3 Calculate System Reliability

The reliability of the 400 Hz Power Distribution System (less the SSFC) was calculated on the basis of the worst-case configuration, which would require the proper operation of five circuit breakers as shown in Figure C-4 of Appendix C. The reliability of the system in this situation is represented by a 97-percent probability of success over a 1500-hour mission, which equates to a system MTBF of approximately 60,000 hours.

7.2.4 Determine System Corrective-Maintenance Man-Hour Burden

While it is recognized that the Teledyne 250 kW SSFC may not be totally representative of the model SSFC finally selected for the CGN-42, there is a possibility that it does have problems similar to those of any solid-state frequency changer. The average yearly corrective-maintenance man-hour burden for these equipments is approximately 94 hours; since there are 6 equipments per ship, this represents a ship burden of 564 hours.

**RMA Analysis of Mk 84 Performance on USS NORTON SOUND (AVM-1), NSWSES, November 1978.*

Examination of the man-hours projected for the SSFCs showed that only 8 hours per equipment per year, or a ship total of 64 man-hours, had been included for the purpose of manning calculations.

7.2.5 Compare Projected and Historic Corrective-Maintenance Man-Hours

Comparison of the historic and projected man-hours shows that the corrective-maintenance man-hour burden of these units has been 12 times greater than anticipated. This is a potential deficit of 500 man-hours per year in the projected corrective-maintenance burden for the Electrician Mate ratings. This comparison again highlights the need to examine the corrective-maintenance load as calculated for an entire work center in order to determine if these differences in the operational versus the projected man-hours for corrective maintenance have a significant impact on the manning level or skill mix required to perform the anticipated maintenance.

7.2.6 Determine Equipment Failure Categories

The failure events for the SSFC were categorized for the 250 kW Teledyne units on the DD-963 Class; they are presented in Appendix D, Table D-6. It appears from these categories that the components of the electronic circuitry were the primary cause of failure, having been identified as the problem element in 42 percent of the failure events. This may not be the case, however, since it was difficult to determine whether what was being reported was the cause of the failure or the effect of another element's failing. The cooling system in general was identified as the cause of 11 percent of the failure events. On the basis of the narrative descriptions of the events involving the cooling system, it is suspected that they were the real cause of some of the electronic failures.

7.3 RECOMMEND CHANGES TO SYSTEM EQUIPMENT SPECIFICATIONS OR DESIGN

7.3.1 Specification Changes

Since the 400 Hz SSFC is to be a Government-furnished item, the MTBF and MTTR requirements will not be specified in the Ship Specification. No other changes to the Ship Specification or MIL-SPECs for this system are required as a result of this analysis. However, the system must remain in Table II of Section 076 of the Ship Specification as one of those to be included in the shipbuilder's R&M Program, so that the system reliability can be examined again when more R&M information is available about the SSFCs to be used in the system.

7.3.2 Other Changes

It is recommended that the corrective-maintenance man-hours projected for the Solid-State Frequency Changer to be reviewed in light of the historical operating experience, which suggests a need to increase the projected man-hours.

It is also recommended that a total ship or work center review of the differences between the historical and the project corrective-maintenance man-hours be conducted to assess more accurately the impact of these differences on the manning levels and skills mix.

CHAPTER EIGHT

ELECTRONIC DRY AIR SYSTEM

8.1 DETERMINE SYSTEM EQUIPMENT CONFIGURATION

8.1.1 CGN-42 Equipment

The Electronic Dry Air System for the CGN-42 consists of a low-pressure air main that is fed by the ship's Vital Air Main through two of four Type II Dehydrators and provides dry air through risers to the Combat System Air Control Panels. The ship's Dry Air Main, as it is called, is backed up by three emergency dehydrators that will be provided by RCA in addition to the various combat system Air Control Panels and are therefore not included in this analysis. The compressed air for all ship services and for the Electronic Dry Air System is normally provided by the Ship Service Low-Pressure Air Compressors and associated Type I Dehydrators. These compressors and dehydrators are therefore not technically part of the Dry Air System; however, they will be analyzed together with the other components to determine their effect on Dry Air System reliability.

Section 551 of the Ship Specification for CGN-42 dated 5 July 1978 specifies three 200-scfm, 125-psi, oil-free low-pressure air compressors manufactured in accordance with MIL-C-1911A and three 200-scfm, Type I Dehydrators in accordance with MIL-D-23523C. Section 551 also specifies four 30-scfm Type II Class 3 Dehydrators in accordance with MIL-D-23523 to be provided for the Electronic Dry Air System. Since the low-pressure air is to be split into a vital service main and a nonvital service main, back-pressure regulating (priority) valves will be installed in accordance with MIL-V-24784 between the vital and nonvital mains to protect vital services if there is insufficient air capacity to meet all demands at one time. Table 8-1 lists all of the major components that will be addressed as part of this system; it includes the applicable MIL-SPEC, rating, and quantity of each component as projected for the CGN-42 Class.

A simplified diagram of the Dry Air System is shown in Figure A-5 of Appendix A. This diagram was prepared as a result of reviewing the L.P. Compressed Air and Dry Air Schematic, NAVSEA Dwg. No. 5170958, and other diagrams prepared as part of a comparison of the CGN-42 requirements with the CGN-38 Class and DDG-47 L.P. Air Systems*. This diagram shows the high

**NAVSEC 6154E Dry Air System Improvement Program, as of March 1978.*

degree of flexibility in lining up the L.P. Air Compressors and Type I Dehydrators with the Type II Dehydrator and the ship's Dry Air Main.

Table 8-1. ELECTRONIC DRY AIR SYSTEM COMPONENTS

Component	Rating	Quantity	MIL-SPEC
L.P. Air Compressor	200 scfm, 125 psi	3	MIL-C-19113A
Dehydrator, Type I	200 scfm	3	MIL-D-23523D
Dehydrator, Type II	30 scfm	4	MIL-D-23523D
Priority Valve	200 scfm	3	MIL-V-24784

8.1.2 Similar Fleet Equipment

An oil-free compressor has been specified for the low-pressure systems. Service use of this type of compressor in the surface ships of the Fleet has been started only in the last three to four years. The term "oil-free" means that no oil is used to lubricate any part of the compressor that will be in contact with the air being compressed. Teflon rings rather than the oil-lubricated type are usually used in order to keep oil out of the compressed air. Because of the relative newness of this type of compressor, a 100-scfm, 150-psi oil-free compressor used on the CG-16 and DDG-37 Classes, APL 061900359, was chosen for analysis rather than the 200-scfm, 125-psi units of the same manufacturer on the CGN-38, for which only a small quantity of operating data was available. Each ship of the two classes was checked against the NAVSEC Dry Air Improvement Program* records to ensure that the oil-free compressors had been installed. The resulting population information is shown on the Data Sheet on page B-48 of Appendix B.

In discussions with the NAVSEC engineers, it was agreed that the 100-scfm compressor was similar enough to the 200-scfm units to permit using the corrective maintenance experience of the smaller equipments for projecting the R&M characteristics of the larger units.

A similar precaution was taken in selecting the Type I and Type II Dehydrators to ensure that the equipments selected for analysis were part of the Dry Air Improvement Program and had sufficient operating time to provide confidence in the resulting R&M indices. The resulting population information for the Type I and Type II Dehydrators is presented in Appendix B, pages B-49 and B-50, respectively. There was only a limited population of the model Type I Dehydrator projected for use on CGN-42. The NAVSEC engineers indicated that in this case a small quantity of data on the exact equipment for CGN-42 was better than R&M indices based on less similar equipments.

The priority valve selected for analysis was one of two APLs that could meet the specification for CGN-42, and it was the only valve on which any data had been reported. The population information for this component is presented in Appendix B, page B-51.

**NAVSEC 6154E Dry Air System Improvement Program, as of March 1978.*

8.1.3 Review Specifications for R&M Values

The Ship Specification contains a requirement for a 1000-hour reliability test of the L.P. Air Compressor only and no maintainability tests for any component of this system. It appears that the Electronic Dry Air System is one of the systems to be included in the shipbuilder's R&M Program; however, the wording "Ship Service Air System" in Table II of Section 076 (R&M) should be clarified to ensure that the Dry Air System is encompassed within that wording.

Although the Dehydrators are not covered by R&M values in the Ship Specification, both the Type I and Type II Dehydrators are subject to a Reliability Demonstration Test of 1000 hours and a Maintainability Demonstration Test for certain designated repairs to be made within a 5-hour time limit required by the MIL-SPEC, MIL-D-23523C. Of the 26 MIL-SPECs reviewed for the equipments of the 7 distributive systems analyzed as part of this study, MIL-D-23523C is the only one that has a quantitative requirement for both MTBF and MTTR.

8.2 REVIEW OPERATIONAL DATA ON SIMILAR FLEET EQUIPMENTS

8.2.1 Calculate R&M Indices

The MTBF and MTTR for the four major components of the Electronic Dry Air System were calculated in accordance with the procedures described in Chapter Two, Section 2.3. For these components, the addition of failures from "part only" corrective maintenance events, as discussed in Section 2.3.1, had a significant impact on the MTBFs of the L.P. Air Compressor and both Dehydrators. The increase in failures was from 33 to 43 for the Compressor, 20 to 27 for the Type I Dehydrator, and 2 to 4 for the Type II Dehydrators. The Priority Valve had only one failure, which was also the only maintenance event reported. The resulting MTBFs are presented in Table 8-2, together with the MTTRs and the specification values discussed in Section 8.1.3.

8.2.1.1 L.P. Air Compressor

The 4359-hour MTBF for the L.P. Air Compressor is based on 43 failures from 48 equipments and has a 90-percent confidence interval from 3270 to 5450 hours about the mean. As additional support for a high level of confidence in this MTBF, a report of a 6000-hour reliability test conducted on the Oil-Free Air Compressor of this study by the David W. Taylor Naval Ship R&D Center* stated that the compressor had successfully completed this test. This finding supports the validity of accepting the 4359-hour MTBF as a reasonable value for this component.

The 17.2-hour MTTR for the L.P. Air Compressor is based on a substantial number of failures (28) and is considered representative of Fleet experience

**Long-Term Evaluation of a Worthington Class S, 100-scfm, 125-psig, Oil-Free Compressor; Commander, David W. Taylor Naval Ship R&D Center, Ltr. 2745: JRB,9551, TM-27-77-84, dated 24 January 1978.*

for these units. The value of 17.2 hours is comparable to values for similar-sized non-oil-free compressors as listed in the NAVSEC Design RMA Data Bank Report and therefore seems reasonable. However, it is not known whether this is high or low when compared with other oil-free units.

8.2.1.2 Type I Dehydrator

The MTBF of 5071 hours for the Type I Dehydrators is based on 27 failures experienced on 28 equipments. The 90-percent confidence interval ranges from 3550 hours to 8114 hours about the mean. This is not as tight a band as that of the L.P. Air Compressor; however, it indicates a 90-percent probability that the true MTBF lies within the interval.

The MTTR of 35.6 hours appears very high in comparison with the 2.2 hours recorded* for another refrigerant-type dehydrator on board a class of nuclear submarines. The 35.6-hour value is based on the mean of the man-hours reported in 15 failure corrective-maintenance events and is considered a reasonably good indication of the time it takes to repair the units.

8.2.1.3 Type II Dehydrator

The MTBF of 6300 hours is based on only four failure events from eight units over a total equipment operating time of 25,200 hours. The 90-percent confidence interval is very wide (3250 hours to 18,472 hours), because of the small number of failures and low operating time. Even though the value of 6300 hours is close to the 6700-hour MTBF from the NAVSEC RMA Design Data Bank Report for a similar type of dehydrator, the value generated for this APL is based on a small sample and merits low confidence.

The MTTR of 7.4 hours is based on only two failure events. Since the MDS data base now has nine additional months of data, a better estimate could be determined with an updated MDS corrective-maintenance data base.

Table 8-2. ELECTRONIC DRY AIR SYSTEM COMPONENT R&M VALUES

System Equipment	MTBF (Hours)			MTTR (Hours)		
	Specification		Operational	Specification		Operational
	Goal	Minimum		Goal	Maximum	
L.P. Air Compressor	None		4,359	None		17.2
Dehydrator, Type I	1,000		5,071	5.0		35.6
Dehydrator, Type II	1,000		6,300	5.0		7.4
Priority Valve	None		> 300,000	None		-

NAVSEC RMA Design Data Bank Report, Revision A, June 1975.

8.2.2 Compare Operational and Specification R&M Values

In determining the configuration of this system the applicable specifications were reviewed for R&M values, as discussed in Section 8.1.3. The values found as a result of this review are listed in Table 8-2, with the corresponding operational values. The table shows that the operational MTBFs for the components of this system are considerably better than the specification values -- when specified -- and that the MTBF of the Priority Valve is estimated to be greater than the expected life of the ship. The strength of the data for calculating the MTBFs for the L.P. Air Compressor and Type I Dehydrator leads to the conclusion that the Ship Specification MTBF values could be raised without a serious risk of increasing the procurement costs of the equipments. The data from the Type II Dehydrator do not strongly support this conclusion, since the data sample is very small. However, if future data substantiates the present high MTBF, the MIL-SPEC MTBF requirement covering both Type I and Type II Dehydrators could be raised from 1000 to at least 3000 hours. This would help to ensure that state-of-the-art improvements are realized in future procurements. Until further data on the Type II units are analyzed, there is only justification for raising the Ship Specification MTBFs for the Type I Dehydrators and the L.P. Air Compressor.

The MTTR of 17.1 hours for the L.P. Air Compressor is high compared with the test values of 4.0 hours observed by NAVSEA 98 for a similar unit as part of the FFG-7 R&M test program, but it is not significantly different from other Fleet values, as discussed in Section 8.2.1. It is concluded that the 17-hour MTTR is reasonable for a value based on operational experience, and that the 4.0-hour test value is also reasonable for use in the Ship Specification.

The operational MTTR for the Type I Dehydrator is considerably above (worse than) the MIL-SPEC maximum value. It is not clear from the data why this is so, except that the problems indicated by the failure categorization were associated with internal parts and involved actions of 40 to 150 hours each. One assumption that can be made from a review of the data for these units is that a large amount of troubleshooting time was expended in these actions, as indicated by the fact that for 50 percent of the maintenance actions no cause was specified. Additional MDS data on these units may provide an explanation for the high MTTR value. The Type II Dehydrator shows an MTTR of 7.4 hours. This value is close to the MIL-SPEC requirement of 5 hours but represents only an estimate at this time. Additional failure information is needed to confirm this preliminary estimate on these relatively new equipments.

8.2.3 Calculate System Reliability

The reliability block diagram for the Electronic Dry Air System is presented in Appendix C, Figure C-5. It shows three series sets of an L.P. Air Compressor and Type I Dehydrator in parallel with each other and these in series with four Type II Dehydrators in parallel with each other. Calculation of the system reliability for this configuration over a 1500-hour period requires the use of a reliability mathematical model for the most accurate solution. To simplify the calculations, it was assumed that the components of the system were not repairable. This is the same assumption made for the other complex systems in this report, and it makes the resulting reliability values lower than if the repairability was considered. As such, the system reliability values should be viewed as lower limit values. The final overall system reliability calculations shown in Appendix C resulted in an 79 percent probability of performing successfully over the 1500-hour (~60-day) period. This is equivalent to a system MTBF of 2450 hours.

8.2.4 Determine System Corrective-Maintenance Man-Hour Burden

8.2.4.1 Operational Corrective-Maintenance Man-Hours

The operational corrective-maintenance man-hour burden for the system is determined by multiplying the man-hours reported per year for each component of the system by the number of components in the system and then summing these totals to obtain the system burden. By this process it is possible to determine the difference between corrective-maintenance man-hour burden being experienced on similar Fleet equipments and that being projected for manning calculations. The annualized results of these calculations for the components and the Dry Air System are presented in Table 8-3 for the operational corrective-maintenance man-hour burden.

Table 8-3. ANNUALIZED OPERATIONAL CORRECTIVE-MAINTENANCE MAN-HOUR BURDEN FOR THE ELECTRONIC DRY AIR SYSTEM

Component (Quantity per Ship)	Man-Hours per Equipment per Year	Man-Hours per Ship per Year
L.P. Air Compressor (3)	73.7	221.1
Type I Dehydrator (3)	27.9	111.8
Type II Dehydrator (4)	23.2	92.8
Priority Valve (3)	--	--
Annual System Total		425.7

8.2.4.2 Projected Corrective-Maintenance Man-Hours for Manning Requirements

The projected corrective-maintenance man-hour burden was obtained from the CGN-42 AEGIS Cruiser *Preliminary Ship Manpower Document*, NAVSEC Report No. 6112F-022-78, 1 September 1978. The components of the system identified for the manning calculation are slightly different from the proposed components of CGN-42 in that an extra set of Dehydrators was used. The projected man-hour figures for these components and a "system" man-hour total are presented in Table 8-4.

Table 8-4. ANNUALIZED PROJECTED CORRECTIVE-MAINTENANCE MAN-HOURS FOR THE ELECTRONIC DRY AIR SYSTEM

Component (Quantity per Ship)	Man-Hours per Equipment per Year	Man-Hours per Ship per Year
L.P. Air Compressor (3)	54.5	163.5
L.P. Air Dryer, Type I (3)	1.9	5.7
Electronic Dry Air System Dehydrator, Type II (4)	38.2	152.8
Dry Air System Dehydrator (5 per ship)	55.9	(279.5)*
Annual System Total		322.0

**Not included in system total.*

The Dry Air System Dehydrator (5 per ship) is believed to represent the Emergency Dehydrators being supplied by RCA in addition to the Type II Dehydrators the Navy is providing. The hours for these components have not been included in the system total.

8.2.5 Compare Projected and Historic Corrective-Maintenance Man-Hours

A comparison of the two corrective-maintenance man-hour burdens shows the L.P. Air Compressor experiencing a 35-percent higher operational burden than planned. The Type I Dehydrator man-hours are different in that there are 15 times more man-hours being experienced that planned for. For the Type II Dehydrators, the difference is significant in the direction of the planned man-hours which are 65-percent greater than those experienced. It is likely that the PMS for the Type II Dehydrators has a high PMS burden associated with changing the filters, which -- because of the formula used to determine projected corrective-maintenance man-hours -- has imbalanced the corrective man-hours toward these less complex units rather than the

Type I units, for which insufficient corrective-maintenance man-hours are projected.

For this system, the conclusion reached is that all equipments of the work center to which this system is assigned should be reviewed to assess the impact.

8.2.6 Review Equipment Failure Categories

The failures for both the L.P. Air Compressor and the Type I Dehydrator are presented in Appendix D, Tables D-7 and D-8. No separate failures categories of the Type I Dehydrators appear significant. Head-gasket leakage is associated with 18 percent of the compressor failures, and cooling system problems constitute another 27 percent of the failure events that could represent significant reliability-improvement areas. These percentages are based on a total of 33 maintenance events, too small a sample to confirm a need for design improvement based on the failure categories.

8.3 RECOMMENDED CHANGES TO SYSTEM EQUIPMENT SPECIFICATIONS OR DESIGN

8.3.1 Specification Changes

Specification changes required for the L.P. Air Compressor and the Dehydrators are discussed in the following subsections.

8.3.1.1 L.P. Air Compressor

The operational MTBF of the L.P. Air Compressor is more than four times the 1000-hour minimum value cited in Section 551 of the Ship Specification. The same compressor used as a data source for this analysis has successfully completed a 6000-hour long-term evaluation, and NAVSEA 0982 has observed a successful 2,820-hour vendor demonstration of a similar compressor for the FFG-7 Class. In view of this information and in the interest of ensuring state-of-the-art achievements in reliability in future procurements, it is recommended that the specification MTBF value for the compressor be raised to a 2820-hour goal. This value was selected because of its credibility as an observed vendor test value. This value should be inserted in both Section 551 and Section 976, Table I of the Ship Specification to ensure specific attention in the shipbuilder's R&M program and inclusion in the procurement specifications.

The MTTR of 17.2 hours for the L.P. Air Compressor is not excessively high for an operational value; however, the NAVSEA 0982 observed test value for this equipment is 4.0 hours. Since this test value has been successfully demonstrated by a vendor for the FFG-7 Program, it is recommended that it be a requirement of the CGN-42 Ship Specification.

8.3.1.2 Dehydrators

The Ship Specification does not now contain R&M values for either Type I or II Dehydrators. The operational values, even though not based on large quantities of data, are five and six times the MIL-SPEC minimum requirement of a 1000-hour MTBF. To ensure that state-of-the-art achievements are obtained through the procurement process, it is recommended that an MTBF goal value of 2000 hours be included in the Ship Specification in both Sections 551 and 076, Table I. This is a conservative recommendation because of the short time these newer Dry Air Improvement Program equipments have been in the Fleet and the caution expected on the part of the vendors in accepting significantly higher requirements. The MIL-SPEC MTTR value of 5.0 hours for the Type I and II Dehydrators is also recommended for use in the Ship Specification until more data are gathered on these units to provide more accurate values.

8.3.2 Other Changes

In view of the differences found in the projected versus the operational corrective-maintenance burdens for the components of this system, it is recommended that a study of all equipments of the work center responsible for maintenance of these units be conducted so that the potential manning-level/skill-mix problem can be properly assessed.

CHAPTER NINE

FIREMAIN SYSTEM

9.1 DETERMINE SYSTEM EQUIPMENT CONFIGURATIONS

The Firemain System for CGN-42 will be configured in what is called a vertical-offset loop system, consisting of two mains running fore and aft on different levels in the ship. The upper main is to be installed under the main deck on the port side of the ship. The lower main is to be installed above the second platform on the starboard side of the ship. The mains are to be cross-connected at the pump risers, and the system will be capable of being segregated into a number of independent sections, each supplied by two or more pumps. Figure A-6 of Appendix A is a simplified diagram of how the pumps and mains will be arranged to provide redundancy and continuity of service to a combat system cooling load or sprinkling system.

9.1.1 CGN-42 Equipment

Section 503 of the Ship Specification lists the type, the rating, and the applicable MIL-SPEC of the pumps that will serve the Firemain System on CGN-42. These major components of the system, as well as the Motor Operated and Pressure Regulating Valves, are listed in Table 9-1. The Motor Operated Valves were identified from the MEL and the Pressure Regulating Valves from the Firemain Systems Section of the SURFLANT COSAL.

It is noted that both the MEL of 24 April 1978 and the Ship Specification of 5 July 1978 are in error concerning the number of Electric Motor Driven Firepumps. The MEL shows three, while the Ship Specification and the NAVSEA Drawing both indicate five. Information from NAVSEC Code 6154F engineers indicates that there are now six Motor Driven Firepumps and two Steam turbine Driven Firepumps required for CGN-42, each with a capacity of 1000 gmp at 150 psi.

9.1.2 Similar Fleet Equipment

9.1.2.1 Firepumps

The selection of Fleet equipments similar to those projected for CGN-42 was made from all 1000 gpm, 150 psi centrifugal firepumps in the fleet. Certain equipments and ship types were eliminated from this initial group

Table 9-1. FIREMAIN SYSTEM COMPONENTS			
Component	Rating	Quantity	MIL-SPEC
Firepump, Turbine Driven	1000 gpm 250 psi	2	MIL-P-17639
Turbine, Firepump	150 hp	2	MIL-T-17523
Firepump, Motor Driven	1000 gpm 150 psi	6	MIL-P-17639
Motor, Firepump	150 hp	6	MIL-M-17060E
Valves, Motor Operated	8" and 10"/250 psi	83	
Valve, Pressure Regulating, Firemain	Various	47	MIL-V-2042

of pumps for three basic reasons: (1) the driving motor or turbine could not be identified; (2) pumps of different sizes were used on the same ship, which complicated the determination of reasonable utilization factors; and (3) the same pump APL was used with both a motor and a turbine on the same ship, preventing identification of pump data to either a motor driven or turbine driven unit. The resulting population data are presented in Appendix B, pages B-52 through B-55. Substantial populations for both pumps and driving units were selected by this process. For the Turbine Drive Firepumps, there are 42 units on 22 ships; and for the Motor Driven Firepump, there are 158 units on 25 ships.

9.1.2.2 Motor Operated Valves

Identification of Motor Operated Valves, both globe and butterfly types, was only partially successful and ultimately resulted in aggregating component data to obtain unit R&M values. For example, it was not possible, from the COSALs, to differentiate between electric and hydraulically powered valves. To resolve this problem, the electric valve operators from the CGN-38 Class were identified and used as the data base for this part of the unit. All globe and butterfly valves listed under Firemain Systems that could be identified from the SURFLANT COSAL and the Master Index of APLs (MIAPL) as power operated were also selected and used to calculate R&M indices for the valve portion of the Motor Operated Valve Units. The total population information for the 197 units selected is presented in Appendix B, pages B-56, B-57, and B-58.

9.1.2.3 Pressure Regulating Valves

Since the Pressure Regulating Valves were not specifically identified as to size or rating, it was decided to use all Pressure Regulating Valves from Firemain Systems in the SURFLANT COSAL as the data base for these components. The population information for the 325 Pressure Regulating Valves identified is contained on pages B-60 and B-61 of Appendix B.

9.1.3 Review Specifications for R&M Valves

A review of Sections 503 and 076 of the Ship Specification and all MIL-SPECs listed in Table 9-1 resulted in the identification of specified MTBFs and MTTRs for the pump units only. These requirements were located in Table I of Section 076 (R&M) of the Ship Specification. The values found are shown in Table 9-2. It is noted that only the MTTR is required to be demonstrated by the shipbuilder/vendor for either of the pump units.

Table 9-2. EXISTING SPECIFICATION REQUIREMENTS FOR THE COMPONENTS OF THE FIREMAIN SYSTEM

Component	MTBF	MTTR
Steam Driven Firepump	2,750 hours goal 1,375 hours minimum No demonstration test	5.4 hours goal 10.8 hours maximum Demonstration test required
Electric Driven Firepump	3,000 hours goal 1,500 hours minimum No demonstration test	4.0 hours goal 8.0 hours maximum Demonstration test required
All Other Components	None required	None required

9.2 REVIEW OPERATIONAL DATA ON SIMILAR FLEET EQUIPMENT

9.2.1 Calculate R&M Indices

The MTBF and MTTR for the components of the Firemain System were calculated in accordance with the procedures described in Chapter Two, Section 2.3 The resulting values are presented in Table 9-3 under the heading of operational values. The following sections present evaluations of these values for each component.

9.2.1.1 Firepumps

Both the Turbine and Motor Driven Firepump MTBFs are based on substantial equipment populations and numbers of failure events, 108 failures from 42 equipments for the Turbine Driven (TD) Firepump and 342 failures from the 158 equipments for the Motor Driven (MD) Firepump. The MTBFs for the two pump units are different, as shown in Table 9-3, with the TD Firepump having the lower value of 1927 hours and the MD Firepump 3,495 hours. This difference is logical in that the Turbine has many more parts that can fail than the Motor. Because of the large numbers of failures for the TD and MD pumps, the 90 percent confidence intervals about the MTBFs for these equipments are within 300 to 500 hours, respectively, of the mean. These values are considered to be representative of Fleet experience.

Table 9-3. FIREMAIN SYSTEM R&M VALUES

System Equipment	MTBF (Hours)			MTTR (Hours)		
	Specification		Operational	Specification		Operational
	Goal	Minimum		Goal	Maximum	
Turbine Driven Firepump	2,750	1,375	1,927	5.4	10.8	20.0
Electric Driven Firepump	3,000	1,500	3,495	4.0	8.0	33.4
Power Operated Valves	No Specification Values		127,000	No Specification Values		20.4
Pressure Regulating Valves	No Specification Values		110,000	No Specification Values		18.0

9.2.1.2 Power Operated Valves

On the basis of a population of 197 Power Operated Valves on a variety of ships, only 15 failures were reported during a period of almost 2 million equipment operating hours, resulting in an MTBF of 127,000 hours for these equipments. With this small number of failures, the 90 percent confidence interval about the Mean is very large and the values range from a lower limit of 87,000 hours to an upper limit of 205,000 hours. These values are still indicative, however, that the MTBF should be relatively high as compared with the other components of the system.

9.2.1.3 Pressure Regulating Valves

From the population of 325 Pressure Regulating Valves, 65 failures were reported over approximately 7 million equipment operating hours, for

an MTBF of 110,000 hours. The 90 percent confidence interval about this mean ranges from 90,000 to 130,000 hours, indicating that the Fleet experience for these valves is in the range of 100,000 hours between failures.

The MTTR of 18.0 hours for these valves is based on a mean of 26 failure events and has a standard deviation of 11.3 hours. This value is considered to be a good representation of the Fleet experience for maintenance of these equipments.

9.2.2 Compare Operational and Specified R&M Values

Both the Firepump operational MTBFs are larger than the Specification minimum values shown in Table 9-3, with the Turbine Driven Firepump MTBF falling halfway between the minimum and goal values and the Motor Driven Firepump approximately 500 hours better than the Specification goal value of 3,000 hours for that pump. This indicates that the Specification MTBF values are reasonably set for the state-of-the-art firepump at this time. It also means that an attempt to obtain a significant increase in operational MTBF as a result of increasing the Specification values would probably be costly.

The MTTRs for the Firepumps are considerably higher than the specification values; however, these operational values are based on a very large body of data, and it is believed that they are a good representation of the average experience in the Fleet on these equipments. The specification values for these pump units have been used and demonstrated in the FFG-7 Program; thus, it is recommended that they continue to be used as the specification values.

9.2.3 Calculate System Reliability

The reliability block diagram and calculations to show the Cruise and Battle Condition reliability situations for the Firemain System are presented in Appendix C, Figure C-6. The worst case for this system is the situation in which six out of the eight pumps must be working to fight a fire. It was assumed for both calculations that the failure rates of the components were constant and the failures were, therefore, distributed exponentially. For the Cruise condition, a reliability approximation for the reliability of two out of eight units was calculated based on the standby redundancy and interchangeability of all units and that the failure rates of both the Steam Turbine and Motor Driven Pumps were the same. To approximate the reliability of the Battle condition with six of eight pumps required over the 1500 hour mission period, the MTBF of the Motor Driven Firepumps was used for all units in order to simplify the calculations. In neither case was the repairability of some components taken into account which makes the reliability lower and, thus, more a conservative value. On the basis of these assumptions, the probability that the Firemain System will be able to accomplish this worst-case mission goal under Battle conditions over 60 days ($\sim$1500 hours) is 53 percent, which is equivalent to the system's having an MTBF of 1,750 hours. The probability of system success in the Cruise condition is 99.8 percent, which is equivalent to a system MTBF of 6,755 hours.

9.2.4 Determine System Corrective Maintenance Man-Hour Burden

As part of a continuing investigation into the difference between the operational and projected maintenance burdens, the system component man-hours were calculated from the MDS data for the operational figures and extracted from the CGN-42 AEGIS CRUISER "Preliminary Ship Manpower Document" for the projected values. The annualized results of these calculations are presented in Table 9-4 for the operational corrective maintenance man-hours and in Table 9-5 for the projected corrective maintenance man-hours used for manning calculations.

Table 9-4. ANNUALIZED OPERATIONAL CORRECTIVE MAINTENANCE MAN-HOUR BURDEN FOR THE FIREMAIN SYSTEM

Component (Quantity per Ship)	Man-Hours Per Equipment Per Year	Man-Hours Per Ship Per Year
Turbine Driven Firepump and Turbine (2)	69.0	138.0
Electric Driven Firepump (6) (Pump End Only)	58.4	350.4 (6)
Power Operated Valves (83)	0.26	21.6
Pressure Regulating Valves (47)	0.7	32.9
Annual System Total		542.9

9.2.5 Compare Projected and Historic Corrective Maintenance Man-Hour Burdens

Comparison of the numbers for the same components on Tables 9-4 and 9-5 shows that the expected burden from the operational data is larger than the projected figures for the pumps and turbine. In the case of the Motor-Driven Pump, the operational hours are four and one-half times the projected on a single-equipment basis; however, since the projected total for the system estimated only three pumps, and there will be six, the difference for the system is approximately nine times the operational man-hours as projected for manning calculations. On the other hand, the annual hours projected for the Power Operated Valves is almost 50 times that being reported operationally. This leads to an overall annual system projected corrective maintenance man-hours total which is two and one-half times the operational total. Although this may appear to enhance the maintenance posture of the ship, it may in fact create an imbalance in the rates, ratings, and skills required to perform the work and may therefore be detrimental to

Table 9-5. ANNUALIZED PROJECTED CORRECTIVE MAINTENANCE MAN-HOURS FOR THE FIREMAIN SYSTEM		
Component (Quantity per Ship)	Man-Hours per Equipment per Year	Man-Hours per Ship per Year
Turbine-Driven Firepump and Turbine (2)	47.6	95.2
Electric Driven Firepump (3 Estimated) (Pump End Only)	13.3	39.9 (3)
Firemain System	81.7	81.7
Water Washdown System (1)	2.8	2.8
Gate Valves, Electrical Operated (83)	12.6	1,046.7
S. W. Reducing Valves (47)	1.9	89.3
Annual System Total		1,356.6

proper maintenance capability and capacity. The results of the comparisons on this system alone are not sufficient to create concern for the manning projections; however, the aggregate of these differences at the Work Center level could be significant.

9.2.6 Determine Equipment Failure Categories

To determine if there were any primary failure modes for these components, the failures of the pump-turbine unit and pump motor units were categorized. The results of this effort are presented in Appendix D, Tables D-9 and D-10. The elements of these components most frequently involved in the failure events are items that are intuitively expected to be the primary maintenance items: the pump wearing rings (14 percent) and the pump bearings (8.3 percent) for the turbine driven pumps; the governor (16.7 percent) for the turbine; the pump bearings (13.4 percent), rotor (12 percent), wearing rings (10.6 percent) and casing (6.5 percent) for the motor driven pump; and the bearings (14.4 percent) and shorted windings (5.1 percent) for the pump motor. It is noted that the pump casing and rotor are a factor in the failures of the motor driven pumps only. This may be caused by favoring certain pumps in port that are located in more remote areas of the ship where they are more easily allowed to run to catastrophic failure than the Steam Turbine Pumps which receive close attention under way (because of their location). The categories of failure are common for all of these components, and significant improvements are not expected without considerable effort and cost.

9.3 RECOMMEND CHANGES TO SYSTEM EQUIPMENT SPECIFICATIONS OR DESIGN

9.3.1 Specification Changes

The operational MTBFs of the Firepumps resulting from Fleet experience are in the same range as the specification values. Since these Specification values have been demonstrated recently by vendors for the FFG-7 Program, it is recommended that the Specification values for MTBF remain as they are. The operational MTBFs for the Power Operated and Pressure Regulating Valves are very high; therefore, there appears to be no reason for adding specific values to the Ship Specification for these components.

The operational MTTRs for the Firepumps, although considerably higher than the Specification values, are reasonable values for Fleet operational experience. The Specification values have been used by the FFG-7 Program and have been demonstrated recently by vendors; therefore, they must also be considered reasonable. No change is recommended for either of these values.

9.3.2 Other Changes

In Section 9.2.5 it was shown that the corrective maintenance man-hour burden for the Firepumps is considerably higher than that being projected for these equipments to determine manning requirements. At the same time, the MTBFs, while satisfactory for system reliability, are relatively low when compared with those of other system equipments in this study. Review of the failure categories did indicate failure modes that accounted for a significant number of the failure events; but since these categories are common and expected for these equipments, they do not by themselves suggest a need for design improvements. However, in view of the high overall corrective maintenance man-hour burden and relatively low MTBFs for these equipments, an attempt to improve the design of the Firepumps in the areas indicated by the primary failure modes could prove cost-effective in terms of manpower savings over the life of the pumps. It is recommended that further study be performed to determine if a manning-level or skill-mix problem exists for the ship work centers responsible for these equipments and, if there is a problem, that consideration be given to possible equipment design improvements as well as changes in the manning.

CHAPTER TEN

SEA WATER COOLING FOR COMBAT SYSTEM

10.1 DETERMINE SYSTEM EQUIPMENT CONFIGURATION

This system consists of those portions of the Sea Water Cooling System used either exclusively or primarily for cooling combat systems, with the firemain used as a back-up supply. There are three independent sections to this system: the AN/APY-1A Radar Forward Array, the AN/SPY-1A Radar After Array, and the AN/SQS-53A Sonar.

10.1.1 CGN-42 Equipment

The Sea Water Cooling System is discussed generally in Section 524 of the Ship Specification and also in the AEGIS Impact Study*, where the three system sections are identified. The major equipments for the system are specified in the MEL and in Section 503 of the Ship Specification. Separate centrifugal sea water pumps will be provided for both the Fore and Aft Radar Arrays, and only one of three Cooling Coil and Miscellaneous Machinery Sea Water Circulating pumps will serve the sonar electronic cooling. Each of these pumps will be backed up by the firemain. The type, rating, and MIL-SPEC requirements of the pump are listed in Table 10-1. The specific model of heat exchanger being developed for the AN/SPY-1A Radar, as specified in Section 524 of the Ship Specification, is also listed in the table.

A simplified diagram of the major components of this system is presented in Figure A-7 of Appendix A. Although Table 10-1 shows three Cooling Coil and Miscellaneous Machinery S. W. Circulating Pumps, only one of the three is used to cool the AN/SQS-53A Sonar electronics.

10.1.2 Similar Fleet Equipment

The initial approach to selecting Fleet equipments similar to those listed in Table 10-1 was to identify all pumps used for the appropriate service application (i.e. sea water cooling for radars) of the rating required for CGN-42. At the time this selection was made, the MEL had listed the sizes for the Cooling Coil and Miscellaneous Machinery Sea

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**AEGIS Impact on CGN-38 Non-Propulsion Piping Systems for CGN-42 Contract Designs*, M. Rosenblatt & Sons, Inc.

Table 10-1. SEA WATER COOLING SYSTEM COMPONENTS			
Component	Rating	Quanity	MIL-SPEC
AEGIS Radar Cooling Pump, Centrifugal, Motor Driven	300 gpm 50 psi 20 hp	2	MIL-P-17480
Cooling Coil and Miscellaneous Sea Water Circulating Pump, Centrifugal Motor Drive	650 gpm 40 psi 25 hp	3	MIL-P-17639
HD-1014/SPY-1A Water Cooling Unit	Unknown	2	None

Water Circulating Pumps at 250, 450, and 550 gpm. The ratings for all three pumps have since been changed to 650 gpm, 40 psi according to the 5 July 1978 issue of the Ship Specification. The initial values of these pumps were lower and much closer to the 300 GPM being specified for the AEGIS Radar Cooling Pumps and the closeness of two different pumps in both type and rating was the reason for one pump being finally chosen to represent both the AEGIS Rad Cooling and the Cooling Coil and Miscellaneous Machinery Sea Water Circulating Pumps. Under Radar Cooling Sea Water Circulating Pumps in the Type Commander's (TYCOM) COSALs, the largest pumps listed were rated at 175 gpm, considered to be inadequate to represent the maintenance characteristic of the specified pumps, which were two to three times larger. Under the heading of Auxiliary Machinery Cooling Water Pumps in the SURFLANT TYCOM COSAL, there were two APLs for pumps of 350 gpm and 450 gpm, 50 psi that were close to both the specified pumps in application and rating. It was decided to use the operational experience of the second group of pumps as being representative of both the AEGIS Radar Cooling Pump and the Cooling Coil and Miscellaneous Machinery Sea Water Circulating Pump. The total Fleet population is 36 pump-motor units on 18 ships, as shown on the R&M Data Sheets, pages B-62 and B-63 of Appendix B.

Since the size of the Radar Water Cooling Unit was not given in the Ship Specification, all the Demineralized Water/Sea Water Heat Exhangers on the CGN-38 Class were used to obtain composite R&M numbers to represent the Fleet operational experience. A total of 18 Heat Exchangers on the 9 ships of the class make up the data base for these components of the system. As it turns out, the majority, if not all, of these heat exchangers for the Combat Systems will be provided by RCA with the Combat Systems, and the required R&M characteristics of the units will be the responsibility of RCA.

10.1.3 Review Specifications for R&M Values

Both the Ship Specification and the applicable MIL-SPECs were reviewed for system equipment R&M requirements. Only the AEGIS Radar Cooling Water Pump was found to have specified MTBF and MTTR values. These values were

found in Table I, Section 076 (R&M) of the Ship Specification. An MTBF goal of 8500 hours and a minimum value of 4,250 hours are specified for the Pump-Motor Unit. A demonstration test has not been specified for this value. An MTTR goal of 8.1 hours and a maximum value of 16.2 hours have also been specified. A demonstration test is required for this value. R&M values were not specified for any other equipments of this system.

10.2 REVIEW OPERATIONAL DATA ON SIMILAR FLEET EQUIPMENT

10.2.1 Calculate R&M Indices

The MTBF and MTTR for the Pump-Motor Units and the Heat Exchanger were calculated in accordance with the procedures described in Chapter Two, Section 2.3, and the resulting values are presented in Table 10-2. There were no maintenance actions on the heat exchangers during the data period; therefore, there were no failure events. Since there were no failures, the MTBF for these units was estimated on the basis of the Chi-Square $(\chi)^2$ lower 60 percent confidence interval, with two degrees of freedom, as a function of the total equipment operating time. This estimate is also presented in Table 10-2 under the column "Operational MTBF". The specification R&M values identified for the pumps, are also presented in this table.

Table 10-2. SEA WATER COOLING FOR COMBAT SYSTEM R&M VALUES

System Equipment	MTBF			MTTR		
	Specification		Operational	Specification		Operational
	Goal	Minimum		Goal	Maximum	
AEGIS Radar Cooling Pump	8,500	4,250	5,720	8.1	16.2	26.6
Air Conditioning Cooling Coil and Miscellaneous Pump	No specification values		5,720*	No specification values		26.6
SW/Demineralized Water Heat Exchanger	↓		73,000	↓		No Reported Failures

*The same operational units used to represent Fleet experience for both pumps.

10.2.1.1 Sea Water Cooling Pumps

The 5720 hour operational MTBF for these pumps is based on an equipment population of 36 units on 18 ships, representing a total equipment operating time of 360,000 hours. The 63 failures events reported during that period resulted in a 90 percent confidence interval about the mean of 4,576 and 6,864 hours. The relatively large equipment population and operating time provide an MTBF that is considered to be representative of Fleet experience.

large equipment population and operating time provide an MTBF that is considered to be representative of Fleet experience.

The operational MTTR of 26.6 hours is also based on the mean of a substantial number of failure events (26), and this value is in the middle of the range of other MTTRs for centrifugal pumps of similar size determined for other systems in this study. Therefore, this MTTR is considered a good representation of Fleet experience of pumps of this type and service application.

10.2.1.2 Sea Water/Demineralized Water Heat Exchanger

Since there were no failures on these equipments, the operational MTBF of 73,000 hours must be considered no more than an educated conservative gues. Equipments of this type are normally designed for the life of the ship/system, which may be 10, 20, or 30 years. Therefore, the fact that there have been no failures in the short period during which these units have been in operation is not unreasonable, and it gives more validity to the 73,000-hour MTBF estimate.

No corrective maintenance actions were reported on the heat exchangers; therefore, no MTTR could be calculated.

10.2.2 Compare Operational and Specification R&M Values

The 5,720-hour MTBF for the pump-motor units used to represent the Fleet experience of pumps similar to the AEGIS Radar Cooling Pump is almost halfway between the Specification Goal and Minimum values of 8,500 hours and 4,250 hours, respectively. The operational MTBF of 5,720 hours is only half the value obtained for larger pumps in similar service, as represented by the 10,923-hour MTBF of the A/C Sea Water Circulating Pump shown in Table 4-3 of Section 4.2.1. This higher value can probably be attributed partly to the greater redundancy of the S.W. Circulating Pumps in A/C Chilled Water Systems, which permits more preventive maintenance flexibility than can be tolerated with the less redundant cooling systems. The higher MTBF may also result from the greater inherent reliability of the larger pump-motor units. The value of 5,720 hours is believed to be a good representation of the MTBF for the 300 GPM AEGIS Radar Cooling Pumps; however, it may not be as representative a value of the now larger (650 gpm) Cooling Coil and Miscellaneous Machinery S.W. Circulating Pump. In the case of both the AEGIS Radar Cooling Pump and the Cooling Coil and Miscellaneous Machinery S.W. Circulating Pump, the high Specification requirement of an 8,500-hour MTBF is desirable in view of the limited redundancy for the system pumps, which is provided only by the Firemain. The equipments are likely to be more costly with the higher MTBF value (8,500 hours) in the specification, than for similar equipments with a lower or no specification value, but for this system the mission-critical nature of the pumps warrant the higher reliability, and the 8,500-hour MTBF should remain in the Ship Specification.

The MTTR of 26.6 hours is three times the Specification goal value of 8.1 hours but, as discussed in Section 10.2.1.1, this operational value of 26.6 hours appears to be typical of pump-motor units of this size and type. The difference between the Specification MTTR and the operational value was discussed in detail in Chapter Three, Section 3.1.3. The conclusion reached was that a vendor can meet even a more stringent test value, e.g. the 4.0-hour MTTR requirement for the Motor Driven Firepumps, however, even the operational value for similar firepumps is eight times the Specification value. It is noted that no operational data have been obtained from the actual equipments used for this vendor maintainability demonstration, so that an exact correlation cannot be made. It appears that the Specification MTTR value of 8.1 hours is adequate to ensure at least as good an operational value as that being experienced.

10.2.3 Calculate System Reliability

The reliability block diagram and calculations showing the system reliability over a 60-day mission (approximate 1,500 hours) are presented in Appendix C, Figure C-7. The reliability of the Radar Cooling Pumps in series is only 60 percent over the 1,500-hour period. When the pumps are provided with a back-up by the firemain, the reliability of these components is increased to a 99.5 percent probability of mission success over the 1,500-hour period. The system reliability for the AEGIS Radar Sea Water Cooling portion of the system including the heat exchanger is a 97.92 percent probability of successfully completing the 60-day mission. This is equivalent to a system MTBF of 6,740 hours.

The reliability of the Sonar Cooling portion of the system is a slightly higher 97.94 percent, with the equivalent system MTBF of 8,047 hours.

10.2.4 Determine System Corrective Maintenance Man-Hour Burden

To compare the corrective maintenance man-hours based on operational history with the man-hours projected for corrective maintenance in the manning calculations, the two man-hour burden values were determined. The historic man-hour burden was calculated from the MDS data as discussed in Chapter Two, Section 2.3.4. The same data was used to represent both the AEGIS Radar Cooling Pump and the Cooling Coil and Miscellaneous Machinery S. W. Circulating Pump; thus the figures shown in Table 10-3 are identical for both pumps. No corrective maintenance man-hours were reported on the heat exchanger; therefore, no historic burden was determined.

The projected corrective-maintenance man-hour figures for this system were extracted from the CGN-42 AEGIS Cruiser *Preliminary Ship Manpower Document*. It is not clear from the manpower document which values were supposed to represent the Cooling Coil and Miscellaneous Machinery S.W. Circulating Pump. The uncertainty arises from the fact that the quantity of S.W. Cooling Pumps is listed as nine, whereas there are currently only three possible pumps designated in the MEL that fit this description. It was assumed that these nine pumps were intended to represent the three

Cooling Coil and Miscellaneous Machinery S.W. Circulating Pumps on CGN-42 (only one of which is required for this system). The annualized man-hour figures projected for the purpose of manning calculations are presented in Table 10-4.

Table 10-3. ANNUALIZED OPERATIONAL CORRECTIVE-MAINTENANCE MAN-HOUR BURDEN FOR THE SEA WATER COOLING FOR COMBAT SYSTEM

Component (Quantity per Ship)	Man-Hours per Equipment per Year	Man-Hours per Ship per Year
AEGIS Radar Cooling Pump (2)	21.9	43.8
Cooling Coil and Miscellaneous Machinery S.W. Circulating Pump (3)*	21.9	65.7
Annual System Total		109.5
**Only one required for this system.*		

Table 10-4. ANNUALIZED PROJECTED CORRECTIVE-MAINTENANCE MAN-HOURS FOR THE SEA WATER COOLING FOR COMBAT SYSTEM

Component (Quantity per Ship)	Man-Hours per Equipment per Year	Man-Hours per Ship per Year
Radar Cooling Pump (AEGIS) (2)	10.2	20.4
Pump Salt Water Cooling (9)*	5.8	52.9
Annual System Total		73.3
**Only one required for this system.*		

10.2.5 Compare Projected and Historic Corrective-Maintenance Man-Hours

A comparison of the two system totals shows a 30 percent deficit in the planned corrective maintenance on an annual basis, even with the total projected man-hours for the nine Salt Water Cooling Pumps included. The

results of this comparison for this system on a percentage basis lead to the assumption that there may be a manning deficiency in the work center responsible for maintenance of this system. Comparison of the actual total man-hour difference shows only a 36-hour deficit (roughly one man-week) over one year's time, which by itself is not significant. The problem with these values at the system level is that the impact of the difference -- either plus or minus -- should be assessed on a work center or shipwide basis, where the manning level or skill-mix situation could be a significant problem. Further study appears necessary to assess this impact for the work centers responsible for this system.

10.2.6 Determine Equipment Failure Categories

The failure categories for the Sea Water Circulating Pumps analyzed for this system are presented in Table D-11 of Appendix D. For the pump end, wearing rings were involved in 33 percent of the reported failures for the pump-motor unit, while motor bearings and grounded windings together accounted for another 30 percent of the unit failures. Neither the categories nor the percentage of failures are surprising from a logical engineering knowledge of the equipment and its operation. Design improvements in these areas for the average Sea Water Circulating Pump would be prohibitively expensive (e.g., the cost of acoustically better bearings for use on submarines is 10 to 15 times the cost of a standard bearing); however, to gain a potential 180 percent increase in the MTBF of the AEGIS Radar Cooling Pumps from a potential 64 percent reduction in failures, it may be necessary to perform a trade-off study of the cost of improving the pump bearings and wearing rings and motor windings versus the cost of adding redundant Radar Cooling Pumps. These design improvements also have the potential of a 66 percent reduction in the operational corrective-maintenance burden for these units.

10.3 RECOMMENDED CHANGES TO SYSTEM EQUIPMENT SPECIFICATION OR DESIGN

10.3.1 Specification Changes

No changes in the R&M specification values are recommended for the AEGIS Radar Cooling Pump. However, a reliability Demonstration Test should be required in the procurement of these pumps to ensure achievement of the required MTBF. The specification of improved quality bearings and wearing rings might produce a significant increase in reliability, which is desirable for these pumps. It is recommended that consideration be given to these design areas in the Ship Specification or in the R&M review of the shipbuilder procurements.

Because there are no specification R&M values for the Cooling Coil and Miscellaneous Machinery Sea Water Circulating Pump, the R&M values recommended for the AEGIS Radar Cooling Water Pump should also be specified for these pumps. These values are an MTBF of 8500 hours and an MTTR of 8.1 hours.

No other recommendations are warranted for this system at this time. A summary of the system recommendations is presented in Table 10-5.

Table 10-5. RECOMMENDED CHANGES IN SEA WATER COOLING FOR COMBAT SYSTEM

Specification			
System Equipment	MTBF	MTTR	Equipment Design/Support
AEGIS Radar Cooling Pump	Require Demonstration Test	No	Yes. Improve bearings, wearing rings, and motor windings.
Cooling Coil and Miscellaneous Machinery Sea Water Circulating Pump	Yes; 8500 hour goal	Yes; 8.1 hour goal	No

CHAPTER ELEVEN

COMPILATION OF SYSTEM RESULTS

11.1 R&M SPECIFICATIONS

Of a total of 32 equipments examined as part of the 7 distributive systems covered by this analysis, MTBF requirements were specified for only 9 equipments and MTTR requirements were specified for only 8 of those 9. These values are listed in Table 11-1. Analysis of the operational data for equipments similar to those projected for use on CGN-42 showed that three of the operational MTBFs were better than the specification goal values, while comparison of the other six operational values with the specified MTBFs showed them to be less than the goal but above the minimum specification values. Comparison of the operational MTTRs with the specified values showed seven out of eight MTTRs to be higher than even the maximum allowable specification values and one operational MTTR for the A/C Chilled Water Plant to be better (lower) than even the specification goal value.

There is a major difference between the operational and specified MTTRs in that the specification value is used to test the inherent maintainability of the equipment by a vendor demonstration while the operational value is the mean time to repair as reported by the Fleet. It was shown in the various equipment analyses that the MTTRs developed by using the Navy's Maintenance Data System (MDS) data are not suitable for use as R&M demonstration values in procurement specifications. Prior to such use, the MTTRs must be adjusted to account for: (1) the basic differences between Fleet failure reporting and the reporting of failures during Demonstration Testing, (2) a lower equipment knowledge and skill level by the sailor, (3) lack of proper tools, and (4) the corroded or frozen condition of the equipment fasteners in actual shipboard environment.

Analysis of these 32 equipments indicated that an MTBF value for one additional equipment and MTTRs for two additional equipments should also be specified in the Ship Specification. There was further indication that the values of five of the specified MTBFs and three of the specified MTTRs should be changed to reflect more accurately state-of-the-art improvements as demonstrated by the Fleet operational experience. Table 11-1 summarizes

Table 11-1. SUMMARY OF RECOMMENDED CHANGES TO SPECIFIED R&M VALUES

System/Equipment	Specification Values		Operational Values		Recommended Changes	
	MTBF (Hours)	MTTR (Hours)	MTBF (Hours)	MTTR (Hours)	MTBF (Hours)	MTTR (Hours)
A/C Chilled Water System						
A/C Chilled Water Plant	6600 goal 3300 minimum	24.6 goal 49.2 maximum	6,407	7.8	None	Change to: 12.5 goal
A/C Chilled Water Circulating Pump	4200 goal 2100 minimum	10.8 goal 21.6 maximum	15,957	31.1	Change to: 8000 goal	None
A/C Sea Water Circulating Pump	6600 goal 3300 minimum	7.1 goal 14.2 maximum	10,923	23.2	Change to: 8000 goal	None
Ventilation System	None	None			None	None
60 Hz Power Distribution System	None	None			None	None
400 Hz Power Distribution System	None	None			None	None
Electronic Dry Air System	None	None			None	None
L.P. Air Compressor	1000 minimum	None	4,359	17.1	Change to: 2820 goal	Add values: 4.0 goal
Type I Dehydrator	1000 minimum	5.0 maximum	5,071	35.6	Change to: 2000 goal	None
Type II Dehydrator	1000 minimum	5.0 maximum	6,300	7.5	Change to: 2000 goal	None
Firemain System						
Turbine Driven Firepump	2750 goal 1375 minimum	5.4 goal 10.8 maximum	1,927	20.0	None	None
Motor Driven Firepump	3000 goal 1500 minimum	4.0 goal 8.0 maximum	3,495	33.4	None	None
Sea Water Cooling for Combat System						
AEGIS Radar Cooling Pump	8500 goal 4250 minimum	8.1 goal 16.2 maximum	5,720	26.6	Add Demonstration Test	None
Cooling Coil and Miscellaneous Machinery Sea Water Pump	None	None			Add values: 8500 goal	Add values: 8.1 goal

the changes and additions to the R&M values of the CGN-42 Ship Specification as indicated by the various system analyses.

11.2 SHIP MANNING

Another aspect of the high MTTR values and CM man-hour burdens determined during the system analyses was the effect these values will have on the projected manning for this new ship class. It was verified that MTTR values as such are not used in the current method of calculating manning requirements. The high MTTRs will affect manning only if the corresponding equipment MTBF is low enough to cause a low system reliability. This could result in the occurrence of more failures than there are maintenance personnel available to make repairs, which would lead to a lower ship availability. To determine whether this condition exists or not, an RMA model which can accommodate manpower considerations should be exercised with the values of MTBF and MTTR developed in this study.

Investigation of the effect that significantly higher MTTRs and CM man-hour burdens would have on the manning level also led to a comparison of the projected system corrective-maintenance man-hour burden as used in the calculation of manning levels and skills to the reported burden for a similar system. Table 11-2 presents for the seven systems of this study, both the projected and reported (operational) corrective-maintenance burdens on an equipment, system, personnel rating, and overall basis. It can be seen that the percentages vary significantly from system to system and could have an effect on the projected quantities of the various personnel ratings involved.

A comparison of the total man-hours, both projected and operational, for all seven systems shows that the projected man-hours are 30 percent greater per year than the operational man-hours. This comparison could be misleading in several respects. First, 28 percent of the projected total consists of hours for nonrated personnel on elements of systems that could not be identified in the operational data. The total of 1040 hours projected for nonrated personnel amounts to 37 percent of all operational hours for all ratings. Second, if the hours for the rated persons only are compared, an overall shortage of 10 percent is observed in the projected man-hours; and for the Machinist Mate rate alone, there is a 19 percent deficit in the projected hours. Third, these seven systems represent only part of the corrective-maintenance workload of the several work centers involved. On an individual system basis, the percentage differences in projected versus operational man-hours go from a 100 percent overprojection to a 91 percent deficit in the projected hours, as shown in Table 11-3. Three of these systems -- ACCW, Dry Air, and S.W. Cooling for Combat -- are normally the responsibility of the same work center for corrective maintenance. This work center will be, on the average, 35 percent undermanned for the three systems. Further study of the manning projections for a total work center is necessary to determine precisely the impact of the projected-versus-operational-man-hour differences on both the manning level and skill mix being anticipated for the corrective maintenance.

Table 11-2. ANNUALIZED CORRECTIVE-MAINTENANCE MAN-HOUR BURDEN

System/Components	Man-Hours per Equipment per year			Man-Hours per Ship per Year	
	Number of Components	Projected	Operational	Projected	Operational
A/C Chilled Water System					
Chilled Water Plant	5	15.3	45.7	76.5	228.5
Chilled Water Circulating Pump*	5	7.3	8.7	36.5	43.5
Sea Water Circulating Pump*	5	17.0	29.3	85.0	146.5
Annual System Totals				198.0	418.5
Ventilation System					
Electrostatic Precipitators	45	3.36	10.8	151.2	486.0
Duct Cooling Coils	48	6.58	.1	315.8	4.8
Vaneaxial Fans	75	2.80	2.5	210.0	187.5
Fan Coil Units	42	2.80	2.5	117.6	105.0
Gravity Cooling Coils	20	.99	.1	19.8	2.0
Unit Coolers	8	2.80	1.0	22.4	8.0
Tubeaxial Fans	4	**	.6	**	2.4
Convection Heaters	33	.10	.1	8.3 (83)	3.3
Vent Duct Heaters (Steam)	124	3.24	**	401.8	**
Vent Duct Heaters (Electric)	10	.49	**	4.9	**
Annual System Totals				1251.8	799.0
60 Hz Power Distribution System					
Electrical Distribution	7	25.7	**	179.9	**
Distribution Panels	82	3.1	**	254.2	**
Annual System Totals				434.1	--
400 Hz Power Distribution System					
400 Hz Solid-State Frequency Converter	6	8.0	94.0	48.0	564.0
Annual System Total				48.0	564.0
Electronic Dry Air System					
L.P. Air Compressor	3	54.5	73.7	163.5	221.1
Type I Dehydrator	3	1.9	27.9	5.7	83.7
Type II Dehydrator	4	38.2	23.2	152.8	92.8
Dry Air System Dehydrator		55.9	**	279.5†	**
Annual System Total				322.0	397.6

**Pump end only.*
***No data reported or projected.*
†Not included in system total

Table 11-2. (Continued)

System/Components	Man-Hours per Equipment per year			Man-Hours per Ship per Year	
	Number of Components	Projected	Operational	Projected	Operational
Firemain System					
Turbine Driven Firepump and Turbine	2	47.6	69.0	95.2	138.0
Electric Driven Firepump (pump end only)	6	13.3	58.4	39.9(3)	350.4(6)
Firemain System	1	81.7	*	81.7	*
Water Washdown System	1	2.8	*	2.8	*
Gate Valves Electrically Operated	83	12.6	0.26	1045.8	21.6
Sea Water Reducing Valves	47	1.9	0.7	89.3	32.9
Annual System Totals				1345.7	542.9
Sea Water Cooling for Combat System					
AEGIS Radar Cooling Pump	2	10.2	21.9	20.4	43.8
Cooling Coil and Miscellaneous Machinery Sea Water Circulating Pump**	3	5.8	21.9	52.2(9)	65.7(3)
Annual System Total				72.6	109.5
Annual Totals of the Seven Distributive Systems Analyzed				3681.2	2831.5
Annual Corrective-Maintenance Man-Hour Totals by Rate					
Machinist Mate				846.9	1046.0
Engineman				431.1	460.6
Electrician Mate				1297.6	1352.1
Subtotal				2575.6	2858.7
Firemain Rate				1040.2	15.3

**Only one required for this system.*
***No data reported.*

Table 11-3. PERCENTAGE DIFFERENCES IN PROJECTED VERSUS OPERATIONAL CORRECTIVE-MAINTENANCE MAN-HOURS BY SYSTEM

System	Percent Greater, Projected	Percent Greater, Operational
A/C Chilled Water System	-	53
Ventilation System	36	-
60 Hz Power Distribution System	100	-
400 Hz Power Distribution System	-	91
Electronic Dry Air System	-	19
Firemain System	60	-
Sea Water Cooling for Combat System	-	34

11.3 R&M IMPROVEMENTS

Analysis of the failure categories of the system equipments presented in Appendix D resulted in the observation that six equipment MTBFs would be increased from 30 to 178 percent by elimination or reduction of the failures caused by selected failure categories. These six equipments are listed in Table 11-4, with an indication of the maximum potential effect of design improvements. For two of these equipments -- the general-purpose type Salt and Fresh Water Circulating Pumps used with the A/C Chilled Water Plant -- the cost of improving and maintain support for a more reliable design does not, by itself, appear warranted. For the other four equipments (Electrostatic Precipitators, Turbine and Motor Driven Firepumps, and AEGIS Radar Cooling Pump) the increase in equipment reliability plus the decrease in total corrective-maintenance burden possible through improved equipment design in the high-failure categories appear to warrant further investigation into a cost trade-off of these potential design improvements versus the reduced corrective-maintenance burden and increased MTBFs. The MTTR of these equipments may not actually improve as a result of improving the inherent reliability of the designs; however, the overall corrective-maintenance burden should be lower because of fewer failures.

Table 11-4. POTENTIAL EFFECTS OF EQUIPMENT R&M IMPROVEMENTS

Equipment	Maximum Potential Effect (Percentage Change) of Reduced Failure Categories on:		
	MTTR	MTBF	Total Corrective-Maintenance Burden
A/C Chilled Water Circulating Pump	+19	+100	-29
A/C Salt Water Circulating Pump	None	+100	-73
Electrostatic Precipitator Air Filter	None	+30	-10.5
Turbine Driven Firepump	None	+43	-28
Motor Driven Firepump	Slight (+)	+100	-44
AEGIS Radar Cooling Pump	None	+178	-66

CHAPTER TWELVE

CONCLUSIONS AND RECOMMENDATIONS

12.1 CONCLUSIONS

Analysis of the 32 major equipments of the 7 distributive systems indicates that an MTBF value for one additional equipment and MTTRs for two additional equipments should be specified in the Ship Specification. It is further concluded that five of the existing specified MTBF values and three of the specified MTTR values should be changed to make them more consistent with state-of-the-art improvements as demonstrated by Fleet operational experience. These changes were summarized in Table 11-1.

The values for MTTR developed by using the Navy's Maintnance Data System (MDS) data are generally much larger than the specified values and are not suitable for use as R&M demonstration values in procurement specifications. In addition, the effect of the high operational MTTRs on ship availability requires the exercising of a comprehensive RMA model.

From the calculation of very conservative system reliability values for the worst-case situations, it is concluded that the current system designs with the operational MTBFs will provide a relatively high probability of mission success (62 to 99 percent) over a 60-day mission period.

A study conducted at the work center level should permit determining precisely the extent to which the manning level or skill mix of the anticipated manning requirements for the CGN-42 Class will be affected by the differences in projected corrective-maintenance man-hours used for manning calculations and the historic corrective-maintenance man-hours for similar operational systems.

It is concluded that a cost-benefit trade-off analysis should be performed on the potential R&M design improvements for four equipments as indicated by the primary failure modes of these equipments. Table 11-4 summarized these equipments.

12.2 RECOMMENDATIONS

As a result of the analysis of the seven distributive systems, the following actions are recommended:

- One additional MTBF value and two additional MTTR values as listed in Table 11-1 should be specified in Section 076 and the appropriate system section of the Ship Specification.

- Five MTBF values and one MTTR value should be changed in the Ship Specification to the value listed in Table 11-1.

- A method should be developed for correlating operational MTTR values with the corresponding maintainability Demonstration Test values for mission-critical equipments.

- The Navy should exercise a large RMA model such as the TIGER model to determine the effect of the higher operational MTTR values on the ship availability.

- The projected corrective-maintenance man-hours used for manning calculations and the operational corrective-maintenance man-hours experienced on similar Fleet equipment should be reviewed for all the equipments that are the responsibility of a work center to determine if there is a significant problem with either the manning level or skill mix required to accomplish the anticipated corrective-maintenance burden.

- A cost-benefit trade-off analysis should be performed on the cost of the potential R&M design improvements of the Electrostatic Precipitator, Turbine and Motor Driven Firepumps, and AEGIS Radar Cooling Pump as compared with increased reliability and lower overall corrective-maintenance burden that could result from these improvements.

SOURCES OF INFORMATION

1. OPNAVINST C9010 (Classified), Nuclear Powered AEGIS Cruiser CGN-42 Top Level Requirements (U) dated 20 January 1978.

2. CGN-42 AEGIS NUCLEAR CRUISER SHIP SPECIFICATIONS, Volumes I through IV, dated 6 and 28 October 1977 and Issue 4, Volumes I through III, dated 5 July 1978.

3. MIL-STD-781C, 21 October 1977, Reliability Design Qualification and Production Acceptance Tests: Exponential Distribution.

4. MIL-STD-785A, 28 March 1969, Reliability Program for Systems and Equipment Development and Production.

5. MIL-STD-470, 21 March 1966, Maintainability Program Requirements (For Systems and Equipments).

6. AEGIS Guided Missile Nuclear Cruiser CGN-42 Class Master Equipment List (MEL), Issue 4, 24 April 1978.

7. AEGIS NUCLEAR GUIDED MISSILE CRUISER CGN-42 CLASS MAPPS/SCN Schedule "A," List of Government-furnished Equipment, Issue 1, dated 27 April 1978 (Preliminary).

8. Maintenance Support Office (MSO) Generation IV MDS Part and Maintenance Data from 1 January 1975 through 31 December 1977.

9. Type Commander's COSAL, SURFLANT & SURFPAC dated 1 December 1977.

10. NAVSEC MECH-DIV Fleet Equipment/Component Application Listing, dated 01/07/78.

11. NAVSEC RMA Design Data Bank Report, June 1975, Revision A.

12. Ship Design Manager CGN-42 Memorandum, NAVSEC Code 6113B2, Serial 32, dated 14 February 1978.

13. AEGIS Shipbuilding Notice No. 42-77 of October 13, 1977. Subject: CGN-42 AEGIS Nuclear Cruiser Design Guidance.

14. Development of Equipment Behavior Measures for Selected Equipments in the Propulsion Plant of DDG-2 Class Ships, ARINC Research Corporation, December 1974.

15. "AEGIS Impact on CGN-38 Non-Propulsion Piping Systems for CGN-42 Contract Design," by M. Rosenblatt & Sons, Inc.

16. CGN-42 AEGIS NUCLEAR CRUISER RMA STUDY, NAVSEC Report Number 6112B-037-78.

17. CGN-42 AEGIS CRUISER "Preliminary Ship Manpower Document," NAVSEC Report No. 6112F-022-78 of 1 September 1978.

18. Reliability Analysis of the AEGIS Mk 84 Solid-State Frequency Converter 19 kHz Power Supply by Lt. Carl W. Rosengrant.

19. Third Interim Mk 84 Operational Performance Report dated 15 October 1977 by R.H. Wheelock and L.N. Sunding, NSWSES, Port Hueneme, California 93403.

20. Long-Term Evaluation of a Worthington Class S, 100 SCFM, 125 PSIG, Oil-Free Air Compressor; Commander David W. Taylor, Naval Ship R&D Center, Ltr. Ser. 2745:JRB,9551,TM-27-77-84, dated 24 January 1978.

21. NAVSEC 6154E Dry Air System Improvement Program, as of March 1978.

APPENDIX A

SYSTEM CONFIGURATION DIAGRAMS

Figures A-1 through A-7 are simplified system configuration diagrams for the seven distributive systems discussed in this report.

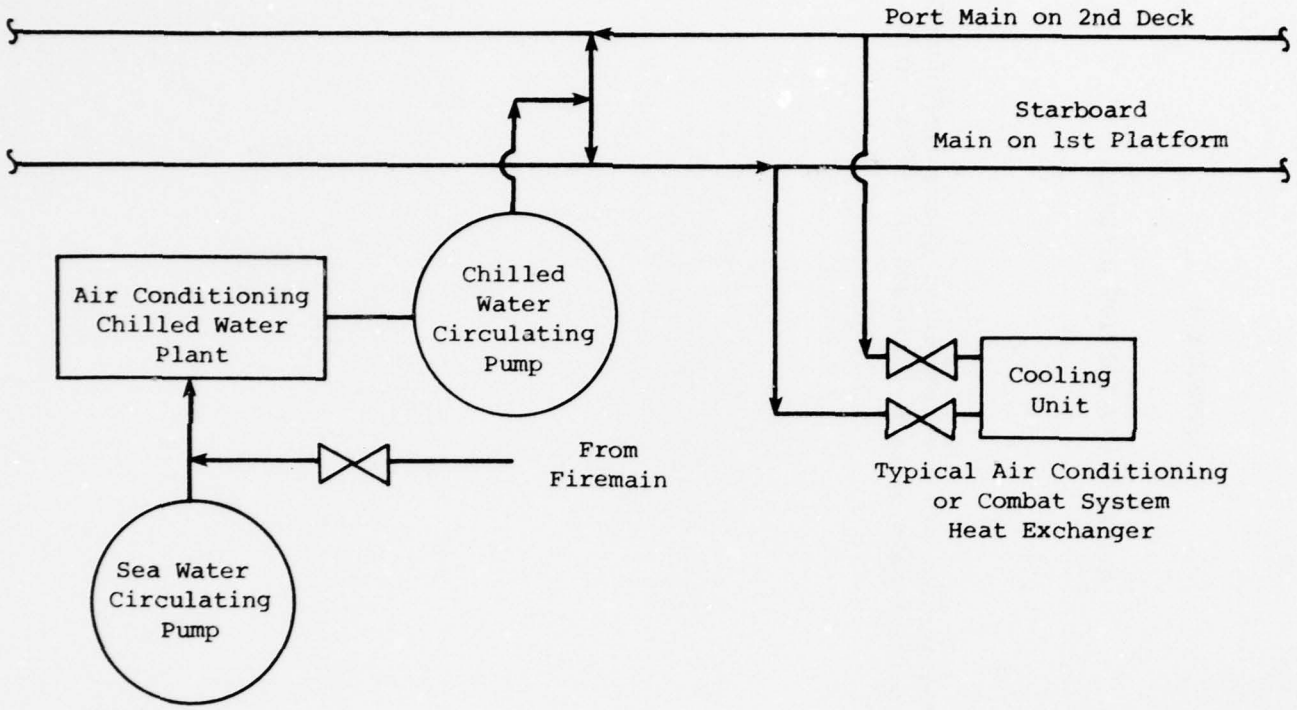


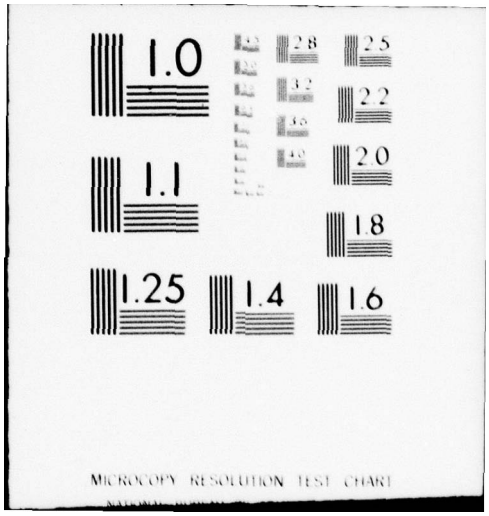
Figure A-1. AIR CONDITIONING CHILLED WATER SYSTEM: TYPICAL ARRANGEMENT FOR COMBAT SYSTEM

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CGN-42 HM AND E EQUIPMENT R AND M STUDY,(U)
JAN 79 E J LUTZ, B W AVERYT N00140-77-D-0417
UNCLASSIFIED 1839-01-1-1861 NL

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MICROCOPY RESOLUTION TEST CHART

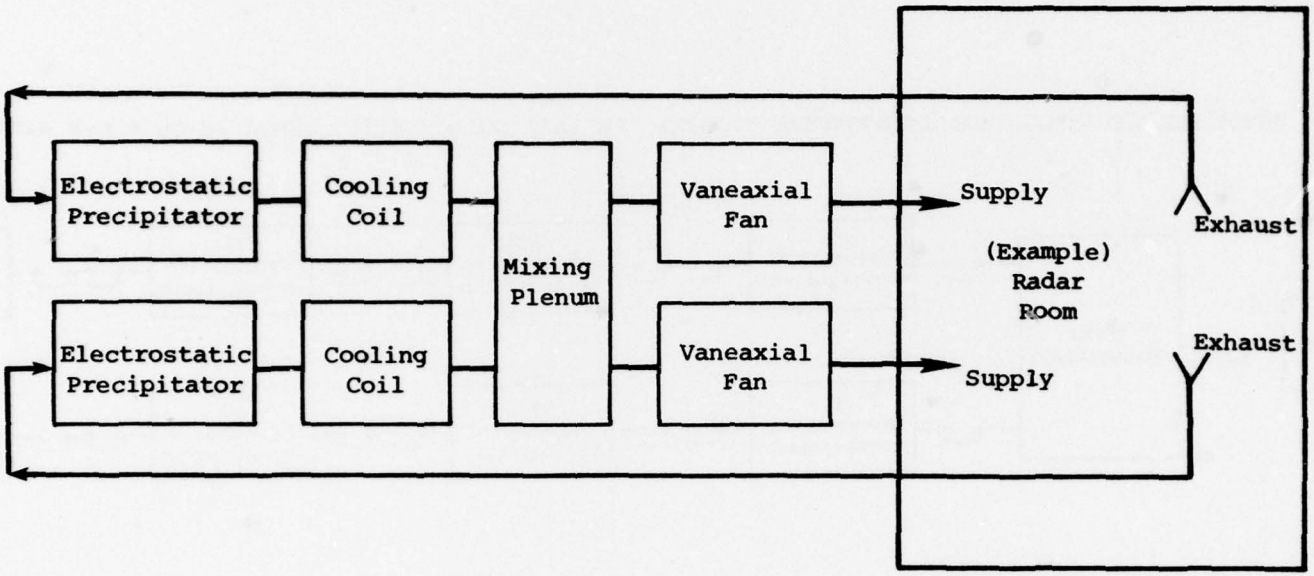


Figure A-2. TYPICAL VENTILATION SYSTEM ARRANGEMENT FOR COMBAT SPACES

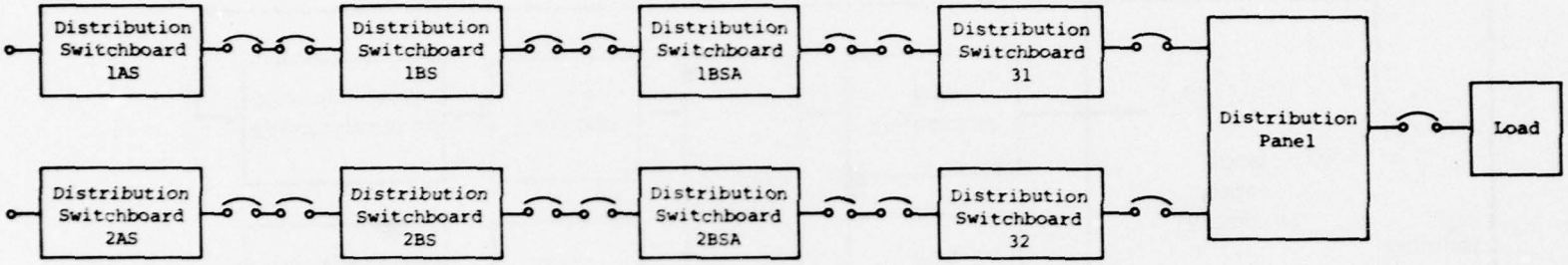


Figure A-3. 60 Hz POWER DISTRIBUTION SYSTEM: TYPICAL ARRANGEMENT FOR COMBAT SYSTEM LOADS

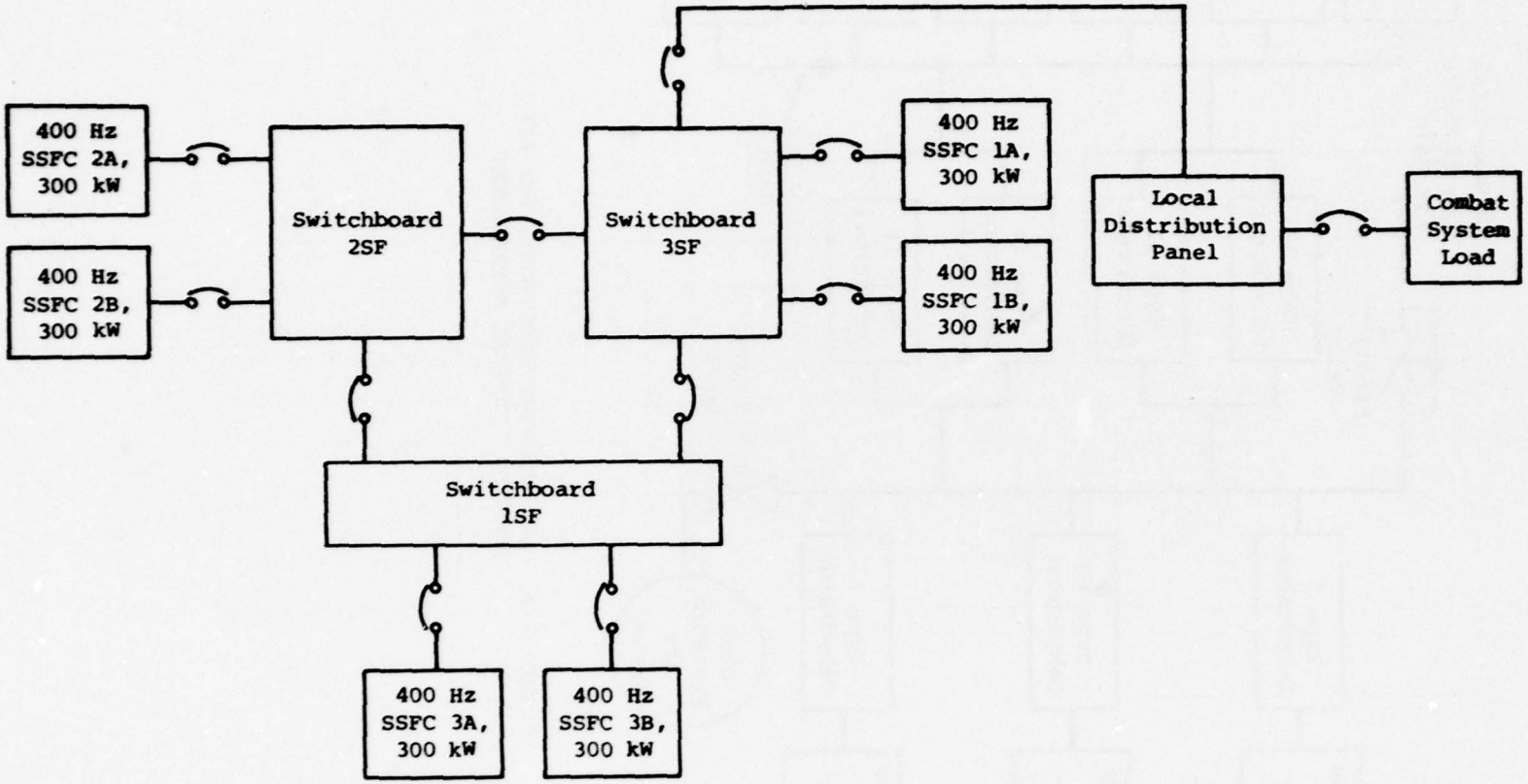


Figure A-4. 400 Hz POWER DISTRIBUTION SYSTEM CONFIGURATION

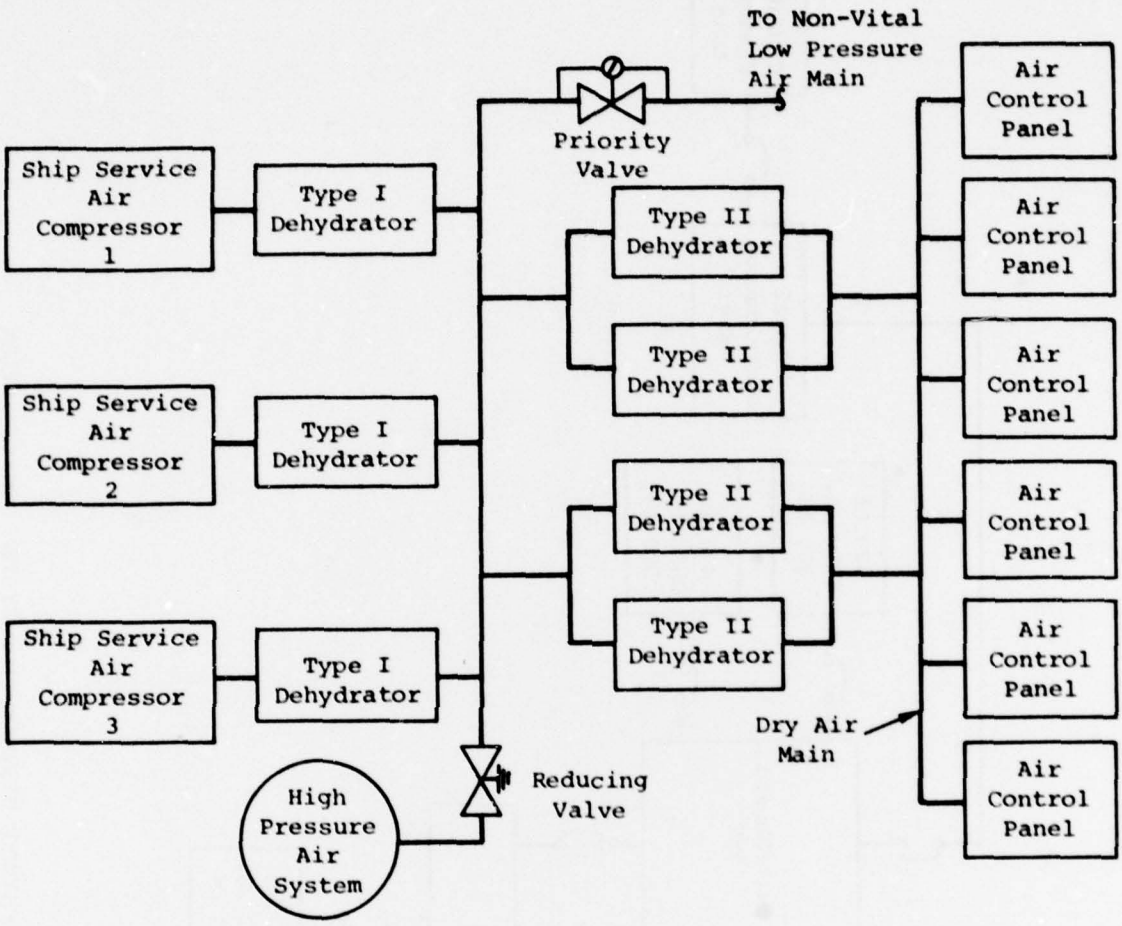


Figure A-5. LOW PRESSURE/ELECTRONIC DRY AIR SYSTEM: TYPICAL ARRANGEMENT

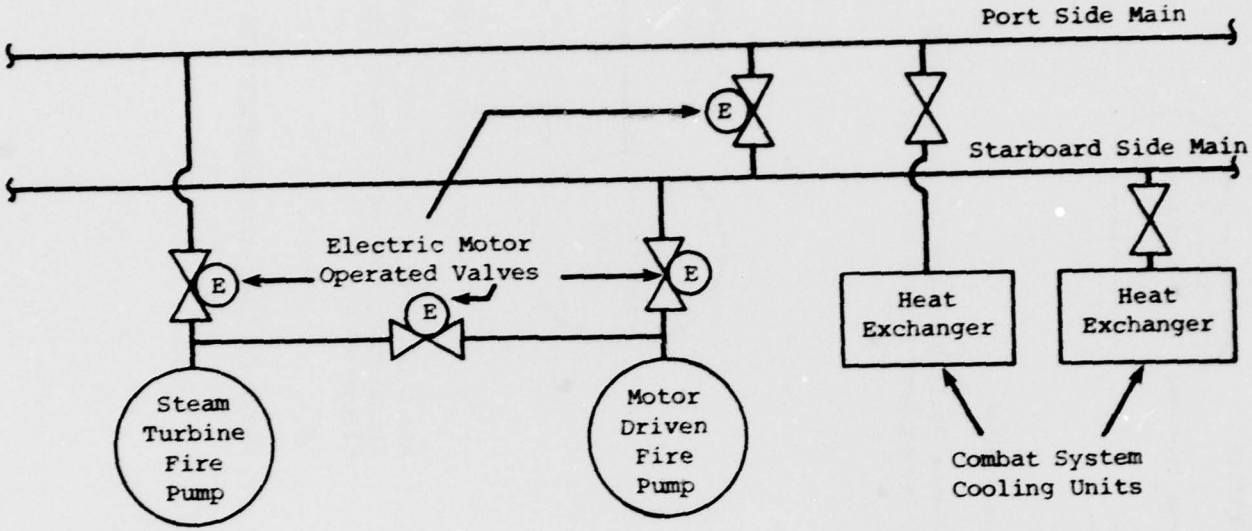
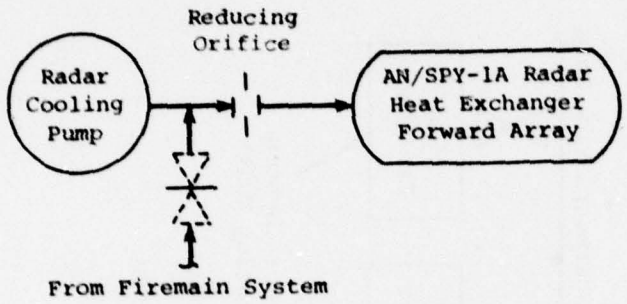
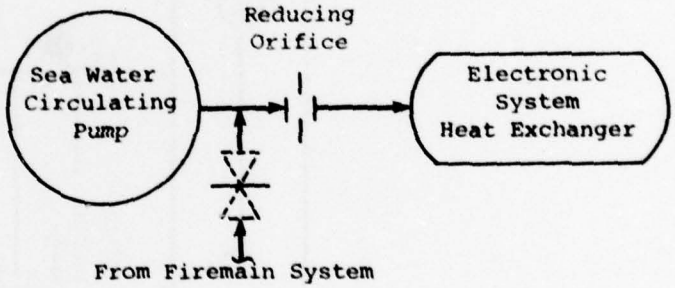


Figure A-6. TYPICAL FIREMAIN SYSTEM ARRANGEMENT FOR COMBAT SYSTEM SUPPORT



AN/SPY-1A Radar Sea Water Cooling System for the Forward Array. An Identical Arrangement Serves the Aft Array.



Air Conditioning and Miscellaneous Machinery Sea Water Circulating Pump as It Serves the AN/SQS-53 Sonar Electronics.

Figure A-7. TYPICAL SEA WATER COOLING ARRANGEMENTS FOR COMBAT SYSTEM SUPPORT

APPENDIX B

RELIABILITY AND MAINTAINABILITY DATA SHEETS

1. INTRODUCTION

Sections 2 through 6 of this appendix provide a detailed explanation of the type of information gathered on each equipment and definitions of the R&M indices calculated from this information.

The actual R&M Data Sheets for the major equipments of the Seven Distributive Systems follow Section Six:

System	Page Numbers
Air Conditioning Chilled Water System	B-4 through B-17
Ventilation System	B-18 through B-37
60 Hz Power Distribution System	B-38 through B-45
400 Hz Power Distribution System	B-46 through B-47
Electronic Dry Air System	B-48 through B-51
Firemain System	B-52 through B-61
Sea Water Cooling for Combat Systems	B-62 through B-65

2. IDENTIFICATION

Equipment identifiers are as follows:

- Noun Name. The service-application description assigned to the equipments as taken from the Equipment Identification Code (EIC) directory.

- Equipment Identification Code. The first four digits of the Equipment Identification Code (EIC), as taken from the EIC Directory, used to code the equipment in reporting maintenance data.

- CID/APL Number(s). The Component Identification (CID) Number/Allowance Part List (APL) Number assigned to the specific equipment. In the case of a system comprising many CID/APLs, or a generic group being used to approximate one set of values, the CID/APL numbers are listed on the second page of the data sheet.

- Manufacturer. The manufacturer of the equipment as identified by the CID/APL number.

- MILSPEC. The military specification (MIL-SPEC), as identified by the CID/APL number, under which the equipment was produced.

3. BASIC DATA

The following basic data elements were used in developing the R&M indices:

Ship Population. The specific hull designations or numbers of the ships on which the equipment is located, as identified by the NAVSEC Mech-Div Fleet Equipment/Component Listing for the appropriate noun name, CID/APL number, and service application.

Equipment Population/Ship. The number of units on each ship as listed in the NAVSEC Mech-Div Fleet Equipment Component listing for the appropriate noun name, CID/APL number, and service application.

Total Equipment Population in Data Base. The total number of equipments in the ship population that constitute the data base for each CID/APL.

Data-Assessment Period. The period of time comprising the data period: beginning month/year - ending month/year - number of months.

Utilization Factors. Required for equipments that do not have individually reported operating time. The factor is the ratio of the equipment's operating time to some other known time base such as ship steaming hours, clock hours, or calendar hours. The Application Code preceding the utilization factor indicates what time base is being used:

Application Code	Related Time Base
S	Steaming Hours
H	Calendar/Clock Hours

4. RELIABILITY INDICES

The following data were used in developing the reliability indices:

Total Number of Failures. The occurrence of any unsatisfactory operation of an equipment that results in the equipment's forced shutdown, failure to start up, or reduced operating capability. The total number of failures for a design application is derived by summing the individual failures of the equipments on the ships being used to develop the reliability index.

Total Equipment Operation Time. The total time all equipments selected within the design category operated during the data assessment period. The method of computing this time is discussed in Chapter Two, Section 2.3.2.

Mean Time Between Failures (MTBF). The average equipment operating time between corrective maintenance events resulting from reduced capability or forced equipment shutdowns, i.e. failures. The 90-percent confidence interval will be based on the assumption that the time between failures follows an exponential distribution.

5. MAINTAINABILITY INDICES

The following data were used in developing the Maintainability Indices:

Total Number of Failures. This number is derived in the same manner. as set forth in Section 4 above. This total number of failures may differ from the total number of failures used in determining MTBF because of the elimination of those failure events for which the repair man-hours information was incomplete, i.e., a maintenance action was not closed out.

Total Reduced Capability or Forced Shutdown Corrective Maintenance Repair Man-Hours. The total number of man-hours required to repair failures -- obtained by summing only those maintenance man-hours resulting from corrective-maintenance events due to equipment failures.

Maximum Observed Man-Hours. The highest reported value of all corrective-maintenance-event man-hours.

Mean Corrective-Maintenance Man-Hours. The average man-hours to perform all corrective maintenance events.

Maintenance Factor. A ratio of men to maintenance events that has been derived from Fleet survey and data analysis for some equipments--used to convert equipment maintenance man-hours to active maintenance time. In this study a factor of 0.67 is used.

Mean Time to Repair (MTTR). Mean time to repair an equipment malfunction that resulted in a reduced capability or a forced equipment shutdown. The index is an average of the hours of active maintenance required to repair an equipment failure; it does not include logistics or administrative time.

Standard Deviation. The standard deviation of the failure/corrective-maintenance event man-hours -- included to indicate dispersion of the individual values about the mean value.

Variance. The variance of the failure/corrective-maintenance event man-hours -- included to indicate the concentration of the individual values about the mean value.

6. CONTINUATION SHEET

The second page of the data sheet and a third page where necessary is utilized in those cases where more than one CID/APL is included in determining the index. This format shows selected items from the Equipment Identification and Basic Data selections in tabular form, recording all pertinent information for each applicable CID/APL.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: AIR CONDITIONING/R-114 CHILLED WATER PLANT/300 TON

Equipment Identification Code: T40S

Manufacturer: York Div. of Borg-Warner

CID/APL Number(s): *

MIL Specification: MIL-R-24085A

Basic Data

Ship Population: LHA 1,2

Equipment Population per Ship: 4

Equipment Population in Data Base: 8

Data Assessment Period: 1/75-12/77

Utilization Factors: S; A=7.5 B=.5 C=.25

Reliability Indices

Total Number of Failures: 19

Mean Time Between Failures (MTBF): 1446

Total Equipment Operating Time (hours): 27472

90% Confidence Interval

Upper Limit: 2209

Lower Limit: 1030

Maintainability Indices

Total Number of Failures: 12

Mean Time to Repair (MTTR): 7.4

Total Corrective Maintenance Repair Man-Hours: 133

Mean Corrective Maintenance Man-Hours: 11.08

Maintenance Factor: .67

Maximum Observed Man-Hours: 36

Standard Deviation: 11.18

Variance: 125.2

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: AIR CONDITIONING/R-114 CHILLED WATER PLANT/300 TON

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
REFRIGERATION PLANT	325010383	300 TON	LHA 1,2	4	8	.75	.5	.25
CONDENSER	043020281	1350 GPM						
COMPRESSOR	060950215							
COMPRESSOR MOTOR	174031473	300 HP						
COOLER	030080592	5.35 Sq. Ft.						
COMPRESSOR STARTER MOTOR	151406663	SZ 6						
DEHYDRATOR	325060158							
PURGE UNIT	327020030							
P.U. COMPRESSOR	060950197							
P.U. MOTOR	174752873	2 HP						
P.U. DEHYDRATOR	325060004							
AUX. OIL PUMP	017210092	3GPM/85PSI						

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: AIR CONDITIONING, R-114 CHILLED WATER PLANT/200 TON

Equipment Identification Code: T40S

Manufacturer: York Div. of Borg-Warner

CID/APL Number(s): *

MIL Specification: MIL-R-24085A

Basic Data

Ship Population: CGN 38,39

Equipment Population per Ship: 4

Equipment Population in Data Base: 8

Data Assessment Period: 1/75-12/77

Utilization Factors: S; A=.75 B=.5 C=.25

Reliability Indices

Total Number of Failures: 5

Mean Time Between Failures (MTBF): 4380

Total Equipment Operating Time (hours): 21902

90% Confidence Interval

Upper Limit: 11126

Lower Limit: 2387

Maintainability Indices

Total Number of Failures: 3

Mean Time to Repair (MTTR): 27.0

Total Corrective Maintenance Repair Man-Hours: 121

Mean Corrective Maintenance Man-Hours: 40.3

Maintenance Factor: .167

Maximum Observed Man-Hours: 98

Standard Deviation: 50.8

Variance: 2,580.6

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: AIR CONDITIONING/R-114 CHILLED WATER PLANT/200 TON

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
REFRIGERATION PLANT	325010402/3	200 TON	CGN 38,39	4	8	.75	.5	.25
CONDENSER	043020301/2							
COMPRESSOR	060950197							
COOLER	030080592	5.35 Sq. Ft.						
COMPRESSOR MOTOR	174342387	250 HP						
COMPRESSOR STARTER MOTOR	151406546	SZ 1						
DEHYDRATOR	325060166							
PURGE UNIT	327020032							
P.U. COMPRESSOR	060950227							
P.U. MOTOR	174753541	2 HP						
P.U. DEHYDRATOR	325060160							
AUX OIL PUMP	017210092	3GPM/85 PSI						

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: AIR CONDITIONING, R-114 CHILLED WATER PLANT/175 TON

Equipment Identification Code: T40S

Manufacturer: York Div. of Borg-Warner

CID/APL Number(s): *

MIL Specification: MIL-R-24085A

Basic Data

Ship Population: SSBN 640-645,654-658

Equipment Population per Ship: 2

Equipment Population in Data Base: 22

Data Assessment Period: 1/75-12/77

Utilization Factors: S; A=.35 B=.5 C=.5

Reliability Indices

Total Number of Failures: 30

Mean Time Between Failures (MTBF): 6407

Total Equipment Operating Time (hours): 192210

90% Confidence Interval

Upper Limit: 9290

Lower Limit: 4485

Maintainability Indices

Total Number of Failures: 18

Mean Time to Repair (MTTR): 7.8

Total Corrective Maintenance Repair Man-Hours: 209

Mean Corrective Maintenance Man-Hours: 11.6

Maintenance Factor: .67

Maximum Observed Man-Hours: 37

Standard Deviation: 5.7

Variance: 32.5

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: AIR CONDITIONING, R-114 CHILLED WATER PLANT/175 TON

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
REFRIGERATION PLANT	325010380	175 TON	11 SSBN	2	22	.35	.5	.5
CONDENSER	043027000/1							
COMPRESSOR	060950213							
COOLER	036080592	5.35 Sq. Ft.						
COMPRESSOR STARTER MOTOR	151209264	SZ 5						
DEHYDRATOR	325060174							
PURGE UNIT	327020025							
P.U. COMPRESSOR	060950197							
P.U. MOTOR	174752466	2 HP						
P.U. DEHYDRATOR	325060160							
AUX. OIL PUMP	017210092	36PM/85PSI						

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: AIR CONDITIONING, R-114 CHILLED WATER PLANT/150 TON

Equipment Identification Code: T40S

Manufacturer: York Div. of Borg-Warner

CID/APL Number(s): *

MIL Specification: MIL-R-24085A

Basic Data

Ship Population: DD963-970

Equipment Population per Ship: 3

Equipment Population in Data Base: 24

Data Assessment Period: 1/75-12/77

Utilization Factors: S; A=.83 B=.5 C=.33

Reliability Indices

Total Number of Failures: 22

Mean Time Between Failures (MTBF): 5360

Total Equipment Operating Time (hours): 117918

90% Confidence Interval

Upper Limit: 8842

Lower Limit: 3203

Maintainability Indices

Total Number of Failures: 12

Mean Time to Repair (MTTR): 10.7

Total Corrective Maintenance Repair Man-Hours: 192

Mean Corrective Maintenance Man-Hours: 16.0

Maintenance Factor: .67

Maximum Observed Man-Hours: 81

Standard Deviation: 21.7

Variance: 470.9

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: AIR CONDITIONING/R-114 CHILLED WATER PLANT/150 TON

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
REFRIGERATION PLANT	325010399	150 TON	DD963-DD970	3	24	.83	.5	.33
CONDENSER	043020295							
COMPRESSOR	0609502246							
COMPRESSOR MOTOR	174342378	194 HP						
COMPRESSOR STARTER MOTOR	151406753	SZ 6						
DEHYDRATOR	325060166							
PURGE UNIT	327020031							
P.U. COMPRESSOR	060950223							
P.U. MOTOR	174752873	2 HP						
P.U. DEHYDRATOR	325060004							
AUX. OIL PUMP	017210092	36PM/85 PSI						

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: PUMP, CHILLED WATER, CIRCULATING, AIR CONDITIONING PLANT

Equipment Identification Code: T400

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: VARIOUS

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 255

Data Assessment Period: 1/75-12/77

Utilization Factors: *

Reliability Indices

Total Number of Failures: 177

Mean Time Between Failures (MTBF): 15957

Total Equipment Operating Time (hours): 2824348

90% Confidence Interval

Upper Limit: 18351

Lower Limit: 13563

Maintainability Indices

Total Number of Failures: 82

Mean Time to Repair (MTTR): 31.1

Total Corrective Maintenance Repair Man-Hours: 3805

Mean Corrective Maintenance Man-Hours: 46.4

Maintenance Factor: .67

Maximum Observed Man-Hours: 235

Standard Deviation: 35.1

Variance: 1232

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: PUMP, CHILLED WATER CIRCULATING, AIR CONDITIONING PLANT

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
PUMP, CENTRIFUGAL	017900026	GPM/PSI 80/50	12DD	4	48	.75	.5	.25
	016110119	175/55	7CG	3	21	.8	.6	.4
	016120348	180/72	2CG	2	4	.8	.6	.4
	016120353	180/72	5CG	2	10	.8	.6	.4
	016031670	200/70	6AOR	4	24	.75	.5	.25
	0160311652	220/70	8AE	4	32	.75	.5	.25
	016060399	220/75	2LPD	4	8	.75	.5	.25
	017030124	225/75	3LPD	4	12	.75	.5	.25
	016110408	296/75	2LPD	4	8	.75	.5	.25
	016110448	300/75	5LSD	4	20	.75	.5	.25
	016020937	350/70	9DDG	4	36	.75	.5	.25
	017030270/1	675/60	2CGN	4	8	.75	.5	.25
	016031566	700/85	2AD	3	6	.83	.67	.4
	016060360	720/75	2LCC	5	10	.8	.6	.4
	016032367/8	900/60	2CGN	4	8	.75	.5	.25
MOTOR, 440 VAC	174750358	7.5 HP	12DD	4	48	.75	.5	.25
	174750583	15 HP	7CG	3	21	.8	.6	.4
	175504203	15 HP	7CG	2	14	.75	.5	.25
	174752515	15 HP	6AOR	4	24	.75	.5	.25
	174751868	15 HP	8AE	4	32	.75	.5	.25
	175503708	20 HP	2LPD	4	8	.75	.5	.25
	175503793	25 HP	3LPD	3	12	.75	.5	.25
	175504192	20 HP	2LPD	4	8	.75	.5	.25
	175504050	20 HP	5LSD	4	20	.75	.5	.25

Remarks: Pumps are listed in order of increasing capacity. Motors are listed in the same order as its associated pump.

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: PUMP, CHILLED WATER CIRCULATING, AIR CONDITIONING PLANT (Page II)

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
	174751198	25 HP	9DDG	4	36	.75	.5	.25
	174342430	50 HP	2CGN	1	2	.75	.5	.25
	175504598	50 HP	2CGN	3	6	.75	.5	.25
	174752907	50 HP	2CGN	1	2	.75	.5	.25
	174751789	50 HP	2AD	3	6	.83	.65	.5
	174750719	50 HP	2LCC	5	10	.8	.6	.4
	174753447/8	50 HP	2CGN	3	6	.75	.5	.25

Remarks: _____

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RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: PUMP, S.W. CIRCULATING, AIR CONDITIONING PLANT

Equipment Identification Code: T400

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: VARIOUS

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 140

Data Assessment Period: 1/75-12/77

Utilization Factors: *

Reliability Indices

Total Number of Failures: 188

Mean Time Between Failures (MTBF): 10923

Total Equipment Operating Time (hours): 2053477

90% Confidence Interval

Upper Limit: 12561

Lower Limit: 9285

Maintainability Indices

Total Number of Failures: 91

Mean Time to Repair (MTTR): 23.2

Total Corrective Maintenance Repair Man-Hours: 3158

Mean Corrective Maintenance Man-Hours: 34.7

Maintenance Factor: .67

Maximum Observed Man-Hours: 140

Standard Deviation: 29.6

Variance: 879.1

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: PUMP, S.W. CIRCULATING, AIR CONDITIONING PLANT

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
		GPM/PSI						
PUMP, CENTRIFUGAL	017900030	250/34	12DD	2	24	1.0	.5	.5
	016031671	450/30	6AOR	2	12	1.0	.5	.5
	016060147	550/50	4CG	2	8	1.0	.75	.5
	016031628	600/30	8AE	2	16	1.0	.5	.5
	017030268/9	600/35	2CGN	4	8	.75	.5	.25
	016032373	625/25	2CGN	3	6	.75	.5	.25
	016032391	625/25	2CGN	1	2	.75	.5	.25
	016060354	650/35	2LCC	5	10	.8	.6	.4
	016110447	650/40	5LSD	2	10	1.0	.5	.5
	016020938	750/50	3CG	2	6	1.0	.75	.5
	016110407	800/50	5LPD	2	10	1.0	.5	.5
	017030123	800/50	2LPD	2	4	1.0	.5	.5
	016020936	800/50	9DDG	2	18	1.0	.5	.5
	016031618	1100/25	2AD	3	6	.83	.67	.5
MOTOR, 440 VAC	174740358	7.5 HP	12DD	2	24	1.0	.5	.5
	174752203	15 HP	6AOR	2	12	1.0	.5	.5
	174750217	25 HP	7CG	1	7	1.0	.75	.5
	174751760	30 HP	7CG	1	7	1.0	.75	.5
	174752116	20 HP	8AE	2	16	1.0	.5	.5
	174753460	25 HP	2CGN	1	2	.75	.5	.25
	174753442	25 HP	2CGN	2	4	.75	.5	.25
	174342437	25 HP	2CGN	1	2	.75	.5	.25
	174752898	25 HP	2CGN	1	2	.75	.5	.25
	175504600	25 HP	2CGN	2	4	.75	.5	.25
	175504627	25 HP	2CGN	1	2	.75	.5	.25
	174752486	20 HP	2LCC	5	10	.8	.6	.4
	175504049	25 HP	5LSD	2	10	1.0	.5	.5
	175503631	50 HP	7LPD	2	14	1.0	.5	.5
	174752038	40 HP	4DDG	2	8	1.0	.5	.5
	174752933	40 HP	5DDG	2	10	1.0	.5	.5
	174752083	25 HP	2AD	3	6	.83	.67	.5

Remarks: Pumps are listed according to increasing capacity. Motors are listed in the same order as their associated pump.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: ELECTROSTATIC PRECIPITATOR AIR FILTER

Equipment Identification Code: T400

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-F-22963A

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 491

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 570

Mean Time Between Failures (MTBF): 16978

Total Equipment Operating Time (hours): 9677610

90% Confidence Interval

Upper Limit: 18676

Lower Limit: 15280

Maintainability Indices

Total Number of Failures: 213

Mean Time to Repair (MTTR): 18.6

Total Corrective Maintenance Repair Man-Hours: 5921

Mean Corrective Maintenance Man-Hours: 27.8

Maintenance Factor: .67

Maximum Observed Man-Hours: 184

Standard Deviation:

Variance:

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: ELECTROSTATIC PRECIPITATOR AIR FILTER

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
		VAC/KV DC INPUT/OUTPUT		(AVG)				
POWER SUPPLY	111800010	115/14	38	5	195	1.0	1.0	1.0
	111800011	115/14	35	1	35			
	111940008	115/12	28	6	175			
	111940011		18	2	35			
	111940012		10	2	21			
	111940013		8	1	10			
	111940014		23	4	97			
	111940015		34	2	58			
	111940017		3	1	5			
AIR FILTER	480720001	30D144-95	36	3	118			
	480720005	23D50-85	7	1	8			
	480720007	40D72-85	5	1	5			
	480720009	20T115-95	5	1	5			
	480720027	BM11377	35	1	35			
	480720028	BM11378	37	2	81			
	480720029	BM11379	35	1	35			
	480720030	BM11380	35	1	35			
	480720031	BM11381	36	1	37			
	480790015	37-8969	27	4	108			
	480790016	37-8970	23	1	36			
	480790017	37-8971	17	1	17			
	480790018	37-8972	20	1	20			
	480790019	37-8973	18	1	18			
	480790024	DWG-9152-1	7	1	8			
	480790025	DWG-9153	8	1	8			
	480790027	DWG-9144	10	1	10			
	480790028	DWG-9145	21	4	90			

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: FAN, VANEAXIAL

Equipment Identification Code: T30B

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-F-18953

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 5285

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 761

Mean Time Between Failures (MTBF): 93,000

Total Equipment Operating Time (hours): 70758900

90% Confidence Interval

Upper Limit: 102,000

Lower Limit: 83,700

Maintainability Indices

Total Number of Failures: 238

Mean Time to Repair (MTTR): 35.4

Total Corrective Maintenance Repair Man-Hours: 12566

Mean Corrective Maintenance Man-Hours: 52.8

Maintenance Factor: .67

Maximum Observed Man-Hours: 331

Standard Deviation:

Variance:

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: FAN, VANEAXIAL

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
FAN, VANEAXIAL	400090118	A 1/4	76	2	156	.6	.6	.6
	400090362	A 1/2	119	4	450			
	400090240	A 1	161	5	775			
	400090260	A 2	160	4	635			
	400090192	A 3	28	7	196			
	400090191	A 4	18	1	18			
	400090238	A 5	95	9	852			
	400090204	A 6	109	5	502			
	400090117	A 7	6	3	20			
	400090259	A 8	32	4	55			
	400090213	A 10	109	5	554			
	400090276	A 11	6	2	12			
	400090233	A 12	63	2	113			
MOTOR, 440 VAC	174660535	1 HP	195	5	921			
	174751510	7.5/3 HP	124	5	578			
	174660625	1.25 HP	158	4	599			
	174751648	10/3 HP	75	2	149			
	174720187	.2 HP	95	3	251			
	174660615	1.5 HP	203	4	872			
	174751623	17.5/5.25 HP	62	3	208			
	174720654	3/1.3 HP	42	6	238			
	174751729	4/1.25 HP	114	8	906			
	174751516	5/1.5 HP	118	4	527			
	174750745	7.5/1.9 HP	12	4	42			
	174751985	6/1.8 HP	36	2	63			
	174752667	6/1.8 HP	8	2	16			
	174752020	7.5/3 HP	3	5	15			

Remarks: Fans are listed in order of increasing capacity. Fan motors are listed in the same order as their associated fan. Motors having two horsepower figures are two-speed motors.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: FAN, TUBEAXIAL

Equipment Identification Code: T30D

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-F-18953

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 173

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=.6 B=.6 C=.6

Reliability Indices

Total Number of Failures: 24

Mean Time Between Failures (MTBF): 95,000

Total Equipment Operating Time (hours): 2273220

90% Confidence Interval

Upper Limit: 152,000

Lower Limit: 66,500

Maintainability Indices

Total Number of Failures: 15

Mean Time to Repair (MTTR): 8.6

Total Corrective Maintenance Repair Man-Hours: 194

Mean Corrective Maintenance Man-Hours: 12.9

Maintenance Factor: .67

Maximum Observed Man-Hours: 49

Standard Deviation:

Variance:

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: FAN, TUBEAXIAL

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
FAN, TUBEAXIAL	400090187	500 cfm	12	4	50	.6	.6	.6
	400090170	500 cfm	2	2	3			
	400090125	500 cfm	40	2	74			
	400090355	1000 cfm	5	3	15			
	400560169	2000 cfm	2	16	31			
MOTOR, 440 VAC	174700098	.066 HP	14	10	136			
	174700089	.066 HP	1	2	2			
	174700105	.066 HP	42	2	79			
	174700067	.125 HP	3	2	5			
	174720608	.25 HP	2	15	31			

Remarks: Fans are listed in order of increasing capacity. Fan motors are listed in the same order as their associated fan.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: FAN COIL UNIT

Equipment Identification Code: T300

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-A-23798

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 218

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=.6 B=.6 C=.6

Reliability Indices

Total Number of Failures: 31

Mean Time Between Failures (MTBF): 93,000

Total Equipment Operating Time (hours): 2864520

90% Confidence Interval

Upper Limit: 102,000

Lower Limit: 83,700

Maintainability Indices

Total Number of Failures: 238

Mean Time to Repair (MTTR): 35.4

Total Corrective Maintenance Repair Man-Hours: 12566

Mean Corrective Maintenance Man-Hours: 52.8

Maintenance Factor: .67

Maximum Observed Man-Hours: 331

Standard Deviation:

Variance:

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: Fan Coil Unit

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
Air Flow Unit Cooler	326040114	3.0	10	3	33	.6	.6	.6
	326040115	5.0	2	26				
	326040116	7.0	10	3	30			
	326040117	10.0	9	1	13			
	326040118	15.0	9	2	17			
	326040234	3.0	3	3	9			
	326040235	5.0	3	8	24			
	326040236	7.5	7	11	33			
	326040237	10.0	3	7	21			
	326040238	15.0	3	4	12			

Remarks: For Vaneaxial fan and motor failure data applied to fan coil unit, see Vaneaxial Fan Data Sheet.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: UNIT COOLER

Equipment Identification Code: T300

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-A-23798

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 698

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=.6 B=.6 C=.6

Reliability Indices

Total Number of Failures: 68

Mean Time Between Failures (MTBF): 135,000

Total Equipment Operating Time (hours): 9171720

90% Confidence Interval

Upper Limit: 174,000

Lower Limit: 107,000

Maintainability Indices

Total Number of Failures: 24

Mean Time to Repair (MTTR): 20.2

Total Corrective Maintenance Repair Man-Hours: 725

Mean Corrective Maintenance Man-Hours: 30.2

Maintenance Factor: .67

Maximum Observed Man-Hours: 178

Standard Deviation:

Variance:

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: Unit Cooler

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
Air Flow	326040122	51UW	78	2	187	.6	.6	.6
Unit Cooler	326040123	52UW	61	2	123			
	326040124	53UW	67	2	126			
	326040121	54UW	77	2	164			
	326040119	55UW	45	2	98			
Unit Cooler	400090163	-	224	2	542			
VNXL Fan	400090164	-	208	2	479			
	400090167	-	113	2	242			
	400090166	-	142	2	316			
	400010165	-	83	2	189			
Unit Cooler	174700047	.05HP	234	2	573			
Fan Motor	174700048	.083HP	218	2	476			
	174700035	.125HP	193	2	534			
	174700026	.125HP	30	2	72			
	174700046	.2HP	103	3	353			

Remarks: Unit Coolers are listed in order of increasing capacity. Fans and fan motors are listed in the same order as its associated cooler.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: COIL, COOLING, SALTWATER TYPE

Equipment Identification Code: T400

Manufacturer: Porter, H. K. Co., Inc.

CID/APL Number(s): 326040225/6/7

MIL Specification: MIL-C-2939

Basic Data

Ship Population: CGN 38,39

Equipment Population per Ship: 12

Equipment Population in Data Base: 24

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 0

Mean Time Between Failures (MTBF): 97,000*

Total Equipment Operating Time (hours): 157680

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures:

Mean Time to Repair (MTTR):

Total Corrective Maintenance Repair Man-Hours:

Mean Corrective Maintenance Man-Hours:

Maintenance Factor:

Maximum Observed Man-Hours:

Standard Deviation:

Variance:

*Remarks *BASED ON CHI-SQUARE (χ^2) LOWER 60% CONFIDENCE INTERVAL WITH TWO DEGREES OF FREEDOM APPLIED TO TOTAL OPERATING TIME. NOTE: NO CORRECTIVE MAINTENANCE ACTIONS REPORTED.

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RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: HEATER, CONVECTION

Equipment Identification Code: T109

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-H-3117

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 6769

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 2

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 14824110

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 14

Mean Time to Repair (MTTR): 8.3

Total Corrective Maintenance Repair Man-Hours: 174

Mean Corrective Maintenance Man-Hours: 12.4

Maintenance Factor: .67

Maximum Observed Man-Hours: 31

Standard Deviation: 14.6

Variance: 215.8

*Remarks *SEE CONTINUATION SHEET. NOTE: MAINTAINABILITY INDICES WERE BASED ON ALL CORRECTIVE MAINTENANCE EVENTS DUE TO LACK OF FAILURE EVENT DATA.

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: Heater, Convection

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
Heater, Convection	070990112	1 1/2 NM	5	3	13	1.0	1.0	1.0
	070990003	2NM	29	2	59			
	070990004	2 1/2 NM	141	4	573			
	070990005	2 1/2 NM	26	3	84			
	070990006	3 1/2 NM	198	6	1,178			
	070990007	3 1/2 NM	66	5	324			
	070990009	4 1/2 NM	85	4	310			
	070990010	6 NM	249	8	2,073			
	070990011	6 NM	30	2	74			
	070990013	8 NM	57	3	164			
	070990014	11NM	220	5	1,151			
	070990015	11NM	18	2	33			
	070990016	15NM	100	5	459			
	070990017	15NM	10	3	33			
	070990097	15NM	4	2	8			
	070990019	20NM	5	2	8			
	070990098	25NM	4	3	11			
	070990099	35NM	5	15	75			
	070990100	45NM	5	5	25			
	070990101	60NM	5	9	45			
	070990102	80NM	5	10	51			
	070990103	110NM	4	3	12			
	070990104	150NM	2	3	6			

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: HEATER, ELECTRIC VENT TYPE

Equipment Identification Code: T109

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-H-4-22594

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 552

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 3

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 12088800

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 1

Mean Time to Repair (MTTR): 2.0

Total Corrective Maintenance Repair Man-Hours: 3

Mean Corrective Maintenance Man-Hours: 3

Maintenance Factor: .67

Maximum Observed Man-Hours: 3

Standard Deviation:

Variance:

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: HEATER, ELECTRIC, VENT-TYPE

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
HEATER, ELECTRIC VENT-TYPE	070840058	.57 kW	12	14	168	1.0	1.0	1.0
	070840045	1.14 kW	12	4	48			
	070840055	1.14 kW	12	2	24			
	070840057	1.71 kW	12	5	60			
	070840053	3.42 kW	12	7	84			
	070840050	4.56 kW	12	3	36			
	070840046	6.84 kW	12	2	24			
	070840048	6.84 kW	12	4	48			
	070840051	6.84 kW	12	5	60			

Remarks: Heaters are listed according to increasing rating.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: COIL, COOLING, GRAVITY TYPE

Equipment Identification Code: T408

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-C-2939

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 3695

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 7

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 80920500

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 7

Mean Time to Repair (MTTR): 10.1

Total Corrective Maintenance Repair Man-Hours: 105

Mean Corrective Maintenance Man-Hours: 15.0

Maintenance Factor: .67

Maximum Observed Man-Hours: 20

Standard Deviation: 13.4

Variance: 179.6

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: Coil, Cooling, Gravity Type

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
Cooling	326990023	SZ1G	205	6	1,128	1.0	1.0	1.0
Coil	326990024	SZ3G	105	2	213			
Gravity	326990025	SZ5G	253	9	2,354			

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: COIL, COOLING, AIR DUCT TYPE

Equipment Identification Code: T400

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-C-2939

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 1820

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 6

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 29858000

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 5

Mean Time to Repair (MTTR): 22.0

Total Corrective Maintenance Repair Man-Hours: 164

Mean Corrective Maintenance Man-Hours: 32.8

Maintenance Factor: .67

Maximum Observed Man-Hours: 68

Standard Deviation: 26.9

Variance: 723.6

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: COIL, COOLING, DUCT TYPE

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
COOLING COIL, AIR DUCT TYPE	326020032		49	1	50	1.0	1.0	1.0
	326040092	42 DWM	46	2	85			
	326040094	45 DWM	51	8	393			
	326040095	46 DWM	34	2	68			
	326990055	52 DW	144	4	615			
	326990056	53 DW	107	3	372			
	326990057	54 DW	105	2	237			

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: SWITCHBOARD, POWER DISTRIBUTION

Equipment Identification Code: 4100

Manufacturer: VARIOUS

CID/APL Number(s): 220660672-220660693

MIL Specification: MIL-S-16036

Basic Data

Ship Population: CGN 38,39

Equipment Population per Ship: 22

Equipment Population in Data Base: 44

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 0

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 578160

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 4

Mean Time to Repair (MTTR): 5.0

Total Corrective Maintenance Repair Man-Hours: 30

Mean Corrective Maintenance Man-Hours: 7.5

Maintenance Factor: .67

Maximum Observed Man-Hours: 15

Standard Deviation: 2.0

Variance: 4.0

*Remarks NOTE: MAINTAINABILITY INDICES WERE BASED ON ALL CORRECTIVE MAINTENANCE EVENTS DUE TO LACK OF FAILURE EVENT DATA.

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RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: CIRCUIT BREAKER, POWER DISTRIBUTION, 60 Hz

Equipment Identification Code: 4000

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-C-17587/17361

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 19561

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 27

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 428385900

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 10

Mean Time to Repair (MTTR): 5.1

Total Corrective Maintenance Repair Man-Hours: 77

Mean Corrective Maintenance Man-Hours: 7.7

Maintenance Factor: .67

Maximum Observed Man-Hours: 23

Standard Deviation: 13.2

Variance: 174

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: Circuit Breakers, 60 Hz Distribution System

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
Circuit Breakers; AQB	140301299	400FR/350TR	19	3	164	1.0	1.0	1.0
	140301317	400FR/400TRP	39	10	402			
	140301826	1600FR/ 800TRP	3	24	72			
	140302023	/30TRP	3	16	48			
	140901259	LF250/125TRP	146	5	707			
	140901260	LF250/125TRP	181	8	1,468			
	140901261	LF250/150TRP	141	5	693			
	140901262	LF250/150TRP	205	6	1,305			
	140901263	LF250/175TRP	84	5	390			
	140901264	LF250/175TRP	183	5	914			
	140901265	LF250/275TRP	81	6	465			
	140901266	LF250/225TRP	177	9	1,630			
	140901267	250FR/275TRP	52	5	270			
	140901268	LF250/250TRP	174	8	1,478			
	149990141	101F/15TRP	100	16	1,574			
	149990142	101F/25TRP	104	14	1,408			
	149990143	101F/50TRP	112	22	2,424			
	149990144	101F/75TRP	111	19	2,103			
	149990145	101F/100TRP	120	17	2,094			

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: FUSE UNIT ASSEMBLY, POWER DISTRIBUTION SYSTEM, 60 Hz

Equipment Identification Code: 4000

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-S-17000L

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 25414

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 31

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 556566600

90% *Confidence Interval*

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 8

Mean Time to Repair (MTTR): 2.5

Total Corrective Maintenance Repair Man-Hours: 30

Mean Corrective Maintenance Man-Hours: 3.7

Maintenance Factor: .67

Maximum Observed Man-Hours: 15

Standard Deviation: 8.0

Variance: 64.0

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: FUSE UNIT ASSEMBLY, POWER DISTRIBUTION SYSTEM, 60 Hz

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
		AMPS						
FUSE UNIT ASSEMBLY	149990097	15x25	205	31	6283	1.0	1.0	1.0
	149990098	15x25	193	34	6515			
	149990099	50x75x100	224	27	6124			
	149990100	50x75x100	192	34	6492			

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: FUSE BOX, POWER DISTRIBUTION SYSTEM, 60 Hz

Equipment Identification Code: 4000

Manufacturer: VARIOUS

CID/APL Number(s): 999970296

MIL Specification: MIL-S-17000L

Basic Data

Ship Population: 381

Equipment Population per Ship: 13(AVG)

Equipment Population in Data Base: 4997

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 0

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 109434300

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 15

Mean Time to Repair (MTTR): 8.2

Total Corrective Maintenance Repair Man-Hours: 184

Mean Corrective Maintenance Man-Hours: 12.3

Maintenance Factor: .67

Maximum Observed Man-Hours: 42

Standard Deviation: 13.7

Variance: 189.3

*Remarks NOTE: MAINTAINABILITY INDICES WERE BASED ON ALL CORRECTIVE MAINTENANCE EVENTS DUE TO LACK OF FAILURE EVENT DATA.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: TERMINAL BOX; POWER DISTRIBUTION SYSTEM , 60 Hz

Equipment Identification Code: 4000

Manufacturer: VARIOUS

CID/APL Number(s): 999970030

MIL Specification: MIL-S-17000

Basic Data

Ship Population: 425

Equipment Population per Ship: 18 (AVG)

Equipment Population in Data Base: 7652

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 0

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 167578800

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 1

Mean Time to Repair (MTTR): 2.0

Total Corrective Maintenance Repair Man-Hours: 3

Mean Corrective Maintenance Man-Hours: 3.0

Maintenance Factor: .67

Maximum Observed Man-Hours: 3

Standard Deviation:

Variance:

*Remarks MAINTAINABILITY INDICES WERE BASED ON ALL CORRECTIVE MAINTENANCE EVENTS DUE TO LACK OF FAILURE EVENT DATA.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: 400 Hz SOLID-STATE FREQUENCY CONVERTER

Equipment Identification Code: 4708

Manufacturer: TELEDYNE INET

CID/APL Number(s): *

MIL Specification:

Basic Data

Ship Population: DD963-970

Equipment Population per Ship: 3

Equipment Population in Data Base: 24

Data Assessment Period: 1/75-12/77

Utilization Factors: S; A=.67 B=.33 C=.05

Reliability Indices

Total Number of Failures: 101

Mean Time Between Failures (MTBF): 645

Total Equipment Operating Time (hours): 65151

90% Confidence Interval

Upper Limit: 774

Lower Limit: 516

Maintainability Indices

Total Number of Failures: 63

Mean Time to Repair (MTTR): 13.0

Total Corrective Maintenance Repair Man-Hours: 1,222

Mean Corrective Maintenance Man-Hours: 19.4

Maintenance Factor: .67

Maximum Observed Man-Hours: 120

Standard Deviation: 32.1

Variance: 1,158.5

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: 400 Hz SOLID-STATE FREQUENCY CONVERTER

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
POWER SUPPLY	112700002		8DD	3	24	.67	.33	.05
VOLTAGE REGULATOR	422110010/1							
FREQ/VOLTAGE MONITOR PANEL	506330001/2							
COOLING PUMP	019670002	50GPM						

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: COMPRESSOR, LP 100SCFM, 150 PSI

Equipment Identification Code: TF03

Manufacturer: WORTHINGTON

CID/APL Number(s): 061900359

MIL Specification: MIL-C-19553D

Basic Data

Ship Population: CG17,18,24,27,29,31,33 DDG 37,41,42,45,46

Equipment Population per Ship: 4

Equipment Population in Data Base: 48

Data Assessment Period: 1/75-12/77

Utilization Factors: S; A=.5 B=.25 C=.018

Reliability Indices

Total Number of Failures: 43

Mean Time Between Failures (MTBF): 4359

Total Equipment Operating Time (hours): 187430

90% Confidence Interval

Upper Limit: 5450

Lower Limit: 3270

Maintainability Indices

Total Number of Failures: 28

Mean Time to Repair (MTTR): 17.2

Total Corrective Maintenance Repair Man-Hours: 717

Mean Corrective Maintenance Man-Hours: 25.6

Maintenance Factor: .67

Maximum Observed Man-Hours: 121

Standard Deviation: 33.0

Variance: 1,089

*Remarks

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: DEHYDRATOR, L.P. AIR, TYPE I

Equipment Identification Code: TF03

Manufacturer: HOWELL LABS INC.

CID/APL Number(s): 440300032

MIL Specification: MIL-D-23523

Basic Data

Ship Population: CG 29,31,33,34 DDG 41,45,46

Equipment Population per Ship: 4

Equipment Population in Data Base: 28

Data Assessment Period: 1/75-12/77

Utilization Factors: S; A=.5 B=.25 C=.25

Reliability Indices

Total Number of Failures: 27

Mean Time Between Failures (MTBF): 5071

Total Equipment Operating Time (hours): 136935

90% Confidence Interval

Upper Limit: 8114

Lower Limit: 3550

Maintainability Indices

Total Number of Failures: 15

Mean Time to Repair (MTTR): 35.6

Total Corrective Maintenance Repair Man-Hours: 798

Mean Corrective Maintenance Man-Hours: 53.2

Maintenance Factor: .67

Maximum Observed Man-Hours: 150

Standard Deviation: 60.8

Variance: 3,696.6

*Remarks

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: DEHYDRATOR, L.P. AIR TYPE II

Equipment Identification Code: TF04

Manufacturer: Electro-Impulse Lab, Inc.

CID/APL Number(s): 440360004

MIL Specification: MIL-D-23523

Basic Data

Ship Population: FF 1071, 1078, 1081, 1087

Equipment Population per Ship: 2

Equipment Population in Data Base: 8

Data Assessment Period: 1/76-3/78

Utilization Factors: S, A = .5 B - .5 C = .5

Reliability Indices

Total Number of Failures: 4

Mean Time Between Failures (MTBF): 6300

Total Equipment Operating Time (hours): 25200

90% Confidence Interval

Upper Limit: 18472

Lower Limit: 3250

Maintainability Indices

Total Number of Failures: 2

Mean Time to Repair (MTTR): 7.4

Total Corrective Maintenance Repair Man-Hours: 22

Mean Corrective Maintenance Man-Hours: 11.0

Maintenance Factor: .67

Maximum Observed Man-Hours: 13

Standard Deviation: 2.8

Variance: 8.0

*Remarks

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: VALVE, PRIORITY, L.P. AIR SYSTEM

Equipment Identification Code: TF03

Manufacturer: Pneumetrics, Inc.

CID/APL Number(s): 88 2095756

MIL Specification: MIL-V-24384A

Basic Data

Ship Population: CG23,29,30,31,32,33 DDG37,45,46,FF1070

Equipment Population per Ship: 2

Equipment Population in Data Base: 20

Data Assessment Period: 1/75-12/77

Utilization Factors: H_i A = 1.0 B = 1.0 C = 1.0

Reliability Indices

Total Number of Failures: 1

Mean Time Between Failures (MTBF): >300,000

Total Equipment Operating Time (hours): 525600

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures: 1

Mean Time to Repair (MTTR): 1.3

Total Corrective Maintenance Repair Man-Hours: 2.0

Mean Corrective Maintenance Man-Hours: 2.0

Maintenance Factor: .67

Maximum Observed Man-Hours: 2.0

Standard Deviation:

Variance:

*Remarks

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: FIREPUMP, TURBINE DRIVEN

Equipment Identification Code: T801

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-P-17639

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 42

Data Assessment Period: 1/75-12/77

Utilization Factors: S; A=.5 B=.25 C=0

Reliability Indices

Total Number of Failures: 108

Mean Time Between Failures (MTBF): 1927

Total Equipment Operating Time (hours): 208119

90% Confidence Interval

Upper Limit: 2216

Lower Limit: 1638

Maintainability Indices

Total Number of Failures: 61

Mean Time to Repair (MTTR): 20.0

Total Corrective Maintenance Repair Man-Hours: 1824

Mean Corrective Maintenance Man-Hours: 29.9

Maintenance Factor: .67

Maximum Observed Man-Hours: 210

Standard Deviation: 38.7

Variance: 1497.7

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: FIREPUMP, CENTRIFUGAL, TURBINE DRIVEN

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
PUMP, CENTRIFUGAL	016020537	1000GPM	1LPH	2	2	.5	.25	0
	016021444	150PSI	1LPH	2	2			
	016031235		1AOR	1	1			
	016031718		5AOR	2	9			
	016031716		8AE	2	16			
	016031667		4LSD	2	8			
	016032310		2CGN	2	4			
TURBINE, FIREPUMP	057950071		2LPH	2	4			
	057950014		1AOR	1	1			
	057950145		5AOR	2	9			
	057950134		8AE	2	16			
	057950133		4LSD	2	8			
	057950183		2CGN	2	4			

Remarks: Pumps are listed according to APL sequence. Turbines are listed in the same order as their associated pump.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: FIREPUMP, MOTOR DRIVEN

Equipment Identification Code: T801

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-P-17639

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 158

Data Assessment Period: 1/75-12/77

Utilization Factors: *

Reliability Indices

Total Number of Failures: 342

Mean Time Between Failures (MTBF): 3495

Total Equipment Operating Time (hours): 1195459

90% Confidence Interval

Upper Limit: 4019

Lower Limit: 2971

Maintainability Indices

Total Number of Failures: 271

Mean Time to Repair (MTTR): 33.4

Total Corrective Maintenance Repair Man-Hours: 13496

Mean Corrective Maintenance Man-Hours: 49.8

Maintenance Factor: .67

Maximum Observed Man-Hours: 379

Standard Deviation: 61.6

Variance: 3794.6

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: FIREPUMP, CENTRIFUGAL, MOTOR DRIVEN

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
PUMP, CENTRIFUGAL	016031662	1000GPM	4LSD	1	4	.8	.75	.75
	016031679	150PSI	5AOR	2	10	.5	.5	.5
	016031679		8AE	4	32	.25	.375	.5
	016031679		20LST	4	80	.5	.25	.25
	016031708		2LCC	4	8	.25	.375	.5
	016032350		2CGN	6	12	.166	.25	.33
	016110105		1LPH	6	6	.166	.25	.33
	016150937		1LPH	6	6	.166	.25	.33
MOTOR, 400VAC	174751787	125HP	4LSP	1	4	.8	.75	.75
	175504023		4AOR	2	10	.5	.5	.5
	175504541		4AE	4	16	.25	.375	.5
	175503919		4AE	4	16	.25	.375	.5
	174751787		20LST	4	80	.5	.25	.25
	174751787		2LCC	4	8	.25	.375	.5
	174342394		2CGN	6	12	.166	.25	.33
	174750687		1LPH	5	5	.166	.25	.33
	174752576		1LPH	1	1	.166	.25	.33
	174803584		1LPH	6	6	.166	.25	.33

Remarks: Pumps are listed by APL sequence. Motors are listed in the same order as their associated pump.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: VALVES, POWER OPERATED

Equipment Identification Code: T801

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: VARIOUS

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 197

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 15

Mean Time Between Failures (MTBF): 127,000

Total Equipment Operating Time (hours): 1900920

90% Confidence Interval

Upper Limit: 205,000

Lower Limit: 87,000

Maintainability Indices

Total Number of Failures: 5

Mean Time to Repair (MTTR): 20.4

Total Corrective Maintenance Repair Man-Hours: 152

Mean Corrective Maintenance Man-Hours: 30.4

Maintenance Factor: .67

Maximum Observed Man-Hours: 73

Standard Deviation: 26.1

Variance: 680.3

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: VALVES, POWER OPERATED

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
VALVE GEAR OPERATORS, MOTOR DRIVEN	619560034		5	39	109	1.0	1.0	1.0
	619560059		2	44	88			
VALVE, GATE POWER OPERATED	882041163	6IPS/ 100PSI	4	12	49			
	882041241	5IPS/ 200PSI	4	3	13			
	882041300	6IPS/ 100PSI	1	3	3			
	882041323	4IPS/ 150PSI	4	2	8			
	882041324	5IPS/50PSI	4	2	8			
	882041325	6IPS/50PSI	4	24	95			
	882041326	8IPS/50PSI	4	12	48			
	882041327	10IPS/ 50PSI	4	4	16			
	882041328	12IPS/ 50PSI	5	10	50			
	882051329	18IPS/ 50PSI	2	18	36			
VALVE, GLOBE POWER OPERATED	882051158	1.5IPS/ 100PSI	13	1	13			
	882051159	2.5IPS/ 100PSI	11	1	11			
	882051160	3.5IPS/ 100PSI	15	2	29			
	882051161	4IPS/ 100PSI	15	2	27			
	882051174	5IPS/ 100PSI	3	3	8			
	882051258	4IPS/ 150PSI	9	2	20			
	882051259	2IPS/ 150PSI	10	2	20			
	882051311	5IPS/ 250PSI	3	2	7			
	882051312	4IPS/ 250PSI	4	4	17			

Remarks: Valves are listed according to APL sequence.

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: VALVES, POWER OPERATED (Continued)

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
VALVE, GLOBE POWER OPERATED (cont.)	882051325	5IPS/ 250PSI	20	10	204	1.0	1.0	1.0
	882051326	4IPS/ 250PSI	11	8	84			
	882051328	3IPS/ 250PSI	17	2	39			
	882051349	1.25IPS/ 150PSI	1	6	6			
	882051350	1IPS/ 200PSI	10	3	30			
	882051352	6IPS/ 150PSI	3	5	15			
	882051749	2IPS/ 250PSI	80	2	146			
	882054275	.75IPS/ 150PSI	176	3	494			
	882054340	1.25IPS/ 250PSI	18	2	27			
VALVES, BUTTERFLY POWER OPERATED	882290014	8IPS/ 150PSI	2	20	39			
	882290016	10IPS/ 150PSI	2	5	9			
	882290049	10IPS/ 150PSI	2	2	3			
	882200055	5IPS/ 150PSI	2	2	4			
	882290056	6IPS/ 150PSI	2	2	4			

Remarks: _____

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RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: VALVE, PRESSURE REGULATION, FIREMAIN

Equipment Identification Code: T801

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: MIL-V-2042

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 325

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 65

Mean Time Between Failures (MTBF): 110,000

Total Equipment Operating Time (hours): 7117500

90% Confidence Interval

Upper Limit: 132,000

Lower Limit: 88,000

Maintainability Indices

Total Number of Failures: 26

Mean Time to Repair (MTTR): 18.0

Total Corrective Maintenance Repair Man-Hours: 697

Mean Corrective Maintenance Man-Hours: 26.8

Maintenance Factor: .67

Maximum Observed Man-Hours: 64

Standard Deviation: 11.3

Variance: 124.1

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: VALVES, PRESSURE REGULATION, FIREMAIN

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
		PSI						
VALVE, PRESSURE REGULATION	882094875	150/30	5	1	5	1.0	1.0	1.0
	882094877	150/30	3	2	6			
	882094927	150/30	4	1	4			
	882094964	150/30	9	3	30			
	882090003	150/60	18	2	31			
	882090023	150/60	18	2	30			
	882095165	150/60	6	3	16			
	882095442	150/60	2	5	10			
	882094876	150/80	11	1	16			
	882095543	150/90	2	2	4			
	882094360	150/125	11	1	13			
	882090325	300/46	30	1	34			
	882090326	300/46	26	2	51			
	882094161	300/80	21	3	53			
	882095053	300/80	14	2	22			

Remarks: Valves are listed according to increasing pressure.

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: PUMP, S.W. CIRCULATING, RADAR COOLING

Equipment Identification Code: T806

Manufacturer: VARIOUS

CID/APL Number(s): *

MIL Specification: VARIOUS

Basic Data

Ship Population: *

Equipment Population per Ship: *

Equipment Population in Data Base: 36

Data Assessment Period: 1/75-12/77

Utilization Factors: *

Reliability Indices

Total Number of Failures: 63

Mean Time Between Failures (MTBF): 5,721

Total Equipment Operating Time (hours): 360410

90% Confidence Interval Upper Limit: 6,864

Lower Limit: 4,576

Maintainability Indices

Total Number of Failures: 26

Mean Time to Repair (MTTR): 26.6

Total Corrective Maintenance Repair Man-Hours: 1032

Mean Corrective Maintenance Man-Hours: 39.7

Maintenance Factor: .67

Maximum Observed Man-Hours: 125

Standard Deviation: 42.3

Variance: 1789.3

*Remarks *SEE CONTINUATION SHEET

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: PUMP, S.W. CIRCULATING, RADAR COOLING

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
PUMP, CENTRIFUGAL	016031685	350GPM/ 50PSI	10DD	2	20	.95	.5	.05
	016060085	400GPM/ 50PSI	8AE	2	16			
MOTOR, 400 VAC	174750273	20 HP	10DD	2	20			
	175503916	20 HP	8AE	2	16			

Remarks: _____

RELIABILITY AND MAINTAINABILITY DATA SHEET

Equipment Identification

Noun Name: HEAT EXCHANGER, DEMINERALIZED WATER/SEAWATER

Equipment Identification Code: T806

Manufacturer: AQUA-CHEM INC.

CID/APL Number(s): *

MIL Specification: MILC 15730J

Basic Data

Ship Population: CGN 38,39

Equipment Population per Ship: 9

Equipment Population in Data Base: 18

Data Assessment Period: 1/75-12/77

Utilization Factors: H; A=1.0 B=1.0 C=1.0

Reliability Indices

Total Number of Failures: 0

Mean Time Between Failures (MTBF): 73,000*

Total Equipment Operating Time (hours): 118260

90% Confidence Interval

Upper Limit:

Lower Limit:

Maintainability Indices

Total Number of Failures:

Mean Time to Repair (MTTR):

Total Corrective Maintenance Repair Man-Hours:

Mean Corrective Maintenance Man-Hours:

Maintenance Factor:

Maximum Observed Man-Hours:

Standard Deviation:

Variance:

*Remarks *BASED ON CHI-SQUARE (χ^2) LOWER 60% CONFIDENCE INTERVAL WITH TWO DEGREES OF FREEDOM APPLIED TO TOTAL OPERATING TIME. NOTE: NO CORRECTIVE MAINTENANCE ACTIONS REPORTED.

RELIABILITY AND MAINTAINABILITY DATA SHEET (continued)

Equipment General Description: Heat Exchanger, Demineralized Water/Sea Water

Noun Name	CID/APL Number(s)	Size or Rating	Population Data			Utilization Factors		
			Number of Ships	Eqpts. per Ship	Total Eqpts.	A	B	C
		Sq. Ft. of Cooling surface						
Cooler, FL	032140052	8.40	CGN38,	1	2	1.0	1.0	1.0
	032140057	15.10	39					
	032140058	29.80						
	032140054	36.90						
	032140051	64.40						
	032140055	94.80						
	032140056	99.00						
	032140059	130.00						
	032140053	158.00						

Remarks: _____

APPENDIX C

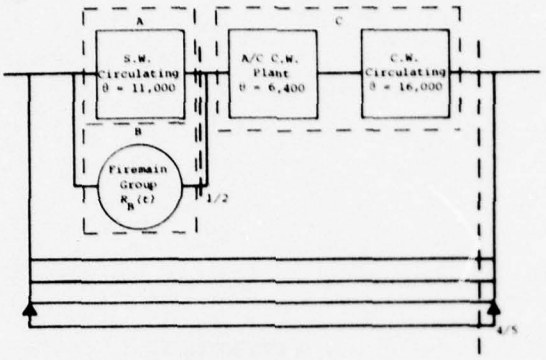
SYSTEM RELIABILITY BLOCK DIAGRAMS

AND

RELIABILITY CALCULATIONS

Figures C-1 through C-7 present the reliability block diagrams and system reliability calculations for the seven distributive systems of this report.

Figure C-1. AIR CONDITIONING CHILLED WATER SYSTEM RELIABILITY BLOCK DIAGRAM AND RELIABILITY CALCULATIONS



This diagram shows the requirement for four out of five ACCW Plants to be in operation during the cruise condition with the fifth plant in standby. The Firemain Group in this diagram is an active redundant element and is approximated by use of the cruise condition reliability presented in Figure C-6 of this Appendix. The formula and resulting system reliability are as follows:

$$R_S(t) = R_B(t) \left[e^{-4\lambda_C t} (1 + 4\lambda_C t)\right] + \bar{R}_B(t) \left[e^{-4(\lambda_A + \lambda_C)t} (1 - 4(\lambda_A + \lambda_C)t)\right]$$

where

$R_B(t)$ = probability of Firemain working in Cruise condition (two out of eight pumps working)

$\bar{R}_B(t)$ = probability of Firemain not working

$\lambda_A = \frac{1}{11,000}$ = failure rate of Sea Water circulating pump

$\lambda_C = \frac{1}{6,400} + \frac{1}{16,000}$ = failure rate of the ACCW Plant and C.W. Circulating Pump combined.

t = 1500 hours

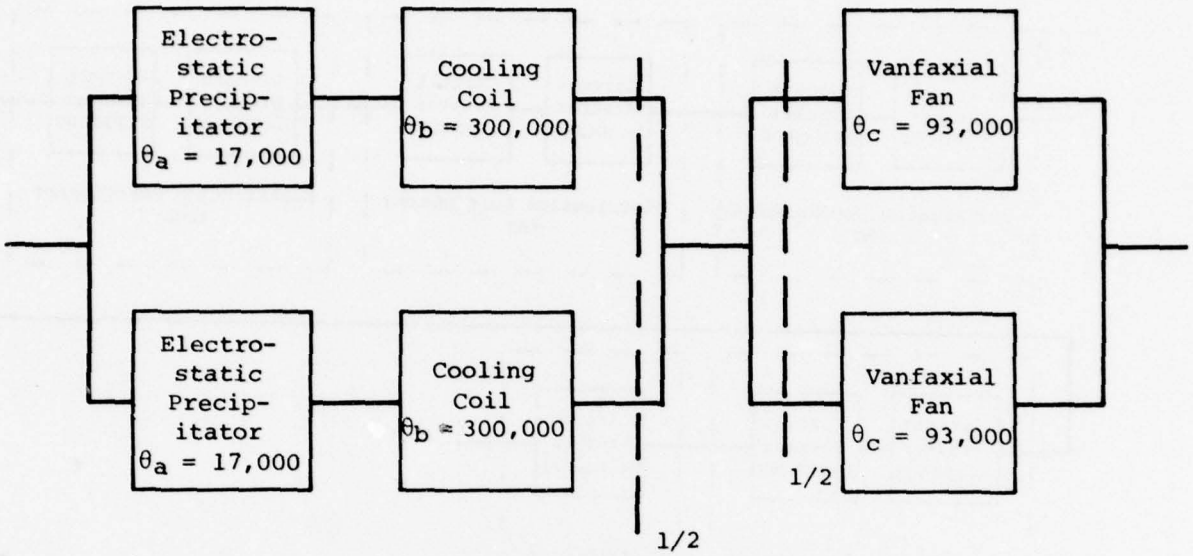
$R_S(t)$ = .62220

The equivalent system MTBF is calculated as follows:

$$MTBF_S = \int_0^\infty R_S(t)dt = \underline{2,223 \text{ hours}}$$

Note: These calculations are conservative in that they do not take into account the repairability of the components and as such they should be viewed as lower limit values.

Figure C-2. VENTILATION SYSTEM BLOCK DIAGRAM AND RELIABILITY CALCULATIONS



System Reliability ($R_S(t)$ is calculated for either set of precipitator and cooling coil in series with either vaneaxial fan as follows:

$$R_S(t) = \left\{ 2(e^{-\lambda_a t})\ (e^{-\lambda_b t}) - \left[(e^{-\lambda_a t})\ \ (e^{-\lambda_b t}) \right]^2 \right\} \left[2e^{-\lambda_c t} - (e^{-\lambda_c t})^2 \right]$$

where

$$\lambda_a = \frac{1}{17,000}, \lambda_b = \frac{1}{300,000}, \lambda_c = \frac{1}{93,000}$$

t = 1500 hours

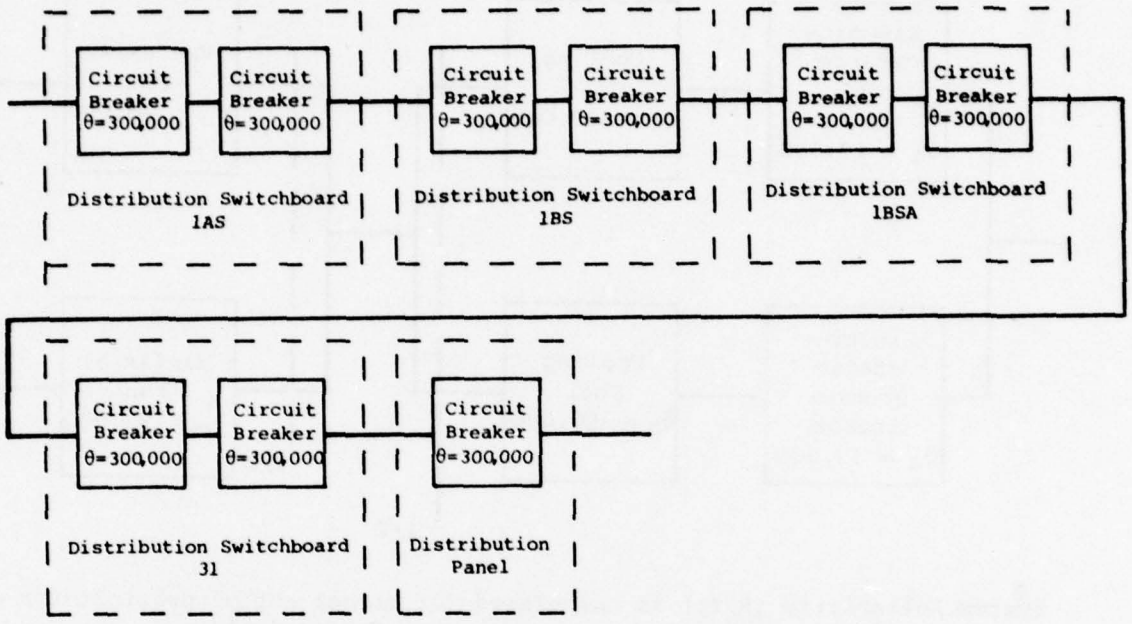
$R_S(t)$ = .99182

The equivalent system MTBF is calculated as follows:

$$MTBF_S = \int_0^\infty R_S(t)\ dt = \underline{23,000 \text{ hours}}$$

Note: These calculations are conservative in that they do not take into account the repairability of the components and as such they should be viewed as lower limit values.

Figure C-3. 60 HZ POWER DISTRIBUTION SYSTEM RELIABILITY BLOCK DIAGRAM AND RELIABILITY CALCULATIONS



Reliability for these identical series components is calculated as follows:

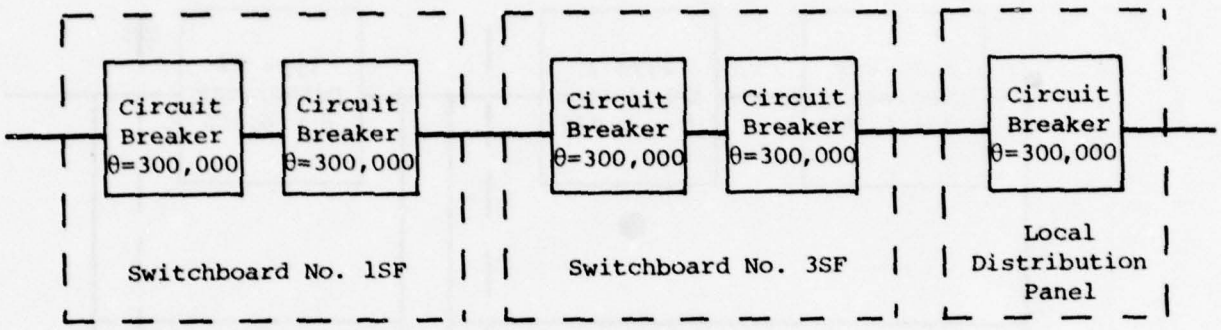
$$R_{(t)} = (e^{-\lambda t})^{n}, \text{ where } t = 1{,}500 \text{ hours and } n = 9$$

$$R_{(t)} = \left(e^{-\frac{1}{300{,}000} \cdot 1500}\right)^{9} = \underline{0.95600}$$

which is equivalent to a System MTBF of θ = 33,335 hours

Note: These calculations are conservative in that they do not take into account the repairability of the components and as such they should be viewed as lower limit values.

Figure C-4. 400 HZ POWER DISTRIBUTION SYSTEM RELIABILITY BLOCK DIAGRAM AND RELIABILITY CALCULATIONS



Reliability for these identical series components is calculated as follows:

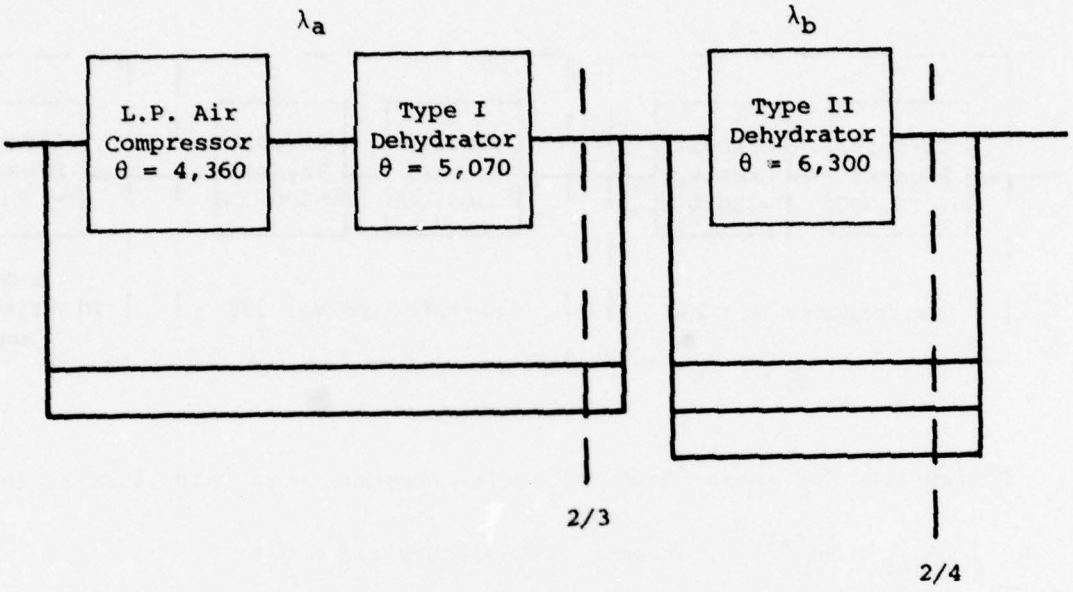
$$R_{(t)} = (e^{-\lambda t})^{n}, \text{ where } t = 1500 \text{ hours and } n = 5$$

$$R_{(t)} = \left(e^{-\frac{1}{300,000} \cdot 1500}\right)^{5} = \underline{0.97531}$$

which is equivalent to a System MTBF of θ = 60,000 hours

Note: These calculations are conservative in that they do not take into account the repairability of the components and as such they should be viewed as lower limit values.

Figure C-5. LOW PRESSURE AIR/ELECTRONIC DRY AIR SYSTEM RELIABILITY BLOCK DIAGRAM AND RELIABILITY CALCULATIONS



This diagram represents the need for two of three Compressor-Type I Dehydrator sets and two of four Type II Dehydrators to be working during the designated time period for system success. The formula for and resulting system reliability are as follows:

$$R_S(t) = e^{-2\lambda_a t}(1 + 2\lambda_a t)\left[e^{-2\lambda_b t}\left(1 + 2\lambda_b t + \frac{4\lambda_b^2 t^2}{2}\right)\right]$$

where: $\lambda_a = \frac{1}{4360} + \frac{1}{5070}$, $\lambda_b = \frac{1}{6300}$, $t = 1500$ hours

$$R_S\ t) = \underline{\underline{0.78624}}$$

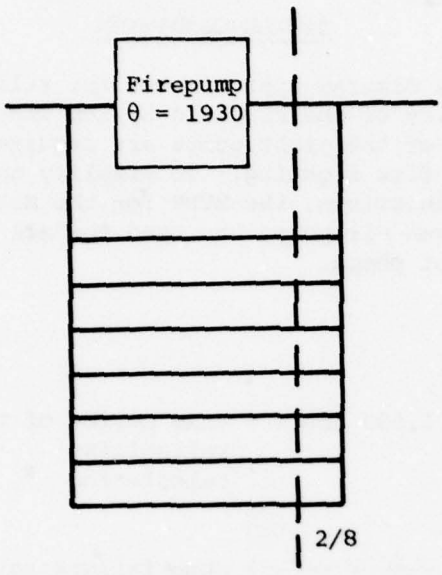
The equivalent system MTBF is calculated as follows:

$$MTBF_S = \int_0^\infty R_S(t)\ dt$$

$$MTBF_S = \underline{\underline{2446 \text{ hours}}}$$

Note: These calculations are conservative in that they do not take into account the repairability of the equipments and as such they should be viewed as lower limit values.

Figure C-6. FIREMAIN SYSTEM RELIABILITY BLOCK DIAGRAMS AND RELIABILITY CALCULATIONS



CRUISE CONDITION

This diagram approximates the reliability of the Firemain System where only two of the eight pumps are required. As a conservative approach the lesser value of the Steam Turbine Driven Pumps was used as the MTBF for all eight pumps.

t = 1,500 hours = time period of the reliability calculation

$\lambda = \frac{1}{MTBF} = \frac{1}{1930}$ = pump failure rate

The system reliability formula for the probability of system success over a 1,500 hour mission period and the resulting probability are as follow:

$$R_s(t) = e^{-2\lambda t}\left[1 + 2\lambda t + \frac{(2\lambda t)^2}{2!} + \frac{(2\lambda t)^3}{3!} + \frac{(2\lambda t)^4}{4!} + \frac{(2\lambda t)^5}{5!} + \frac{(2\lambda t)^6}{6!}\right]$$

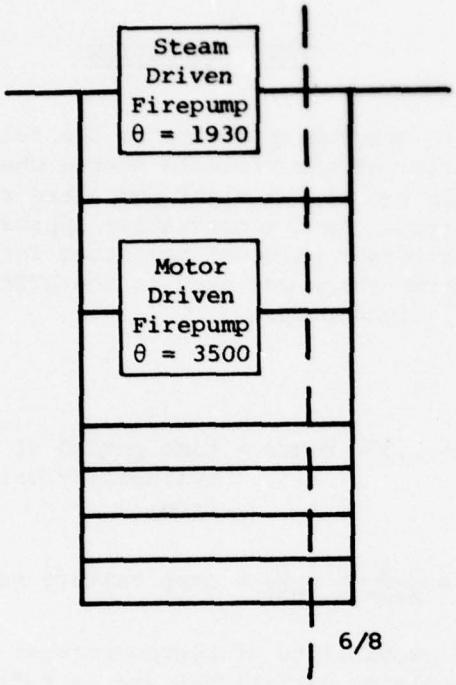
$$R_s(t) = \underline{0.99887}$$

The equivalent system MTBF is calculated as follows:

$$MTBF_{(s)} = \int_0^\infty R_s(t)\,dt$$

$$= \underline{6,755 \text{ hours}}$$

Figure C-6. (continued)



BATTLE CONDITION

This diagram approximates the reliability of the Firemain System where six of the eight pumps are required for fire fighting. To simplify the calculations, the MTBF for the Motor Driven Firepumps was used for all eight pumps.

t = 1,500 hours = time period of the reliability calculation

$\lambda = \frac{1}{MTBF} = \frac{1}{3500}$ = pump failure rate

The system reliability is calculated in a similar manner to the cruise condition, however, system success is now the probability that six of the eight pumps will operate over the 1500 hour period. The formula used is as follows:

$$R_s(t) = e^{-6\lambda t}\left[1 + 6\lambda t + \frac{(6\lambda t)^2}{2}\right]$$

$$R_s(t) = \underline{\underline{.5256}}$$

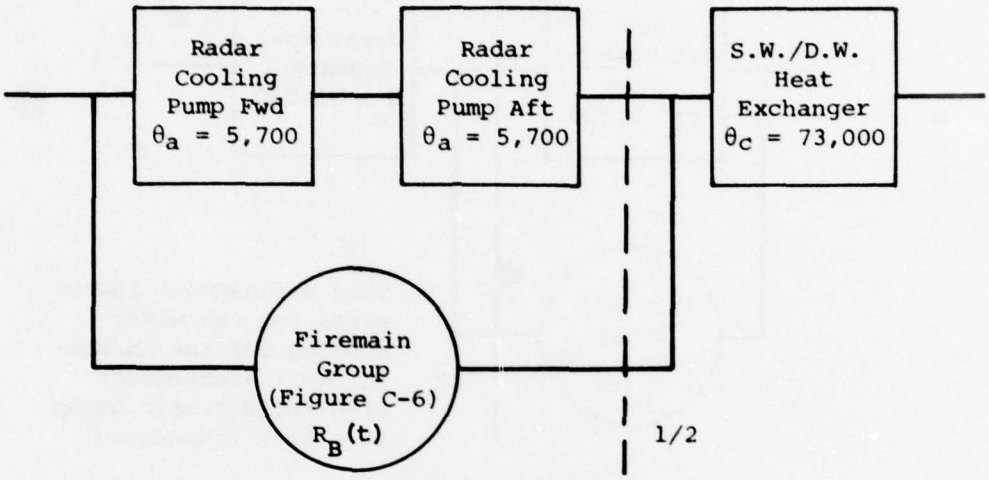
The equivalent system MTBF is calculated as follows:

$$MTBF_{(s)} = \int_0^\infty R_s(t)\, dt$$

$$= \underline{\underline{1,750 \text{ hours}}}$$

Note: These calculations are conservative in that they do not take into account the repairability of the components and as such they should be viewed as lower limit values.

Figure C-7. SEA WATER COOLING FOR COMBAT SYSTEM RELIABILITY BLOCK DIAGRAM AND RELIABILITY CALCULATIONS



SEA WATER COOLING ARRANGEMENT FOR FULL AN/SPY- 1A RADAR CAPABILITY

The reliability of this portion of the system is calculated using the following formula to account for the active redundancy of the Firemain Group:

$$R_S(t)_{\text{Radar Cooling}} = \left[1-(1-R_A)\left(1-R_B(t)\right)\right]R_C$$

where: $R_A = \left(e^{-\lambda_a t}\right)^2$, $R_C = e^{-\lambda_c t}$

$R_B(t)$ = Same as Figure C-6 for Cruise Condtion

$$\lambda_a = \frac{1}{5{,}700}\ ,\ \lambda_c = \frac{1}{73{,}000}\ ,\ t = 1{,}500 \text{ hours}$$

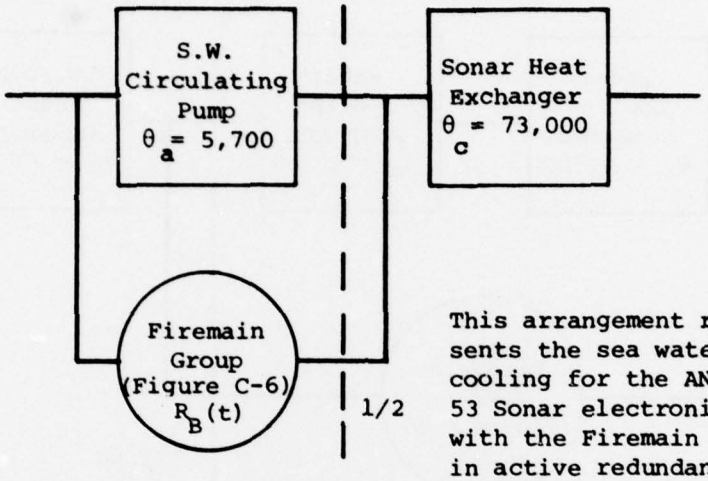
$$R_S(t)_{\text{Radar Cooling}} = \underline{\underline{0.9792}}$$

The equivalent system MTBF for this portion is calculated as follows:

$$\text{MTBF}_{\text{Radar Cooling}} = \int_0^\infty R_S(t)_{\text{Radar Cooling}}\, dt$$

$$\text{MTBF}_{\text{Radar Cooling}} = \underline{\underline{6{,}744 \text{ hours}}}$$

Figure C-7. (continued)



This arrangement represents the sea water cooling for the AN/SQS-53 Sonar electronics with the Firemain Group in active redundancy.

The reliablility for this portion of the system is calculated as follows:

$$R_S(t)_{\text{Sonar Cooling}} = \left[1-(1-R_A)\left(1-R_B(t)\right)\right] R_C$$

where: $R_A = e^{-\lambda_a t}$, $R_C = e^{-\lambda_a t}$

R_B = Same as Figure C-6 for Cruise Condition

$$\lambda_a = \frac{1}{5,700}, \quad \lambda_C = \frac{1}{73,000}, \quad t = 1,500 \text{ hours}$$

$$R_S(t)_{\text{Sonar Cooling}} = \underline{\underline{0.97940}}$$

The equivalent system MTBF for this portion is calculated as follows:

$$\text{MTBF}_{\text{Sonar Cooling}} = \int_0^\infty R_S(t)_{\text{Sonar Cooling}}\, dt$$

$$\text{MTBF}_{\text{Sonar Cooling}} = \underline{\underline{8,047 \text{ hours}}}$$

Note: These calculations are conservative in that they do not take into account the repairability of the components and as such they should be viewed as lower limit values.

APPENDIX D

EQUIPMENT FAILURE CATEGORIES

Tables D-1 through D-11 contain the categorization of the equipment failures of those system equipments for which an adequate number of failures was described in such a way that the category could be determined. This number was 20 or more failures.

Table D-1. AIR CONDITIONING CHILLED WATER SYSTEM FAILURE CATEGORIES

EQUIPMENT: CHILLED WATER PLANT

	Subassembly		Component	
	Failures	Percent	Failures	Percent
REFRIGERATION PLANT			22	48.9
Thermal/Pressure Switches	6	13.3		
Capacity Control System	4	8.9		
Transducer	4	8.9		
Filter/Heater Elements	2	4.4		
Manual Loading Valve	2	4.4		
Condenser Tubing (Fouled)	2	4.4		
Freon Leakage	2	4.4		
COMPRESSOR			8	22.2
Motor	3	6.7		
Bearings	2	4.4		
Shaft Seal	2	4.4		
Compressor	1	2.2		
PURGE UNIT			10	22.2
Compressor	3	6.7		
Compressor Bearings	3	6.7		
Purge Unit	2	4.4		
Purge Unit Controller	2	4.4		
AUXILIARY OIL PUMP			5	11.1
Shaft Seal	3	6.7		
Unspecified	2	4.4		

Table D-2. AIR CONDITIONING CHILLED WATER SYSTEM COMPONENT FAILURE CATEGORIES

EQUIPMENT: AIR CONDITIONING SALT WATER CIRCULATING PUMP

	Subassembly		Component	
	Failures	Percent	Failures	Percent
PUMP			40	40.0
Wearing Rings	21	21.0		
Shaft	5	5.0		
Bearings	4	4.0		
Recirc Line	4	4.0		
Casing	3	3.0		
Shaft Seal	2	2.0		
Impeller	1	1.0		
MOTOR			55	55.0
Bearings	26	26.0		
Windings Grounded	15	15.0		
Shaft	5	5.0		
Windings Burned	3	3.0		
Impeller Fan	2	2.0		
Pump/Motor Alignment	2	2.0		
Coupling	2	2.0		
UNSPECIFIED			5	5.0

Table D-3. AIR CONDITIONING CHILLED WATER SYSTEM COMPONENT FAILURE CATEGORIES

EQUIPMENT: AIR CONDITIONING CHILLED WATER CIRCULATING PUMP

	Subassembly		Component	
	Failures	Percent	Failures	Percent
PUMP			44	44.9
Wearing Rings	26	26.5		
Leak-Off	11	11.2		
Bearings	4	4.1		
Shaft	2	2.0		
Casing	1	1.0		
MOTOR			47	48.0
Bearings	28	28.6		
Windings Grounded	9	9.2		
Windings Burned	6	6.2		
Shaft	2	2.0		
Pump/Motor Alignment	1	1.0		
Coupling	1	1.0		
UNSPECIFIED			7	7.1

Table D-4. VENTILATION SYSTEM COMPONENT FAILURE CATEGORIES

EQUIPMENT: ELECTROSTATIC PRECIPITATOR AIR FILTER

	Subassembly		Component	
	Failures	Percent	Failures	Percent
PRECIPITATOR			11	4.2
Safety Switch	8	3.0		
Mounting Plants	2	.8		
Filter	1	.4		
COLLECTING CELL				
Excessive Dirt Accumulation	31	11.7	31	11.7
IONIZING CELL			76	28.8
Ionizing Wire	60	22.7		
Insulators	16	6.1		
POWER PACK			128	48.5
Transformer	23	8.7		
Rectifier	20	7.6		
Circuit Breakers	18	6.8		
Power Pack Burned Out	13	4.9		
Excessive Voltage	13	4.9		
Power Pack Grounded	12	4.5		
Ammeter	11	4.2		
Hi-Voltage Leads	9	3.4		
Attenuator	7	2.7		
Fuse Holder	2	.8		
UNSPECIFIED	18	6.8	18	6.8

Table D-5. VENTILATION SYSTEM COMPONENT FAILURE CATEGORIES

EQUIPMENT: VANEAXIAL FAN

	Subassembly		Component	
	Failures	Percent	Failures	Percent
FAN			13	4.7
Impeller	13	4.7		
MOTOR			246	89.8
Bearings	128	46.7		
Windings Burnt	70	25.5		
Windings Grounded	43	15.7		
Shaft	5	1.8		
UNSPECIFIED			15	5.5

Table D-6. 400 Hz POWER DISTRIBUTION SYSTEM COMPONENT FAILURE CATEGORIES

EQUIPMENT: 400 Hz SOLID STATE FREQUENCY CONVERTER

	Subassembly		Component	
	Failures	Percent	Failures	Percent
ELECTRONIC CIRCUITRY			42	56.0
Capacitors	14	18.7		
Fuses	11	14.7		
Logic Card Assy.	8	10.7		
SCR	6	8.0		
Diodes	3	4.0		
TRANSFORMER			7	9.3
DEIONIZED WATER SYS.			5	6.7
SALT WATER LEAKAGE			5	6.7
COOLING WATER HOSE			3	4.0
UNSPECIFIED			13	17.3

Table D-7. ELECTRONIC DRY AIR SYSTEM COMPONENT FAILURE CATEGORIES

COMPONENT: L.P. AIR COMPRESSOR

	Subassembly		Component	
	Failures	Percent	Failures	Percent
COMPRESSOR			8	24.2
Head Gasket Leakage	6	18.2		
H.P. Suction Valve	1	3.0		
Piston Rings	1	3.0		
COOLING SYSTEM			9	27.3
Cooling Water Control Valve	4	12.1		
Cooling Water Pump	3	9.1		
Cooling Water Piping	2	6.1		
RELIEF VALVE			2	6.1
UNSPECIFIED			14	42.4

Table D-8. ELECTRONIC DRY AIR SYSTEM COMPONENT FAILURE CATEGORIES

COMPONENT: TYPE I DEHYDRATOR

	Subassembly		Component	
	Failures	Percent	Failures	Percent
FILTERS			3	12.5
Clogged	3	12.5		
REFRIGERATION SYSTEM			6	25.0
Worn Internals	4	16.7		
Compressor	1	4.2		
Check Valve	1	4.2		
CHAMBER ASSY. STIFFENERS			2	8.3
Buckled	2	8.3		
UNSPECIFIED			13	54.2

Table D-9. FIREMAIN SYSTEM COMPONENT FAILURE CATEGORIES

EQUIPMENT: STEAM DRIVEN FIREPUMP

	Subassembly		Component	
	Failures	Percent	Failures	Percent
PUMP			24	33.3
Wearing Rings	10	13.9		
Bearings	6	8.3		
Mechanical Seal	3	4.2		
Coupling	2	2.8		
Pressure Regulator	1	1.4		
Shaft	1	1.4		
Excessive Vibration	1	1.4		
TURBINE			29	40.3
Governor	12	16.7		
Bearings	4	5.6		
Rotor	3	4.2		
Lube Oil Cooler	3	4.2		
Carbon Packing Rings	3	4.2		
Root Steam Valve	2	2.8		
Casing	1	1.4		
Oil Slingers	1	1.4		
UNSPECIFIED			19	26.4

Table D-10. FIREMAIN SYSTEM COMPONENT FAILURE CATEGORIES

EQUIPMENT: ELECTRIC DRIVEN FIREPUMP

	Subassembly		Component	
	Failures	Percent	Failures	Percent
PUMP			104	48.1
Bearings	29	13.4		
Rotor	26	12.0		
Wearing Rings	23	10.6		
Casing	14	6.5		
Packing Gland Leak	9	4.2		
Impeller	3	1.4		
MOTOR			76	35.2
Bearings	31	14.4		
Windings Grounded	11	5.1		
Pump/Motor Alignment	9	4.2		
Rotor	7	3.2		
Windings Burned	6	2.8		
Coupling	6	2.8		
Phase Imbalance	4	1.9		
Impeller Fan	2	.9		
MOTOR CONTROLLER			5	2.3
UNSPECIFIED			31	14.4

Table D-11. SALT WATER COOLING SYSTEM FOR COMBAT SYSTEMS COMPONENT FAILURE CATEGORIES

EQUIPMENT: AEGIS RADAR COOLING WATER PUMP

	Subassembly		Component	
	Failures	Percent	Failures	Percent
PUMP			18	50.0
Wearing Rings	12	33.3		
Shaft	2	5.6		
Bearings	1	2.8		
Impeller	1	2.8		
Housing	1	2.8		
Shaft Leakage	1	2.8		
MOTOR			15	41.7
Bearings	6	16.7		
Windings Grounded	5	13.9		
Windings Burned	3	8.3		
Rotor	1	2.8		
UNSPECIFIED			3	8.3