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RELIABILITY AND MAINTAINABILITY EVAUATION OF THE MODE S SYSTEM.(U)
MAY 82 A R MOSS, G C APOSTOLAKIS

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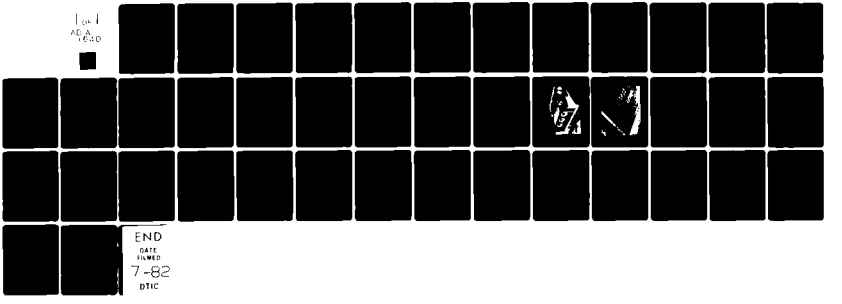

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Reliability and Maintainability Evaluation of the Mode S System

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May 1982

Final Report

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16. Abstract

A reliability and maintainability evaluation was performed on Mode S (formerly the Discrete Address Beacon System (DABS)) engineering model sensors located at the Federal Aviation Administration Technical Center, Elwood, and Clementon, New Jersey. The observed system mean-time-between-failure (MTBF) based on chargeable failures ranged from 767 hours for the Technical Center sensor to 1,913 hours for the Elwood site sensor. The preponderance of failures at the Technical Center sensor probably occurred because the system was stressed to a greater extent than the other two sites. Elements which failed and caused system outage at all three sites were the transmitter, processor, and WWVB receiver.

The transmitter and processor, which are single-string elements, were found to be the weak points in the system reliability design. The measured failure rates for these two elements, in particular the processor, exceeded the predicted values.

Problem areas were: inadequate radio station WWVB receiver output, damage to wire-wrap pins in the computer ensembles caused by power cables rubbing against them, excessive failures in the traveling wave tube associated circuitry, failure of cooling fans, susceptibility of the sensor to lightning damage, and loose and dirty printed circuit board contacts.

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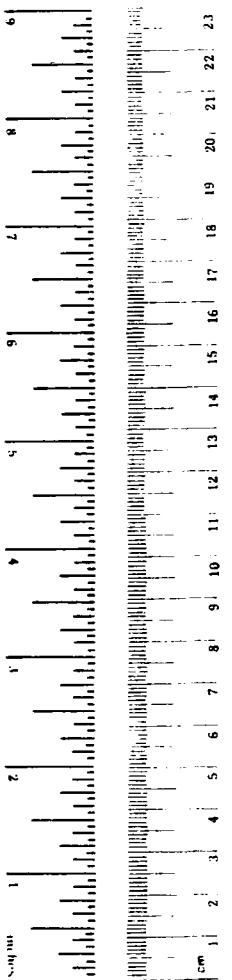
METRIC CONVERSION FACTORS

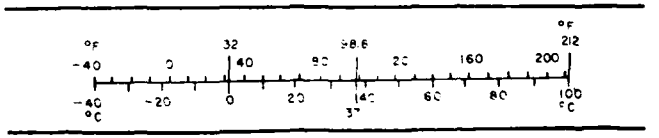
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5 9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9 5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

This report summarizes the hardware reliability and maintainability evaluation which was performed on three Mode S (formerly the Discrete Address Beacon System (DABS)) engineering model sensors. The evaluation consisted of collecting and analyzing data concerning failures in the system hardware. The analysis provided mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR) values, which are figures of merit or numerical indexes of reliability and maintainability, respectively. The measured MTBF and MTTR values were then compared to corresponding specified and predicted values. By analyzing the nature and number of hardware failures, those areas of the Mode S sensor which adversely affect reliability and maintainability are identified and recommendations for improvement are offered.

The Federal Aviation Administration (FAA) Technical Center final report, FAA-CT-81-60, "Discrete Address Beacon System (DABS) Software Systems Reliability Modeling and Prediction," contains information on software reliability.

BACKGROUND.

The three Mode S sensors are engineering laboratory models specifically developed for the purpose of testing and evaluating all aspects of system performance including reliability and maintainability. Information gained from these evaluations will be used in the preparation of a specification for a production Mode S sensor.

The sensors were installed at the FAA Technical Center, Atlantic City Airport, and two nearby sites: Elwood and Clementon, New Jersey. The Technical Center sensor was installed in June 1978; the other two sensors were installed later. Reliability and maintainability data were collected on the sensors over the following intervals:

1. Technical Center — October 1, 1978, through May 31, 1980 (20 months);
2. Elwood — July 1, 1979, through May 31, 1980 (11 months);
3. Clementon — October 1, 1979, through May 31, 1980 (8 months).

DISCUSSION

TEST OBJECTIVES/APPROACH.

One objective of the Mode S reliability and maintainability evaluation was to obtain quantitative expressions of the reliability and maintainability of the sensors in the form of MTBF and MTTR values and to compare them against specified and predicted values. Another objective was to ascertain any weak points or problem areas in the system design and to recommend improvements. These are indicated by the nature and number of the hardware failures as well as by unusual difficulties encountered in diagnosing, isolating, and correcting these failures.

These objectives were accomplished by recording and analyzing each hardware failure that occurred in each of the sensors over the stated intervals of observation.

The failures were then grouped according to location and type. Element type, subsystem, and system reliability and maintainability summaries were obtained using computerized mathematical models.

SYSTEM DESCRIPTION.

The Mode S is an improved surveillance and communications system for air traffic control. Each aircraft is assigned a discrete permanent address or unique code. By means of a software system resident in the ground-based sensor, a track is maintained on each aircraft under surveillance. Each Mode S-equipped aircraft within the antenna beam width is individually interrogated at the proper time by means of its discrete address code.

With reference to reliability, the Mode S sensor consists of three subsystems: the interrogator and processor (I&P) subsystem, the computer subsystem, and the communications subsystem. The I&P subsystem consists essentially of hardware. It transmits the interrogations to the aircraft, receives the replies from the aircraft's transponder, and processes these replies. The computer subsystem performs most of the software functions including internal scheduling, tracking, and message processing. It does this by means of 32 independent Mode S computers, each of which contains a portion of the operational program. Five redundant computers are included in the computer subsystem.

To perform many of its functions, Mode S incorporates a distributed computer architecture. This architecture features the multiple use of common modules such as computers, memory couplers, data bus lines, and modems. The application of redundancy at the module level increases the reliability. Common backup (as standby units) is provided on-line for each module type such that failure recovery, in general, can be accomplished at the local level without major perturbation to the remainder of the subsystem. All communication between computers is through global memory such that each computer with its tasks becomes an independent subsystem. If a computer fails, its tasks can be switched automatically to another computer with minimum interference with the rest of the subsystem. Mode S computers are grouped into ensembles with up to four computers in each ensemble. These computers are connected to an ensemble data bus line through which they communicate with the rest of the subsystem. Each Mode S computer consists of two central processors, voting logic for the central processors, and 8,192 bits of local error-correcting code memory. The code of a Mode S computer is executed simultaneously by each central processor. Results from the central processor executions are compared (or voted). If results agree, they are passed on to their destination; otherwise, the Mode S computer involved is immediately switched off-line to prevent any erroneous data from being passed to the data bus and onto the global memory.

The communications subsystem provides for communications with other Mode S sensors and with air traffic control facilities. It consists of three Mode S computers, one of which is redundant. The redundant communications subsystem computer is also available for use by the computer subsystem if needed.

For reliability purposes, each Mode S sensor is broken down into 22 element types comprising a total of 209 individual reliability elements per sensor. These element types, which are determined by physical, functional, and redundancy considerations, are shown in table 1.

TABLE 1. RELIABILITY ELEMENTS COMPRISING THE MODE S SENSOR

	Element Type	No. Evaluated
1.	Air-Conditioner	1
2.	Antenna	1
3.	Channel Transfer Unit	1
4.	Transmitter	1
5.	Receiver	1
6.	Processor (Including Air Traffic Control Radar Beacon System (ATCRBS) and Mode S)	1
7.	WWVB Receiver (Including Uninterruptable Power Supply)	1
8.	Bus Lines	12
9.	Couplers	42
10.	Interface Printed Circuit Boards (PCB's)	5
11.	+5-Volt Triplex Power Supplies	36
12.	±12-Volt Power Supplies	4
13.	12-Volt Power Supply Common	1
14.	Mode S Computers	35
15.	176K Memories	6
16.	Memory Monitor Switching Element (Part of Memory Monitor PCB)	2
17.	Memory Monitor Serial Element (Part of Memory Monitor PCB)	2
18.	Communications Interface Serial Element (Part of Communications PCB)	13
19.	Communications Interface Channel Element (Part of Communications PCB)	25
20.	Modems	16
21.	Link Switches	2
22.	Primary Radar Interface	1
	Total	209

TEST CONFIGURATION.

The reliability and maintainability evaluation was performed during the normal everyday use of the three sensors. Hence, it was not necessary to perform any special tests nor was any special system or equipment configuration required for the reliability and maintainability evaluation.

During this reporting period the sensors were used in varying degrees, including baseline and other performance testing by FAA personnel, on-the-job training for FAA maintenance personnel, etc. While the Mode S engineering requirement, FAA-ER-240-26, called for a maximum of 4 to 6 hours of preventive maintenance per month, preventive maintenance was actually performed on the sensors on a daily, weekly, and monthly basis. The average time devoted to preventive maintenance was 1 hour for daily procedures and 2 hours each for weekly and monthly procedures, or approximately 30 hours per month. These preventive maintenance activities included filter cleaning, which was performed monthy, off-line and diagnostic programs, which were performed daily. These diagnostic programs exercised the various logical functions of the hardware including the computers and global memories. As these diagnostic programs exercised all computers and memories simultaneously, the sensor was not available for operational use during the preventive maintenance intervals.

The sensors were energized continuously, but were generally used about 24 percent of the time from 8 a.m. to 4:30 p.m. on work days. This reliability and maintainability evaluation is based upon all times that the three sensors were electrically energized. This comprises a total period of almost 28,000 system hours of energized time.

DATA COLLECTION AND REDUCTION.

Data were collected from two sources: the Facility Maintenance Logs (FAA Form 6030-1) upon which failure and maintenance data as well as changes in operational status were recorded by FAA site personnel, and Mode S Trouble Reports maintained by Texas Instruments (TI) site personnel.

From these two sources each failure incident and change in operational status was associated with the proper reliability element. Data were obtained on 627 (209 x 3) reliability elements. Each reported hardware failure was assessed to determine whether or not it was to be considered as chargeable.

A failure is considered as chargeable if it: (1) is independent, that is, it did not occur as a result of a related failure or a hardware modification; (2) caused a loss or degradation of performance of the Mode S element in which it occurred; and (3) required actual maintenance effort to correct.

A failure is considered nonchargeable if it resulted from: (1) factors external to the equipment under test, i.e., failures of commercial power, etc.; (2) personnel error; or (3) manufacturing or wiring defects which, when corrected, preclude the possibility of recurrence.

Periodic consultation concerning the reported failures was held with FAA and TI personnel to determine the chargeability of these failures and to improve the accuracy of the reported information.

After this coordination, the reported data were encoded for data processing by the Automated Reliability Assessment Program (ARAP). The ARAP is a set of computer programs specifically developed to process and present the failure, maintenance, and operational status history of the various hardware reliability elements which comprise the three Mode S sensors. Further information concerning the ARAP programs is provided in reference 1. The ARAP data were then processed on the Honeywell 66/60 computer at the Technical Center.

After generating the basic ARAP summaries, a special computer program generated element-type, subsystem, and system summaries. These summaries include system calculated MTBF and MTTR values. The system MTBF is defined as the average length of time between system outages due to chargeable failures. MTTR is defined as the average length of time required to restore an element, subsystem, or system to operational status after a chargeable failure has occurred.

The computer program which generates these summaries incorporates mathematical models based upon the reliability block diagrams of the three subsystems which comprise the sensor; i.e., the I&P, computer, and communications subsystems. The reliability block diagrams for these three subsystems are shown in figures E-1 through E-3 of appendix E.

The program calculates the failure rates for each subsystem according to its reliability block diagram. These failure rates are determined by adding the failure rates for each box in the block diagram. Where parentheses are shown in a box, the presence of redundant elements in that box is indicated. Such redundancy is provided for in the mathematical models which are based upon these reliability block diagrams. For example, $\binom{2}{1}$ means there are two identical elements, only one of which is required.

After computing the failure rates for each of the three subsystems, the program adds them to generate the calculated system failure rate. The reciprocal of the calculated system failure rate is the calculated system MTBF.

The computations were made by entering into the computer the total uptime, number of chargeable failures, and total repair times for each of the 22 element types shown in table 1. This information was obtained from the ARAP printouts. In addition to these 66 quantities, the average time to replace failed PCB's was entered. The reason being is that in the design and development of the Mode S, it was felt that when removing a failed PCB from a bus line, the bus line should first be deenergized to prevent undesirable spikes or transients. Because of this, redundant elements connected to certain bus lines would be repaired immediately upon failure since these bus lines could be deenergized without causing system outage.

In the case of bus lines which must be continuously energized for the system to operate, failed redundant elements (or PCB's) would remain connected to such bus lines until a convenient time occurred in which to power down the bus line and remove the failed PCB. Under worse case conditions, this would be the next 30-day scheduled maintenance period (720 hours) as designated in the engineering requirement. Since a PCB is equally likely to fail at any time during this 720-hour interval, the average time to replacement will be one-half the maximum or 360 hours. In actual practice, preventive maintenance was performed daily; hence, these failure rate determinations are made for both 360- and 12-hour average times

to replacement of failed PCB's. These average replacement time factors are used in the determination of the failure rates of the computer and the communications subsystems since these make extensive use of redundant elements. Replacement time factors are not used in the determination of the I&P subsystem failure rate.

The failures per million hours and MTTR are then calculated for each of the 22 element types. This is done by the formulas:

$$\text{Failures per million hours} = \frac{\text{No. of failures} \times 10^6}{\text{Total uptime}}$$

$$\text{MTTR (hours)} = \frac{\text{Total repair time (hours)}}{\text{No. of failures}}$$

The subsystem failure rates and MTTR are computed by mathematical models described in reference 2. The system failure rate is the sum of the failure rates of the three subsystems. The system MTBF was computed by the formula:

$$\text{MTBF} = \frac{10^6}{\text{System failures per million hours.}}$$

TEST RESULTS AND ANALYSIS

TECHNICAL CENTER SENSOR.

GENERAL. During this interval 144 hardware failures occurred, of which 76 were chargeable. The location and nature of the 76 chargeable failures are shown in table 2.

Of 76 chargeable failures, 18 actually caused the sensor to go down. These system failures are distributed as follows: transmitter (5), receiver (4), processor (4), interface PCB's (3), WWVB receiver (1), and antenna (1). Considering system chargeable failures only, the measured (observed) MTBF was 767.3 hours ($\frac{13813}{18}$). When all system failures which caused sensor outage are included (chargeable and nonchargeable) the MTBF was 281.9 hours ($\frac{13813}{18+31}$).

Of the 68 nonchargeable failures, 20 were traveling wave tube (TWT) filament faults in the transmitter. The fault detection circuits work to detect improper filament voltage to the TWT tubes. The fault is indicated by a light which is reset manually. Two consecutive faults without reset will power the transmitter down. Several instances of such powering down occurred during overnight periods when the system was unattended. The high incidence of these filament faults was initially improper alignment of the fault detection circuitry. This was religned in May 1979; since then six faults have occurred. These instances of consecutive faults

TABLE 2. LIST OF CHARGEABLE FAILURES FOR THE TECHNICAL CENTER SENSOR

Type	No.
1. Antenna — 1 chargeable failure (shorted brake release solenoid)	
2. Transmitter — 5 chargeable failures	
a. Inoperative TWT cooling switch	1
b. Shorted optical coupler on main grid modulator PCB	1
c. TWT cooling air fault	1
d. Loose fault control PCB	1
e. No roll-call replies due to defective exciter modulator control PCB	1
3. Receiver — 4 chargeable failures	
a. Defective intermediate frequency (IF) sum log amplifier PCB	1
b. Boresite off tolerance	1
c. Loose or defective performance monitor PCB's	2
4. Processor — 4 chargeable failures	
a. Defective message decode and overtemperature interrupt due to *dirty filter*	1
b. Defective power supply	1
c. Loose processor control PCB	1
d. Out-of-tolerance boresite error	1
5. WWVB Receiver — 1 chargeable failure (status bit circuitry caused interrupts)	1
6. Bus Lines — 7 chargeable failures	
a. General cooling fan failures	3
b. Burned out cooling fan	1
c. *Defective cooling fan bearings*	2
d. Defective priority PCB	1
7. Couplers — 4 chargeable failures	
a. Dirty connectors or contact problems	3
b. General	1
8. Interface PCB — 3 chargeable failures	
a. Loose or dirty contacts	1
b. Miscellaneous	2

TABLE 2. LIST OF CHARGEABLE FAILURES FOR THE TECHNICAL CENTER SENSOR (CONTINUED)

Type			No.
9.	+5-Volt Triplex Power Supplies — 4 chargeable failures		
	a. Overvoltage kicked off		1
	b. Cooling fan failures		3
10.	Mode S Computers — 24 chargeable failures		
	a. Voting errors		10
	(1) Defective AU-1 PCB's	6	
	(2) Defective Voter PCB's	2	
	(3) Defective Local Memory PCB	1	
	(4) Loose connector	1	
	b. Other AU-1 PCB failures		1
	c. Other local memory PCB failures		7
	d. Other voter PCB failures		4
	e. Loose PCB's		1
	f. Miscellaneous		1
11.	176K Memories — 3 chargeable failures		
	a. Defective 176K memory PCB's		1
	b. Defective standby power supply module		1
	c. Defective 48K memory PCB		1
12.	Memory Monitor PCB, Switching Element — 1 chargeable failure (global B bus line hangup traced to defective memory monitor PCB)		
13.	Communications Interface PCB, Serial Element — 2 chargeable failures		
	a. Bad modem receive data traced to failed Communications Interface PCB		1
	b. Loss of surveillance transmit function at two modems traced to defective Communications Interface PCB		1
14.	Communications Interface PCB, Channel Element — 2 chargeable failures (no communications messages on two channels traced to defective communications interface PCB's)		2
15.	Modems — 11 chargeable failures		
	a. Carrier or data errors		6
	b. Power supply or regulator failures		2
	c. Miscellaneous		3

are considered failures in the sense that the transmitter is made unavailable; but since this is due to environmental conditions, the failures are considered nonchargeable.

The air-conditioner was not representative of the one used in Mode S and its four failures are considered nonchargeable. Another 12 of the nonchargeable failures involved the isolation and replacement of defective chips on the local memory PCB's, which are component parts of the Mode S computers. The PCB's were located through the use of diagnostic routines during scheduled preventive maintenance time. The defective chips are used in the error-correcting circuitry. Failures in one such chip are considered nonchargeable because they will not cause degradation of performance of the associated computer since its error-correcting functions will be taken over by a spare.

The remaining 32 of these nonchargeable failures were due to miscellaneous causes. They are documented in log books and computer printouts at the Technical Center. Of the 68 nonchargeable failures, 31 actually caused sensor outage. Twenty of these were due to the TWT filament faults described previously. Two were caused by defective antenna drive motor coupling plates and a transmitter preheat problem which was cleared by recycling of alternating current power switches. Four were attributable to the air-conditioner. The other five were in the WWVB receiver. These included three loss-of-timing signals, one transient, and one human error failures.

Tables A-1 and A-2 of appendix B show the the overall summaries for the sensor at the Technical Center for the 20-month period extended from October 1, 1978, through May 31, 1980. These summaries are for the 360- and 12-hour average PCB replacement rates, respectively. These tables show that for this period the calculated MTBF of the Technical Center sensor was 526 hours for the 360-hour replacement rate and 543 hours for the 12-hour rate. The corresponding MTTR was 1.3 hours for each replacement rate.

PART FAILURES. During this reporting period, 110 component failures, replacements, and/or adjustments were recorded for the Technical Center sensor. Of these actions, 44 occurred on Mode S Computer PCB's: 24 in the Local Memory PCB's, 13 in the arithmetic unit (AU)-1 PCB's, and 7 in the voter PCB's. Of the 24 local memory PCB part actions, 15 were nonchargeable in that they comprised replacement of spare chips as described in the preceding paragraph. Therefore, there was 13 AU part actions, 9 local memory PCB part actions, and 7 voter PCB actions which were directly related to computer failures.

Thirteen cooling fan replacements occurred. Seven of these were in the bus lines, while six occurred in the individual 5-volt triplex power supply modules. There are three kinds of cooling fans in the bus lines and 5-volt power supplies. The first type of fan is a Rotron 113. There are 24 of these fans, two in each of the 12 bus lines. The second type of fan is a Boxer WS2107FL. These fans are in the individual 5-volt triplex power supply modules, of which there are 36. The third type is a Rotron type MU-2B-1 muffin fan. There is one of these muffin fans on each of the 12 triplex power supply drawers. Seven of the cooling fan failures occurred in the Rotron 113 fans; the other six occurred in the Boxer fans. No failures occurred in the muffin fans.

ELWOOD SENSOR.

GENERAL. During this interval a total of 38 hardware failures occurred, of which 21 were chargeable. The location and nature of these 21 chargeable failures are shown in table 3. Four of the 21 chargeable failures actually caused the sensor to go down. One each occurred in the transmitter, the air-conditioner, the WWVB receiver, and the processor. Considering chargeable failures only, the measured (observed) system MTBF was 1913.6 hours $(\frac{7654.4}{4})$. When all system failures are included (chargeable and nonchargeable) the MTBF was 956.8 hours $(\frac{7654.4}{4+4})$.

Most of the 17 nonchargeable failures were due to external causes. The distribution of these nonchargeable failures are as follows:

1. Shipping damage (1)
2. Human error (2)
3. Manufacturing defects (4)
4. Maintenance causes (3)
5. External equipment (1)
6. Previous lightning strike (1)
7. Directly related to previous failure (2)
8. WWVB timing signal loss (1)
9. Battery replacement (2).

Four of these seventeen nonchargeable failures caused system outage. One each occurred in the transmitter, the receiver, the processor, and the WWVB receiver.

Tables B-1 and B-2 of appendix B show the overall summaries for the Elwood sensor for the 11-month period extending from July 1, 1979, through May 31, 1980. These summaries are for the 360- and 12-hour replacement rates, respectively. The tables show that for this period the calculated MTBF of the Elwood sensor was 1,242 hours for the 360-hour replacement rate and 1,271 hours for the 12-hour rate. The corresponding MTTR was 1.2 hours for each replacement rate.

PART FAILURES. During this reporting period 33 part or component failures, replacements, and/or adjustments were recorded for the Elwood sensor. Of these actions 13 occurred on computer PCB's: 8 in the local memory PCB's, 3 in the AU-1 PCB's, and 2 in the voter PCB's. Six of the eight local memory PCB actions involved replacement of spare chips used in the error-correcting circuitry. Four cooling fan failures occurred in the Elwood sensor. Three of these occurred in bus lines, while one occurred in a +5-volt triplex power supply individual module. No failures occurred in the muffin fans.

TABLE 3. LIST OF CHARGEABLE FAILURES FOR THE ELWOOD SENSOR

	Type	No.
1.	Air-Conditioner — 1 chargeable failure (low output, ambient temperature above 90° F)	1
2.	Transmitter — 1 chargeable failure (preheat did not go off, recurring problem)	1
3.	Processor — 1 chargeable failure (defective Mode S data assembler PCB)	1
4.	WWVB Receiver — 1 chargeable failure (intermittent temperature control, recurring problem)	1
5.	Bus Lines — 5 chargeable failures	
	a. Intermittent short circuits in interface lines	2
	b. Defective cooling fans	3
6.	Couplers — 1 chargeable failure (poor contact)	1
7.	+5-Volt Triplex Power Supplies — 3 chargeable failures	
	a. General	2
	b. Defective cooling fan	1
8.	Mode S Computers — 3 chargeable failures (voting errors)	
	a. Loose AU-1 PCB's	2
	b. Defective Voter PCB's	1
9.	176K Memories — 2 chargeable failures (data errors due to bad chips)	2
10.	Communications Interface PCB, Serial Element — 1 chargeable failure (defective communications interface PCB)	1
11.	Communications Interface PCB, Channel Element — 1 chargeable failure (incorrect data word traced to defective communications interface PCB)	1
12.	Modems — 1 chargeable failure (carrier loss)	1

CLEMENTON SENSOR.

GENERAL. A total of 17 hardware failures occurred during this interval. Seven of these were chargeable. The location and nature of these seven chargeable failures are shown in table 4.

TABLE 4. LIST OF CHARGEABLE FAILURES FOR THE CLEMENTON SENSOR

1. Transmitter — 1 failure (main TWT filament lamp intermittent), defective fault control No. 1 PCB

2. Processor — 2 failures

   a. Mode S clock inoperative due to defective 16-megahertz (MHz) oscillator in processor control A PCB

   b. Cold start error due to defective one-shot on performance monitor PCB

3. WWVB Receiver — 1 failure (wrong numerics, recurring problem)

4. Couplers — 1 failure (parity error caused by loose Coupler PCB)

5. +5-Volt Triplex Power Supplies — 1 failure

6. Communications Interface PCB, Channel Element — 1 failure (transient parity error due to defective PCB)

Four of the seven chargeable failures actually caused the system to go down. One failure was in the transmitter, two failures were in the processor, and one failure was in the WWVB receiver. The measured (observed) system MTBF was 1417.4 hours $(\frac{5669.8}{4})$. Counting chargeable and nonchargeable system failures, the measured (observed) system MTBF was 629.9 hours $(\frac{5669.8}{4+5})$.

The distribution of the 10 nonchargeable failures was as follows:

1. Maintenance causes (3)
2. External equipment (2)
3. Previous lightning strike (1)
4. Corrected design deficiency (1)
5. Unrelated to system operation (2)
6. Improper operation (1)

Five of these ten nonchargeable failures caused system outage. One of these occurred in the air-conditioner; the others occurred two apiece in the antenna and transmitter.

Tables C-1 and C-2 of appendix C show the overall summaries for the Clementon sensor for the 8-month period extending from October 1, 1979, through May 31, 1980. These summaries are for the 360- and 12-hour replacement rates, respectively. These tables show that for this period the calculated MTBF of the Clementon sensor were 1,407 and 1,417, respectively, for the 360- and 12-hour replacement rates. The corresponding MTTR was 0.6 hour for each replacement rate.

PART FAILURES. During this reporting period 18 part or component failures, replacements, and/or adjustments were recorded for the Clementon sensor. Five of these concerned computer PCB's: one local memory, two AU-1, and two voter PCB's.

COMPARISON OF FAILURES AT SITES. Table 5 tabulates the number of chargeable and nonchargeable system failures for the Technical Center, Elwood, and Clementon sites. Table 6 tabulates the number of chargeable element failures on a site basis. About 0.9, 0.36, and 0.5 chargeable system failures per month occurred at the Technical Center, Elwood, and Clementon sites, respectively.

The Technical Center sensor has the highest system failure rate. The identification of the problem areas that contribute to low reliability will help lead to recommendations for remedial action. Data from all three sites are not combined to determine failure rates and MTBF values because of the significant difference in the number of failures for a time interval. The preponderence of failures at the Technical Center sensor may have occurred because it was stressed to a greater extent than the other two sites.

OVERALL MTTR. Figure 1 is a histogram of the repair times of the 104 total chargeable failures incurred by the individual elements of all three sensors. This shows that the repair times of the element failures appear to be exponentially distributed. The MTTR of these 104 failures is 0.8 hour and is shown as line "A" in figure 1. This meets the requirement of paragraph 3.9.4.1(i), FAA-ER-240-26, that the mean corrective maintenance time shall not exceed 1 hour. The 90th percentile value of maximum repair times is approximately 1 hour and is shown as line "B" of figure 1. This is below the 2-hour maximum requirement specified in the same paragraph of the engineering requirement. The measured system MTTR of 1.1 hour (for the 360-hour replacement rate) is shown as line "C" in figure 1.

PROBLEM AREAS.

AIR-CONDITIONER PROBLEMS. While only one actual chargeable air-conditioner failure occurred at the combined Elwood and Clementon sites during this reporting period, several instances occurred in which the air-conditioners failed to maintain the ambient temperature below 90° F. This was particularly evident during the hot summer of 1980 (subsequent to the observed interval of this report). This condition was also due to the additional equipment in the trailers such as the Aircraft Reply and Interference Environment Simulator (ARIES) and components of the computer performance measurement system (hardware monitoring and PDP-11 peripherals).

An additional four tons (50-percent increase) of air-conditioning capacity was added to the Elwood site. While this reduced the ambient temperature within the sensor trailer, it also increased the relative humidity from 35 to 55 percent. Specifically, it was reported that the Elwood Mode S transmitter had failed due to arcing within the power supply. This arcing was attributed to high absolute humidity.

TABLE 5. CHARGEABLE AND NONCHARGEABLE SYSTEM FAILURE COMPARISONS BY SITE

	Technical Center		Elwood		Clementon	
Element	Chargeable	Non-chargeable	Chargeable	Non-chargeable	Chargeable	Non-chargeable
1		4	1			1
2	1	1				2
3						
4	5	21	1	1	1	2
5	4			1		
6	4		1	1	2	
7	1	5	1	1	1	
8						
9						
10	3					
11-22 (No system failures were attributable to elements 11 through 22)						
Totals	18	31	4	4	4	5
Combined Totals	49		8		9	

Note: Element identifications are shown in table 1.

TABLE 6. CHARGEABLE ELEMENT FAILURE COMPARISONS

Element	Technical Center	Elwood	Clementon
1	0	1*	0
2	1*	0	0
3	0	0	0
4	5*	1*	1*
5	4*	0	0
6	4*	1*	2*
7	1*	1*	1*
8	7	5	0
9	4	1	1
10	3*	0	0
11	4	3	1
12	0	0	0
13	0	0	0
14	24	3	0
15	3	2	0
16	1	0	0
17	0	0	0
18	2	1	0
19	2	1	1
20	11	1	0
21	0	0	0
22	0	0	0
Totals	76	21	7

*These chargeable failures caused system outage.

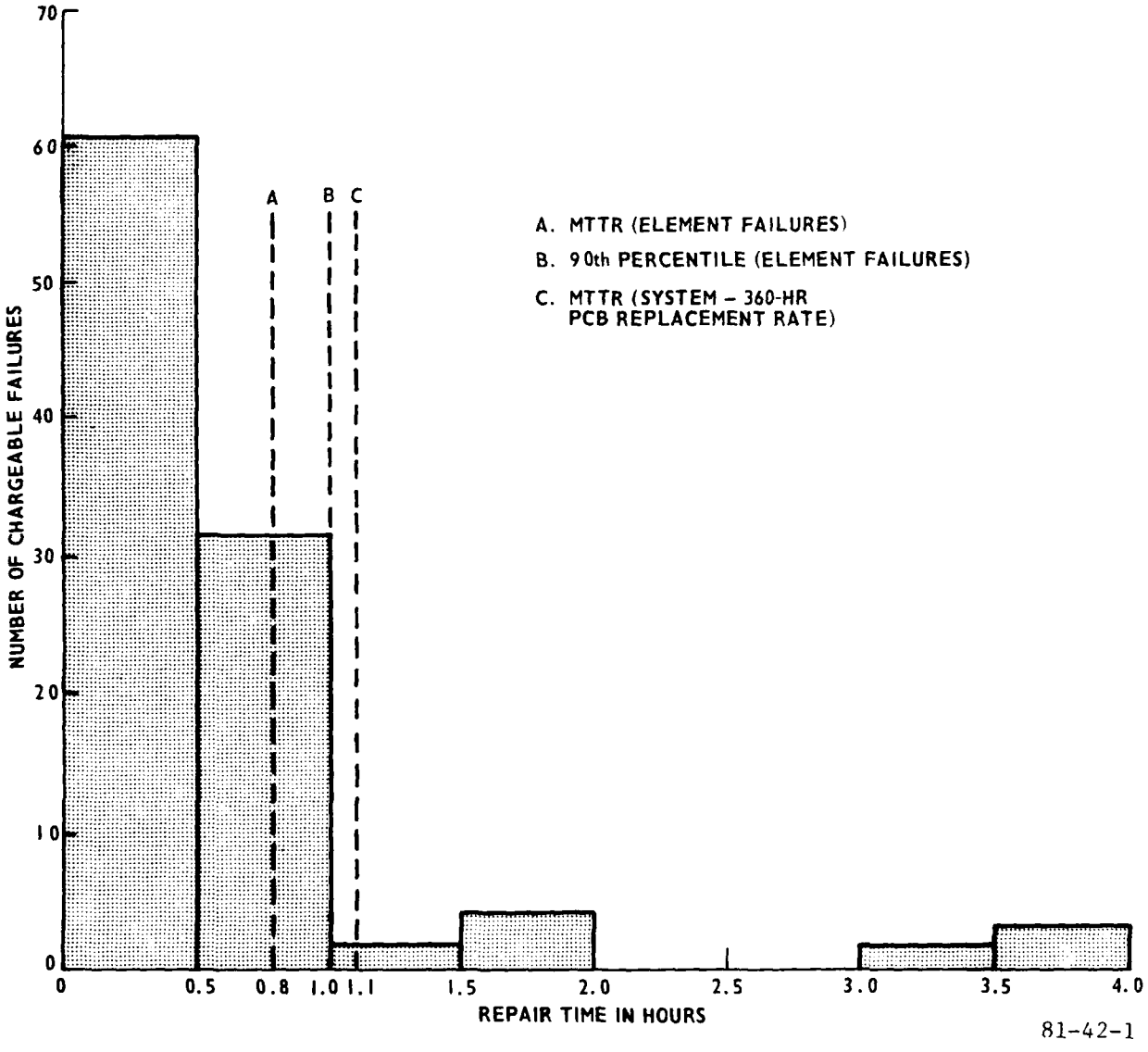

FIGURE 1. DISTRIBUTION OF REPAIR TIMES OF OVERALL CHARGEABLE FAILURES

COOLING FAN PROBLEMS. Cooling fan failures occurred in the bus lines and the 5-volt triplex power supplies. Of the 12 chargeable bus line failures, 9 involved defective cooling fans. Of the 8 chargeable triplex power supply failures, 5 involved defective Boxer fans. This type of fan has an enclosed oil wick for lubricating purposes. These wicks run dry and are difficult to relubricate because of their inaccessibility. (Figure 2 illustrates this inaccessibility.) Consequently, the fans fail. The lubricating hole is in back of the fan, away from the front panel of the triplex drawer. To gain accessibility, it is necessary to remove the module from the triplex drawer and then disassemble the module to remove the fan.

COMPUTER SUBSYSTEM PROBLEMS. One problem area concerning the computer subsystem was the bending and shorting out of the wire-wrap pins on the bottom of the assemblies when the power supply drawer below it was pulled out. Two large power cables are tied down; but when the drawer is shut, they flex upward and rub against the pins. Figure 3 shows some of these bent pins.

WWVB PROBLEMS. In addition to the two chargeable WWVB failures which were reported, there were several instances of loss of timing signal of the WWVB receiver due to insufficient signal strength at the antenna.

The WWVB receiver is critical to the operation of the Mode S sensor. It provides a time standard for the processor and is used throughout the sensor as a time base. The WWVB receiver receives the transmission from the National Bureau of Standards radio station WWVB located in Boulder, Colorado. This signal, which is transmitted at 60 kilohertz (kHz), is decoded by the WWVB receiver and displayed as time of day.

The field intensity of this WWVB signal is particularly weak in the South Jersey area where the three sensors are located. Many cases of this have been noted, particularly during the winter months.

LIGHTNING DAMAGE. Lightning caused extensive damage to all three sensors during the summer of 1979.

PART FAILURE/REPLACEMENT RATES.

Table D-1 of appendix D list the number of parts which failed, were adjusted, or replaced as a result of maintenance actions. The parts include PCB's and cooling fans. These part maintenance actions are expressed in terms of failure and replacement rates.

Table D-2 of appendix D further lists those part types of table D-1 for which two or more failures and/or replacements occurred. These are listed in decreasing order of failure or replacement rate per element type. It will be noted from table D-2 that the five part types which have experienced the highest failure or replacement rates are in the transmitter, the receiver, and the processor. These are single-string elements in the I&P subsystem which have relatively high failure rates and tend to lower the system MTBF.

The corresponding MTBF's, which are the reciprocals of the failure and replacement rates, are also shown for each part in table D-2 for convenience.

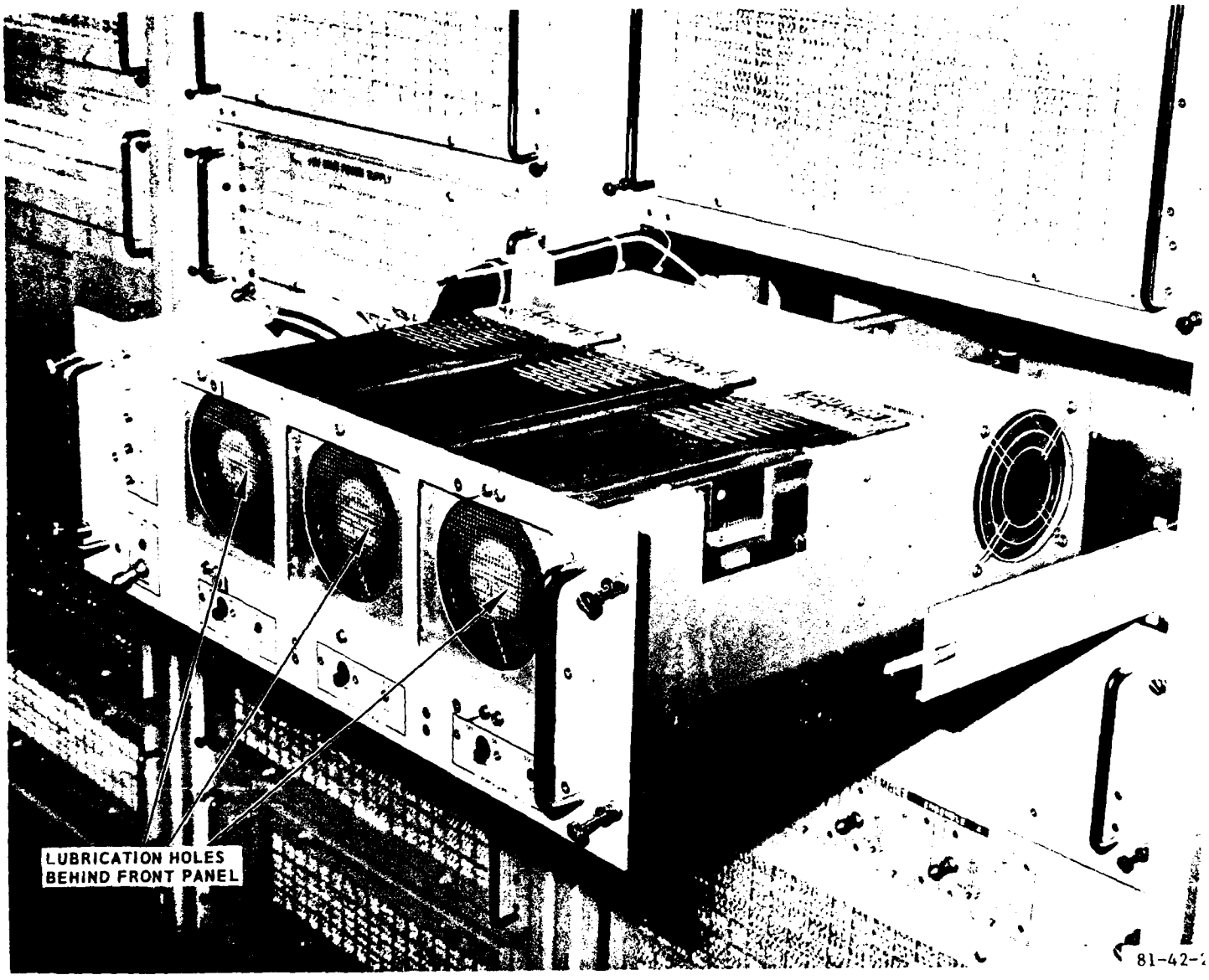

FIGURE 2. TRIPLEX POWER SUPPLY COOLING FANS

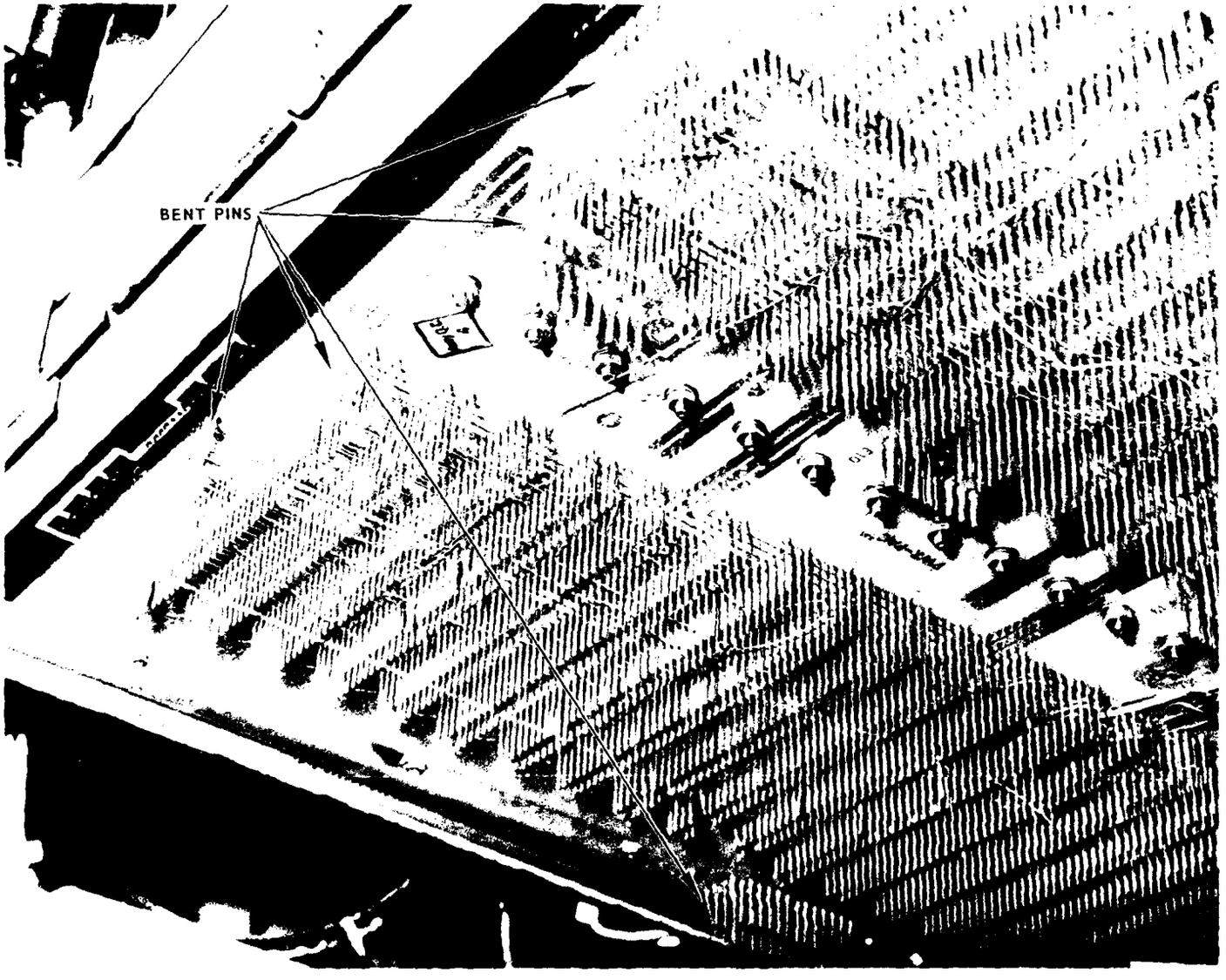

FIGURE 3. BENT WIRE-WRAP PINS ON COMPUTER ENSEMBLE

SUMMARY OF RESULTS

1. The measured (observed) system MTBF for the Mode S sensor at the Technical Center site was 767.3 hours. This value was obtained over a 20-month interval extending from October 1, 1978, through May 31, 1980. Eighteen chargeable system failures occurred.

2. The measured (observed) system MTBF for the Elwood sensor was 1913.6 hours. This value was obtained over an 11-month interval extending from July 1, 1979, through May 31, 1980. Four chargeable system failures occurred.

3. The measured system MTBF for the Clementon sensor was 1417.4 hours. This value was obtained over an 8-month interval extending from October 1, 1979, through May 31, 1980. Four chargeable system failures occurred.

4. A total of 104 chargeable failures occurred among all three sensors during this reporting interval. Of these 104 failures, 26 chargeable failures caused the sensor to go down. These system failures are distributed as follows: transmitter (7), receiver (4), processor (7), interface PCB's (3), antenna (1), and WWVB receiver (3). In addition, 20 transient TWT filament faults in the transmitter at the Technical Center caused system outages.

5. The elements which contributed to the low MTBF value for the Technical Center are the processor, transmitter, bus lines, and memory monitor switching.

6. Exercising diagnostic programs for all computers and memories simultaneously results in th nonavailability of Mode S for operational use.

7. The five PCB types which experienced the highest failure and/or replacement rates are fault No. 1, fault No. 2, the exciter-modulator control, the performance monitor, and the processor control B PCB's. The first three are located in the transmitter, the other two in the receiver and the processor, respectively.

8. The average time devoted to preventive maintenance was approximately 30 hours per month versus a specified value of 4 hours per month.

9. The cumulative measured failure rate of Mode S computers was 27.803 failures per million hours, compared to their predicted value of 214.316. This is equivalent to saying that the measured MTBF of these computers is nearly eight times better/greater than their predicted values.

10. About one in four of the chargeable failures occurred in the Mode S computers. Nearly 50 percent of these computer failures were voting errors.

11. Several problems concerning bending and shorting of wire-wrap pins were encountered. These pins are on the bottom of the computer assembly drawers and are bent when the power supply drawer below them is pulled out.

12. Seventeen cooling fan failures occurred among all three sensors. Ten of these occurred in the bus lines while seven occurred in the +5-volt triplex power supplies.

13. The cooling fans in the +5-volt triplex power supplies have an enclosed oil wick for lubricating purposes. These wicks run dry and, due to their inaccessibility, are difficult to relubricate; consequently, the fans fail.

14. The MTTR of the 104 element chargeable failures was estimated to be 0.8 hour, which is less than the 1-hour maximum allowable limit specified in paragraph 3.9.4.1(i) of the engineering requirement. The estimated maximum repair time of the 104 element chargeable failures is approximately 1 hour at the 90th percentile, which is less than the 2-hour maximum allowable limit specified in paragraph 3.9.4.1(i) of the engineering requirement.

15. Several instances of loss of the timing signal have occurred in the WWVB receiver.

16. Substantial damage was sustained by all three sensors as a result of lightning strikes during the summer of 1979.

17. A substantial proportion of the chargeable failures which occurred in the triplex power supply modules and the bus lines were cooling fan failures.

18. The 360-hour versus 12-hour average PCB replacement philosophy was not actually tested.

CONCLUSIONS

1. The measured mean-time-to-repair (MTTR) values for both the system and the element chargeable failures were better than the requirements specified in FAA-ER-240-26.

2. From a reliability standpoint, the weak elements in the Mode S sensor are the processor and transmitter.

3. The five printed circuit board (PCB) types which experienced the highest replacement rates are located in the transmitter, the receiver, and the processor.

4. The Mode S sensor is subject to failure due to transient power surges in the filament voltages applied to the traveling wave tubes (TWT's) in the transmitter.

5. From a hardware standpoint, the Mode S computers were found to be nearly eight times more reliable than the predicted value.

6. The wire-wrap pins on the bottom of the computer assemblies are subject to damage when the power supply drawer below it is shut. This is due to the flexing upward of power cables which run against the pins, thereby, bending and shorting them.

7. Cooling fan failures have been a problem in the bus lines and the 5-volt triplex power supplies.

8. Difficulty in relubricating the oil wicks in the cooling fans located in the +5-volt triplex power supplies have been encountered. This difficulty arises because of the inaccessibility of these fans and has contributed to their failure.

9. The WWVB receiver is subject to loss of timing signals.

10. The Mode S sensor is subject to damage by lightning strikes if suitable grounding and lightning protection techniques are not employed.

11. The 360-hour versus 12-hour average PCB replacement philosophy was not tested.

12. Definitive failure information on replaced PCB's was not made available by the maintenance contractor.

13. Repair experience did not substantiate the contractor anticipated need for a delayed repair philosophy.

14. The channel transfer unit, the WWVB receiver, and the 12-volt power supply common were not included in the contractor's reliability mathematical model. Although there were no failures of the channel transfer unit and the 12-volt power supply common, there were four chargeable WWVB failures at the Technical Center, one failure at Elwood, and one failure at Clementon.

15. The system mean-time-between failure (MTBF) at the Technical Center was 767.3 hours for chargeable failures and 281.9 hours for chargeable and nonchargeable failures. The Elwood sensor values were 1913.6 and 956.8 hours, respectively; the Clementon sensor values were 1417.4 and 629.9 hours, respectively.

16. The five part types which have experienced the highest failure rates are in the processor, transmitter, and receiver.

17. Significant increases in system reliability could result by including redundancy of equipments in the interrogator and processor (I&P) subsystem.

18. Design requirements for production systems should advocate an immediate repair criteria.

19. The checkout of traveling wave tubes in the sensor is time consuming and makes the sensor unavailable for operational use.

20. The engineering requirement for preventive maintenance was not met. About 30 hours a month was devoted to preventive maintenance versus a specified value of 4 hours.

21. The failure rate for the air-conditioner was an assumed value rather than a predicted one.

RECOMMENDATIONS

1. In the design of future Mode S sensors, the reliability of the processor and transmitter should be increased. High failure rate circuit boards associated with these elements, i.e., fault No. 1, fault No. 2, the exciter-modulator control, the performance monitor, and the processor control B PCB, are particularly suitable candidates for reliability improvement.

2. For production systems, a redesign to prevent the damaging of the wire-wrap pins on the bottom of the computer assembly should be made.

3. Suitable lightning protection methods should be incorporated in all future Mode S systems to protect against damage due to lightning strikes.

4. An investigation of the inadequate signal output from the WWVB receiver should be conducted.

5. Cooling fans in the +5-volt triplex power supplies should be made more accessible for ease of lubrication with lubrication added to the preventive maintenance procedures; fans which have sealed bearings should be considered for replacement.

6. Data should be collected, analyzed, and reported upon for the initial Mode S field installation to further define weak points in the reliability design and to recommend improvements.

7. The capability for an automatic restart for the transmitter following shutdown because of transient occurrences should be a design requirement.

8. Methods and techniques for conducting diagnostic maintenance procedures without requiring interruption to system operation should be a design requirement.

9. The WWVB receiver is a critical element in Mode S and its failure rate should be considered in the reliability prediction model for production systems.

10. A failure rate prediction should be made for the commercial type air-conditioner.

REFERENCES

1. Wojciechowicz, John J., Automated Reliability Assessment Program, Final Report, FAA-RD-74-16, April 1974.

2. Moss, Arthur R., Plan for the Reliability and Maintainability Evaluation of the Discrete Address Beacon System (DABS) Engineering Laboratory Models, Final Report, FAA-NA-78-31, October 1978.

APPENDIX A

RELIABILITY AND MAINTAINABILITY SUMMARIES FOR THE TECHNICAL CENTER SENSOR

TABLE A-1. RELIABILITY AND MAINTAINABILITY SUMMARIES FOR TECHNICAL CENTER SENSOR FOR 360-HOUR AVERAGE PCB REPLACEMENT RATE

MODE S RELIABILITY AND MAINTAINABILITY SUMMARIES- SINGLE CHANNEL

SITE= TECH CEN FROM= OCTOBER 1, 1978 TO= MAY 31, 1980

AVERAGE TIME TO REPLACEMENT OF FAILED PCB'S= 360 HOURS

1. ELEMENT TYPE SUMMARY

	TOTAL UPTIME (ELEMENT-HOURS)	NO. OF FAILURES	TOTAL REPAIR TIME (ELEMENT-HOURS)	FAILURES PER MILLION HOURS	MEAN TIME TO REPAIR (HOURS)
1. AIR CONDITIONERS	13885.11	4	7.10	288.078	1.8
2. ANTENNA	13624.71	1	3.08	73.396	3.1
3. CHANNEL TRANSFER UNIT	14008.05	0	0.	0.	0.
4. TRANSMITTER	13011.56	5	10.87	384.274	2.2
5. RECEIVER	13968.62	4	4.17	286.356	1.0
6. PROCESSOR	13969.30	4	2.67	286.342	0.7
7. WWVB RECEIVER	13310.51	1	0.90	75.129	0.9
8. BUS LINES	168280.94	7	4.33	41.597	0.6
9. COUPLERS	588773.32	4	1.38	6.794	0.3
10. INTERFACE PCB'S	69997.42	3	1.50	42.859	0.5
11. +5-VOLT POWER SUPPLIES	504832.22	4	2.00	7.923	0.5
12. +/-12-VOLT POWER SUPPLIES	56102.87	0	0.	0.	0.
13. +/-12-VOLT POWER SUPPLY COMMON	14025.80	0	0.	0.	0.
14. MODE S COMPUTERS	488683.50	24	14.34	49.112	0.6
15. 176K MEMORIES	84121.68	3	1.62	35.663	0.5
16. MEMORY MONITOR SWITCHING ELEMENT	28381.71	1	4.00	35.234	4.0
17. MEMORY MONITOR SERIAL ELEMENT	28385.71	0	0.	0.	0.
18. COMM. I/F PCB SERIAL ELEMENT	180648.80	2	3.83	11.071	1.9
19. COMM. I/F PCB CHANNEL ELEMENT	348828.58	2	1.00	5.733	0.5
20. MODEMS	222835.13	11	7.77	49.364	0.7
21. LINK SWITCHES	28042.02	0	0.	0.	0.
22. PRIMARY RADAR INTERFACE	14025.80	0	0.	0.	0.

2. SUBSYSTEM SUMMARY - SINGLE CHANNEL

A. INTERROGATOR AND PROCESSOR SUBSYSTEM	1323.525	1.5
B. COMPUTER SUBSYSTEM		
1) ATCRBS GROUP	86.393	0.6
2) ENSEMBLE GROUP	18.294	0.3
3) GLOBAL MEMORY GROUP	261.313	0.5
TOTAL COMPUTER SUBSYSTEM	366.000	0.5
C. COMMUNICATIONS SUBSYSTEM		
1) COMMUNICATIONS CONSOLE (INCLUDING COMPUTERS)	46.973	0.6
2) COMMUNICATIONS INTERFACE CONSOLE (INCLUDING MODEMS)	91.960	0.7
TOTAL COMMUNICATIONS SUBSYSTEM	138.933	0.7

3. SYSTEM SUMMARY - SINGLE CHANNEL 1898.508 1.3

SYSTEM MTBF 526 HOURS

81-42-A-1

TABLE A-2. RELIABILITY AND MAINTAINABILITY SUMMARIES FOR TECHNICAL CENTER SENSOR FOR 12-HOUR AVERAGE PCB REPLACEMENT RATE

MODE S RELIABILITY AND MAINTAINABILITY SUMMARIES- SINGLE CHANNEL

SITE= TECH CEN FROM= OCTOBER 1, 1978 TO= MAY 31, 1980

AVERAGE TIME TO REPLACEMENT OF FAILED PCB'S= 12 HOURS

1. ELEMENT TYPE SUMMARY

	TOTAL UPTIME (ELEMENT-HOURS)	NO. OF FAILURES	TOTAL REPAIR TIME (ELEMENT-HOURS)	FAILURES PER MILLION HOURS	MEAN TIME TO REPAIR (HOURS)
1. AIR CONDITIONERS	13885.11	4	7.10	288.078	1.8
2. ANTENNA	13624.71	1	3.08	73.396	3.1
3. CHANNEL TRANSFER UNIT	14008.05	0	0.	0.	0.
4. TRANSMITTER	13011.56	5	10.87	384.274	2.2
5. RECEIVER	13968.62	4	4.17	286.356	1.0
6. PROCESSOR	13969.30	4	2.67	286.342	0.7
7. WWVB RECEIVER	13310.51	1	0.90	75.129	0.9
8. BUS LINES	168280.94	7	4.33	41.597	0.6
9. COUPLERS	588773.32	4	1.38	6.794	0.3
10. INTERFACE PCB'S	69997.42	3	1.50	42.859	0.5
11. +5-VOLT POWER SUPPLIES	504832.22	4	2.00	7.923	0.5
12. +/-12-VOLT POWER SUPPLIES	56102.87	0	0.	0.	0.
13. +/-12-VOLT POWER SUPPLY COMMON	14025.80	0	0.	0.	0.
14. MODE S COMPUTERS	488683.50	24	14.34	49.112	0.6
15. 176K MEMORIES	84121.68	3	1.62	35.663	0.5
16. MEMORY MONITOR SWITCHING ELEMENT	28381.71	1	4.00	35.234	4.0
17. MEMORY MONITOR SERIAL ELEMENT	28385.71	0	0.	0.	0.
18. COMM. I/F PCB SERIAL ELEMENT	180648.80	2	3.83	11.071	1.9
19. COMM. I/F PCB CHANNEL ELEMENT	348828.58	2	1.00	5.733	0.5
20. MODEMS	222835.13	11	7.77	49.364	0.7
21. LINK SWITCHES	28042.02	0	0.	0.	0.
22. PRIMARY RADAR INTERFACE	14025.80	0	0.	0.	0.

2. SUBSYSTEM SUMMARY - SINGLE CHANNEL

A. INTERROGATOR AND PROCESSOR SUBSYSTEM	1323.525	1.5
B. COMPUTER SUBSYSTEM		
1) ATCRBS GROUP	84.523	0.6
2) ENSEMBLE GROUP	0.567	0.3
3) GLOBAL MEMORY GROUP	254.860	0.5
TOTAL COMPUTER SUBSYSTEM	339.949	0.5
C. COMMUNICATIONS SUBSYSTEM		
1) COMMUNICATIONS CONSOLE (INCLUDING COMPUTERS)	41.782	0.6
2) COMMUNICATIONS INTERFACE CONSOLE (INCLUDING MODEMS)	65.237	0.8
TOTAL COMMUNICATIONS SUBSYSTEM	107.019	0.7

3. SYSTEM SUMMARY - SINGLE CHANNEL 1840.543 1.3

SYSTEM MTBF 543 HOURS

81-42-A-2

APPENDIX B

RELIABILITY AND MAINTAINABILITY SUMMARIES FOR THE ELWOOD SENSOR

TABLE B-1. RELIABILITY AND MAINTAINABILITY SUMMARIES FOR ELWOOD SENSOR FOR 360-HOUR AVERAGE PCB REPLACEMENT RATE

MODE S RELIABILITY AND MAINTAINABILITY SUMMARIES- SINGLE CHANNEL

SITE= ELWOOD FROM= JULY 1, 1979 TO= MAY 31, 1980

AVERAGE TIME TO REPLACEMENT OF FAILED PCB'S= 360 HOURS

1. ELEMENT TYPE SUMMARY

	TOTAL UPTIME (ELEMENT-HOURS)	NO. OF FAILURES	TOTAL REPAIR TIME (ELEMENT-HOURS)	FAILURES PER MILLION HOURS	MEAN TIME TO REPAIR (HOURS)
1. AIR CONDITIONERS	7979.80	1	2.00	125.316	2.0
2. ANTENNA	7860.55	0	0.	0.	0.
3. CHANNEL TRANSFER UNIT	7967.30	0	0.	0.	0.
4. TRANSMITTER	7921.30	1	1.00	126.242	1.0
5. RECEIVER	7962.80	0	0.	0.	0.
6. PROCESSOR	7888.80	1	2.00	126.762	2.0
7. WWVB RECEIVER	7937.55	1	1.00	125.983	1.0
8. BUS LINES	95601.76	5	3.50	52.300	0.7
9. COUPLERS	334627.32	1	0.50	2.988	0.5
10. INTERFACE PCB'S	39836.50	0	0.	0.	0.
11. +5-VOLT POWER SUPPLIES	286825.30	3	2.00	10.459	0.7
12. +/-12-VOLT POWER SUPPLIES	31869.20	0	0.	0.	0.
13. +/-12-VOLT POWER SUPPLY COMMON	7967.30	0	0.	0.	0.
14. MODE S COMPUTERS	278831.36	3	0.58	10.759	0.2
15. 176K MEMORIES	47802.05	2	0.75	41.839	0.4
16. MEMORY MONITOR SWITCHING ELEMENT	15934.60	0	0.	0.	0.
17. MEMORY MONITOR SERIAL ELEMENT	15934.60	0	0.	0.	0.
18. COMM. I/F PCB SERIAL ELEMENT	103492.78	1	0.50	9.663	0.5
19. COMM. I/F PCB CHANNEL ELEMENT	199025.85	1	0.50	5.024	0.5
20. MODEMS	127475.80	1	1.00	7.845	1.0
21. LINK SWITCHES	15934.60	0	0.	0.	0.
22. PRIMARY RADAR INTERFACE	7966.47	0	0.	0.	0.

2. SUBSYSTEM SUMMARY - SINGLE CHANNEL

A. INTERROGATOR AND PROCESSOR SUBSYSTEM	504.304	1.5
B. COMPUTER SUBSYSTEM		
1) ATCRBS GROUP	52.434	0.7
2) ENSEMBLE GROUP	5.957	0.3
3) GLOBAL MEMORY GROUP	108.425	0.7
TOTAL COMPUTER SUBSYSTEM	166.816	0.7
C. COMMUNICATIONS SUBSYSTEM		
1) COMMUNICATIONS CONSOLE (INCLUDING COMPUTERS)	52.614	0.7
2) COMMUNICATIONS INTERFACE CONSOLE (INCLUDING MODEMS)	81.067	0.6
TOTAL COMMUNICATIONS SUBSYSTEM	133.681	0.6

3. SYSTEM SUMMARY - SINGLE CHANNEL 804.800 1.2

SYSTEM MTBF 1242 HOURS

81-42-B-1

TABLE B-2. RELIABILITY AND MAINTAINABILITY SUMMARIES FOR ELWOOD SENSOR FOR 12-HOUR AVERAGE PCB REPLACEMENT RATE

MODE S RELIABILITY AND MAINTAINABILITY SUMMARIES- SINGLE CHANNEL

SITE= ELWOOD FROM= JULY 1, 1979 TO= MAY 31, 1980

AVERAGE TIME TO REPLACEMENT OF FAILED PCB'S= 12 HOURS

1. ELEMENT TYPE SUMMARY

	TOTAL UPTIME (ELEMENT-HOURS)	NO. OF FAILURES	TOTAL REPAIR TIME (ELEMENT-HOURS)	FAILURES PER MILLION HOURS	MEAN TIME TO REPAIR (HOURS)
1. AIR CONDITIONERS	7979.80	1	2.00	125.316	2.0
2. ANTENNA	7860.55	0	0.	0.	0.
3. CHANNEL TRANSFER UNIT	7967.30	0	0.	0.	0.
4. TRANSMITTER	7921.30	1	1.00	126.242	1.0
5. RECEIVER	7962.80	0	0.	0.	0.
6. PROCESSOR	7888.80	1	2.00	126.762	2.0
7. WWVB RECEIVER	7937.55	1	1.00	125.983	1.0
8. BUS LINES	95601.76	5	3.50	52.300	0.7
9. COUPLERS	334627.32	1	0.50	2.988	0.5
10. INTERFACE PCB'S	39836.50	0	0.	0.	0.
11. +5-VOLT POWER SUPPLIES	286825.30	3	2.00	10.459	0.7
12. +/-12-VOLT POWER SUPPLIES	31869.20	0	0.	0.	0.
13. +/-12-VOLT POWER SUPPLY COMMON	7967.30	0	0.	0.	0.
14. MODE S COMPUTERS	278831.36	3	0.58	10.759	0.2
15. 176K MEMORIES	47802.05	2	0.75	41.839	0.4
16. MEMORY MONITOR SWITCHING ELEMENT	15934.60	0	0.	0.	0.
17. MEMORY MONITOR SERIAL ELEMENT	15934.60	0	0.	0.	0.
18. COMM. I/F PCB SERIAL ELEMENT	103492.78	1	0.50	9.663	0.5
19. COMM. I/F PCB CHANNEL ELEMENT	199025.85	1	0.50	5.024	0.5
20. MODEMS	127475.80	1	1.00	7.845	1.0
21. LINK SWITCHES	15934.60	0	0.	0.	0.
22. PRIMARY RADAR INTERFACE	7966.47	0	0.	0.	0.

2. SUBSYSTEM SUMMARY - SINGLE CHANNEL

A. INTERROGATOR AND PROCESSOR SUBSYSTEM	504.304	1.5
B. COMPUTER SUBSYSTEM		
1) ATCRBS GROUP	52.305	0.7
2) ENSEMBLE GROUP	0.300	0.3
3) GLOBAL MEMORY GROUP	104.733	0.7
TOTAL COMPUTER SUBSYSTEM	157.338	0.7
C. COMMUNICATIONS SUBSYSTEM		
1) COMMUNICATIONS CONSOLE (INCLUDING COMPUTERS)	52.311	0.7
2) COMMUNICATIONS INTERFACE CONSOLE (INCLUDING MODEMS)	72.338	0.6
TOTAL COMMUNICATIONS SUBSYSTEM	124.649	0.7

3. SYSTEM SUMMARY - SINGLE CHANNEL 786.291 1.2

SYSTEM MTBF 1271 HOURS

81-42-B-2

APPENDIX C

RELIABILITY AND MAINTAINABILITY SUMMARIES FOR THE CLEMONTON SENSOR

TABLE C-1. RELIABILITY AND MAINTAINABILITY SUMMARIES FOR CLEMENTON SENSOR FOR 360-HOUR AVERAGE PCB REPLACEMENT RATE

MODE S RELIABILITY AND MAINTAINABILITY SUMMARIES- SINGLE CHANNEL

SITE= CLEMENTON FROM= OCTOBER 1, 1979 TO= MAY 31, 1980

AVERAGE TIME TO REPLACEMENT OF FAILED PCB'S= 360 HOURS

1. ELEMENT SUMMARY

	TOTAL UPTIME (ELEMENT-HOURS)	NO. OF FAILURES	TOTAL REPAIR TIME (ELEMENT-HOURS)	FAILURES PER MILLION HOURS	MEAN TIME TO REPAIR (HOURS)
1. AIR CONDITIONERS	5793.23	0	0.	0.	0.
2. ANTENNA	5689.23	0	0.	0.	0.
3. CHANNEL TRANSFER UNIT	5817.23	0	0.	0.	0.
4. TRANSMITTER	5695.10	1	1.00	175.590	1.0
5. RECEIVER	5816.73	0	0.	0.	0.
6. PROCESSOR	5816.65	2	0.58	343.841	0.3
7. WWVB RECEIVER	5816.57	1	0.67	171.923	0.7
8. BUS LINES	69806.80	0	0.	0.	0.
9. COUPLERS	243015.37	1	0.17	4.115	0.2
10. INTERFACE PCB'S	29086.17	0	0.	0.	0.
11. +5-VOLT POWER SUPPLIES	209419.90	1	0.30	4.775	0.3
12. +/-12-VOLT POWER SUPPLIES	23268.93	0	0.	0.	0.
13. +/-12-VOLT POWER SUPPLY COMMON	5817.23	0	0.	0.	0.
14. MODE S COMPUTERS	203603.17	0	0.	0.	0.
15. 176K MEMORIES	34903.40	0	0.	0.	0.
16. MEMORY MONITOR SWITCHING ELEMENT	11634.47	0	0.	0.	0.
17. MEMORY MONITOR SERIAL ELEMENT	11634.47	0	0.	0.	0.
18. COMM. I/F PCB SERIAL ELEMENT	75624.03	0	0.	0.	0.
19. COMM. I/F PCB CHANNEL ELEMENT	145430.00	1	1.00	6.876	1.0
20. MODEMS	93075.73	0	0.	0.	0.
21. LINK SWITCHES	11634.47	0	0.	0.	0.
22. PRIMARY RADAR INTERFACE	5817.23	0	0.	0.	0.

2. SUBSYSTEM SUMMARY - SINGLE CHANNEL

A. INTERROGATOR AND PROCESSOR SUBSYSTEM	691.353	0.6
B. COMPUTER SUBSYSTEM		
1) ATCRBS GROUP	0.096	0.1
2) ENSEMBLE GROUP	2.008	0.1
3) GLOBAL MEMORY GROUP	0.288	0.1
TOTAL COMPUTER SUBSYSTEM	2.392	0.1
C. COMMUNICATIONS SUBSYSTEM		
1) COMMUNICATIONS CONSOLE (INCLUDING COMPUTERS)	0.120	0.1
2) COMMUNICATIONS INTERFACE CONSOLE (INCLUDING MODEMS)	16.743	0.9
TOTAL COMMUNICATIONS SUBSYSTEM	16.864	0.9

3. SYSTEM SUMMARY - SINGLE CHANNEL 710.608 0.6

SYSTEM MTBF 1407 HOURS

81-42-C-1

TABLE C-2. RELIABILITY AND MAINTAINABILITY SUMMARIES FOR CLEMENTON SENSOR FOR 12-HOUR AVERAGE PCB REPLACEMENT RATE

MODE S RELIABILITY AND MAINTAINABILITY SUMMARIES- SINGLE CHANNEL

SITE= CLEMENTON FROM= OCTOBER 1, 1979 TO= MAY 31, 1980
AVERAGE TIME TO REPLACEMENT OF FAILED PCB'S= 12 HOURS

1. ELEMENT TYPE SUMMARY

	TOTAL UPTIME (ELEMENT-HOURS)	NO. OF FAILURES	TOTAL REPAIR TIME (ELEMENT-HOURS)	FAILURES PER MILLION HOURS	MEAN TIME TO REPAIR (HOURS)
1. AIR CONDITIONERS	5793.23	0	0.	0.	0.
2. ANTENNA	5689.23	0	0.	0.	0.
3. CHANNEL TRANSFER UNIT	5817.23	0	0.	0.	0.
4. TRANSMITTER	5695.10	1	1.00	175.590	1.0
5. RECEIVER	5816.73	0	0.	0.	0.
6. PROCESSOR	5816.65	2	0.58	343.841	0.3
7. WWVB RECEIVER	5816.57	1	0.67	171.923	0.7
8. BUS LINES	69806.80	0	0.	0.	0.
9. COUPLERS	243015.37	1	0.17	4.115	0.2
10. INTERFACE PCB'S	29086.17	0	0.	0.	0.
11. +5-VOLT POWER SUPPLIES	209419.90	1	0.30	4.775	0.3
12. +/-12-VOLT POWER SUPPLIES	23268.93	0	0.	0.	0.
13. +/-12-VOLT POWER SUPPLY COMMON	5817.23	0	0.	0.	0.
14. MODE S COMPUTERS	203603.17	0	0.	0.	0.
15. 176K MEMORIES	34903.40	0	0.	0.	0.
16. MEMORY MONITOR SWITCHING ELEMENT	11634.47	0	0.	0.	0.
17. MEMORY MONITOR SERIAL ELEMENT	11634.47	0	0.	0.	0.
18. COMM. I/F PCB SERIAL ELEMENT	75624.03	0	0.	0.	0.
19. COMM. I/F PCB CHANNEL ELEMENT	145430.00	1	1.00	6.876	1.0
20. MODEMS	93075.73	0	0.	0.	0.
21. LINK SWITCHES	11634.47	0	0.	0.	0.
22. PRIMARY RADAR INTERFACE	5817.23	0	0.	0.	0.

2. SUBSYSTEM SUMMARY - SINGLE CHANNEL

A. INTERROGATOR AND PROCESSOR SUBSYSTEM	621.353	0.6
B. COMPUTER SUBSYSTEM		
1) ATCRBS GROUP	0.003	0.1
2) ENSEMBLE GROUP	0.069	0.1
3) GLOBAL MEMORY GROUP	0.010	0.1
TOTAL COMPUTER SUBSYSTEM	0.082	0.1
C. COMMUNICATIONS SUBSYSTEM		
1) COMMUNICATIONS CONSOLE (INCLUDING COMPUTERS)	0.004	0.1
2) COMMUNICATIONS INTERFACE CONSOLE (INCLUDING MODEMS)	13.855	1.0
TOTAL COMMUNICATIONS SUBSYSTEM	13.859	1.0

3. SYSTEM SUMMARY - SINGLE CHANNEL 705.294 0.6

SYSTEM MTBF 1417 HOURS

81-42-C-2

APPENDIX D

PART FAILURE AND REPLACEMENT RATE SUMMARY

TABLE D-1. PART FAILURE/REPLACEMENT RATES BY ELEMENT TYPE

Element Type	Part	Part No.	No. Per Element	Element Hours	Part Hours	Number Replaced	Replacement Rate*
Channel Transfer Unit	Relay Driver PCB	325729-1	1	27,793	27,793	1	35.98
Transmitter	Fault #1 PCB	325763	1	26,627	26,627	5	187.78
	Fault #2 PCB	323684	1	26,627	26,627	3	112.67
	Exciter-Modulator Control	323867	1	26,627	26,627	2	75.11
	Main Grid Mod. Assembly	329824	1	26,627	26,627	1	37.56
Receiver	IF Log Amp PCB	323166	3	27,748	83,244	2	24.03
	Perform. Monitor PCB	323178	1	27,748	27,728	3	108.11
Processor	Perform. Monitor PCB	885613	1	27,675	27,675	1	36.13
	Processor Control A PCB	885607	1	27,675	27,675	1	36.13
	Processor Control B PCB	885610	1	27,675	27,675	2	72.27
	Mode S Data Assy PCB	885583	1	27,675	27,675	1	36.13
Bus Lines	Priority PCB	323793	1	333,690	333,690	1	3.00
	Rotron Type 113 Cooling Fan		2	333,690	667,739	10	14.98
Couplers	Coupler PCB	323784	1	1,166,416	1,166,416	6	5.14
Interface	Interface PCB	323790	1	138,920	138,920	3	21.59
+5V Triplex Pwr Supply	Boxer Type Cooling Fans	WS2107FL	1	1,001,007	1,001,077	7	6.99
Mode S Computer	Local Memory PCB	323781	1	971,118	971,118	32	32.95
	Voter PCB	323778	1	971,118	971,118	9	9.27
	Arithmetic Units (AU)	328579	2	971,118	1,942,236	17	8.75
176K Memory	48K Controller PCB	329817	1	166,827	166,827	3	17.98
	128K Expansion PCB	329818	1	166,827	166,827	4	23.98
	Standby P.S. Assy	323667	1	166,827	166,827	1	5.99
Memory Monitor	Memory Monitor PCB	323787	1	55,955	55,955	2	35.74
Comm. Interface	Communications Interface	323802	1	359,766	359,766	7	19.46
Modem	A3 PCB		1	444,387	444,387	6	13.50
	A4 PCB		1	444,387	444,387	3	6.75
	A5 PCB		1	444,387	444,387	1	2.25
	Pwr Supply Regulator		1	444,387	444,387	2	4.50

*Number of failed and/or replaced units per million hours.

TABLE D-2. PART REPLACEMENT RATES

Element Type	Part	Part No.	Number Replaced	Replacement Rate Per Million Hrs.	MTBF (Hours)
Transmitter	Fault No. 1 PCB	325763	5	187.78	5,325
	Fault No. 2 PCB	323684	3	112.67	8,875
	Exciter-Modulator Ctl PCB	323867	2	75.11	13,314
Receiver	Perform. Monitor PCB	323178	3	108.11	9,250
	IF Log Amplifier PCB	323166	2	24.03	41,615
Processor	Proc. Control B PCB	886610	2	72.27	13,837
Memory Monitor	Memory Monitor PCB	323787	2	35.74	27,980
Mode S Computer	Local Memory PCB	323781	32	32.95	30,349
	Voter PCB	323778	9	9.27	107,875
	Arithmetic Unit (AU)	328579	17	8.75	114,286
176K Memory	128K Expansion PCB	329818	4	23.98	41,701
	48K Controller PCB	329817	3	17.98	55,617
Interface	Interface PCB	323790	3	21.59	46,307
Comm. Interface	Comm. Interface	323802	7	19.46	51,387
Modem	A3 PCB		6	13.50	74,074
	A4 PCB		3	6.75	148,148
	Pwr Supply Regulator		2	4.50	222,222
Bus Lines	Rotron Type 113 Cool. Fan		10	14.98	66,756
+5V Triplex Pwr Supply	Boxer Type WS2107FL Cool. Fan		7	6.99	143,061
Coupler	Coupler PCB	323784	6	5.14	194,552

APPENDIX E

RELIABILITY BLOCK DIAGRAMS

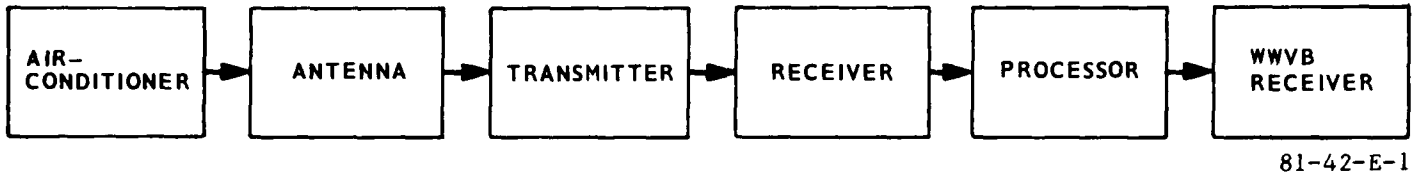

FIGURE E-1. RELIABILITY BLOCK DIAGRAM OF THE INTERROGATOR AND PROCESSOR SUBSYSTEM

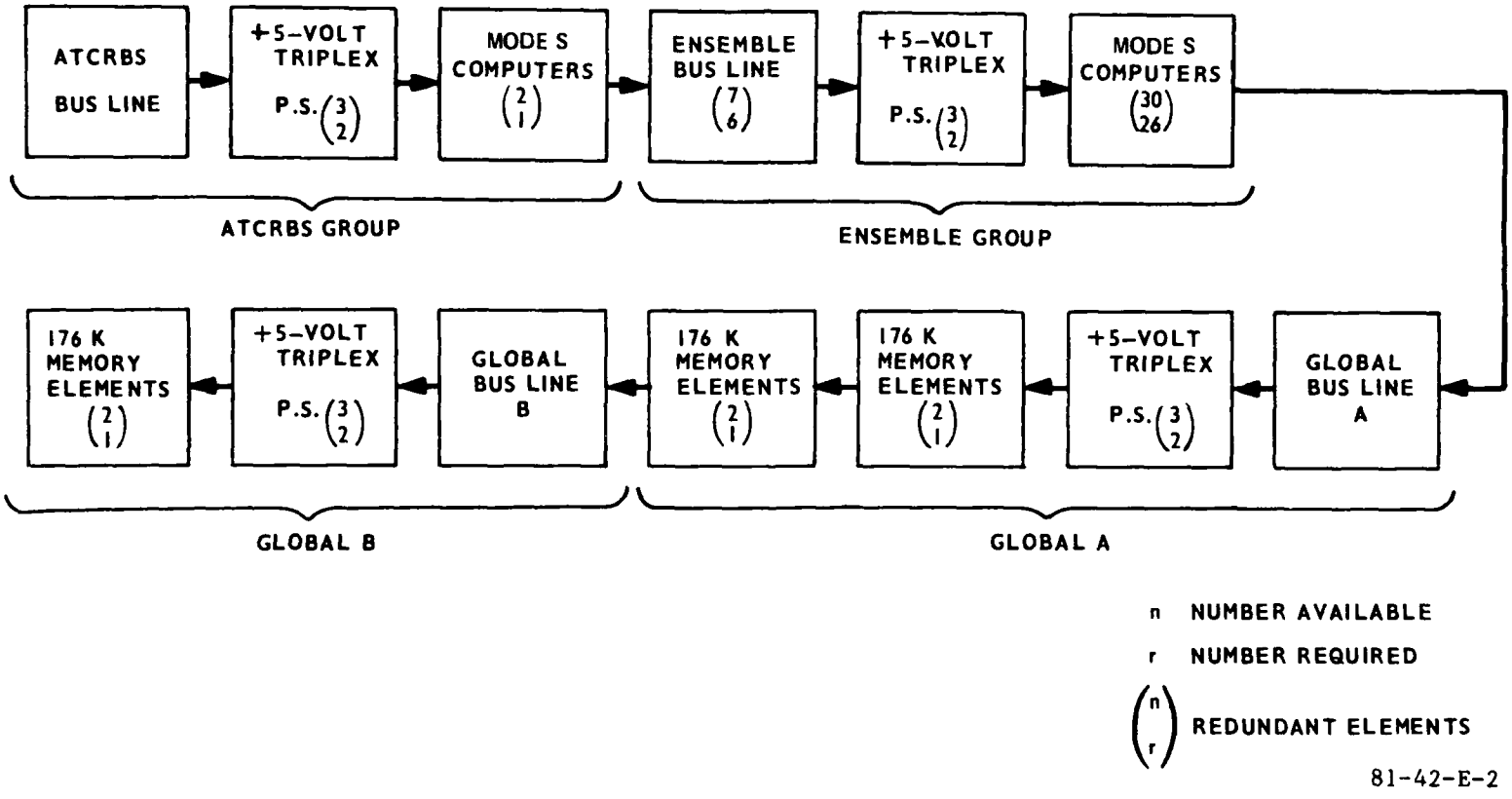

FIGURE E-2. RELIABILITY BLOCK DIAGRAM OF THE COMPUTER SUBSYSTEM

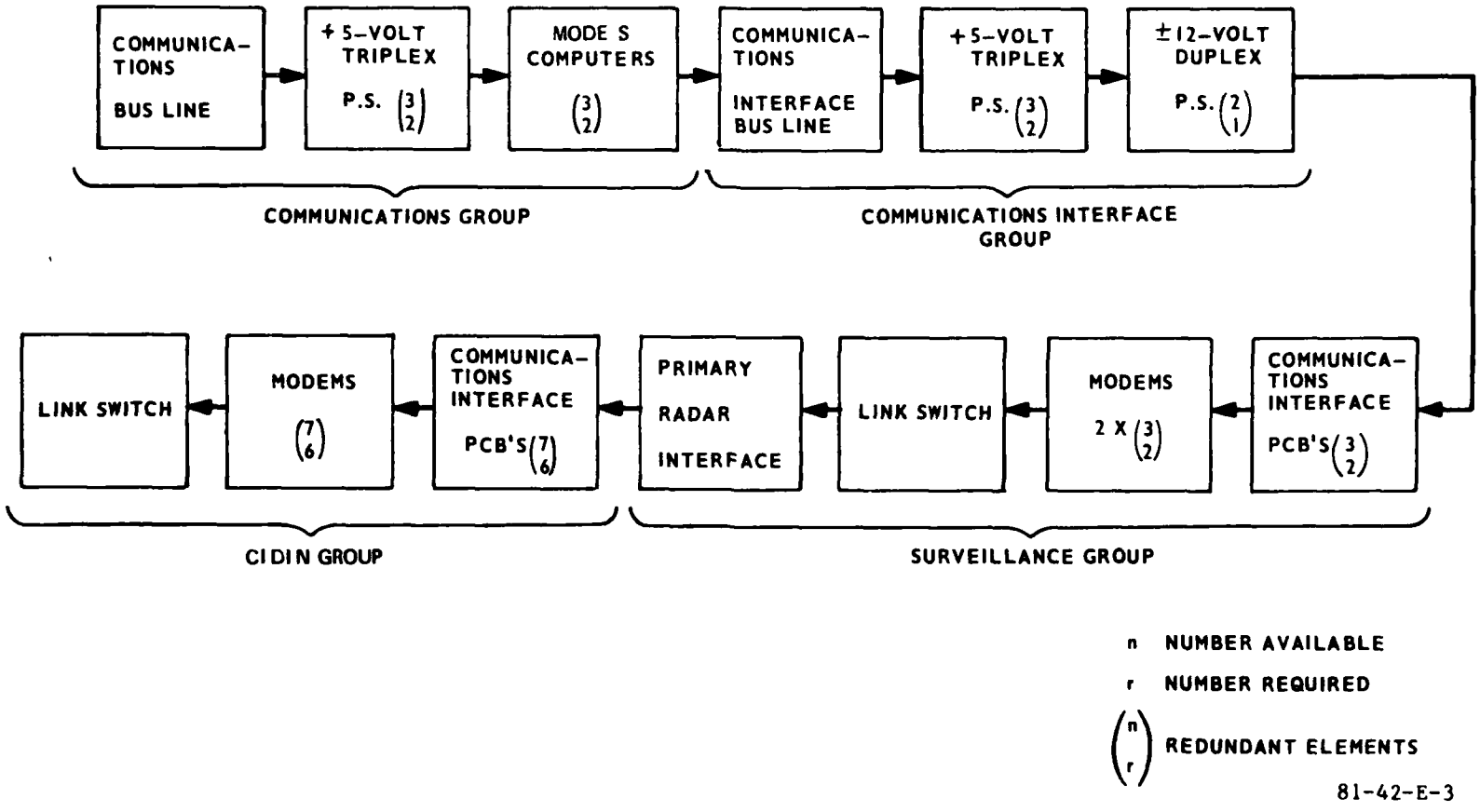

FIGURE E-3. RELIABILITY BLOCK DIAGRAM OF THE COMMUNICATIONS SUBSYSTEM

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