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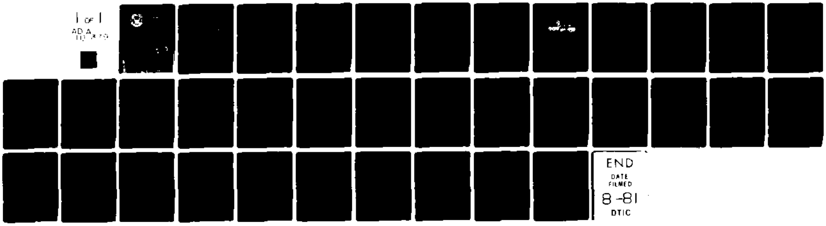

CR 81.015

NAVAL CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

RELIABILITY MAINTAINABILITY AVAILABILITY (RAM) ANALYSIS - EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

July 1981

An Investigation Conducted by
VSE CORP.
3410 South A Street
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Earthmover controls reliability, automatic blade control, laser control reliability, controls reliability prediction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Report contains Reliability Availability Maintainability (RAM) analysis of the earthmover automatic blade control system developed by NCEL. Purpose of the analysis is to investigate RAM aspects of control system and prepare plan to validate mean-time-between-failures (MTBF) of system.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

RAM EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

TABLE OF CONTENTS

I. INTRODUCTION

This report contains the Reliability Availability Maintainability (RAM) analysis of the earthmover automatic blade control system developed by the Civil Engineering Laboratory (CEL), Port Hueneme, California, 93043. The system is described in the Society of Automotive Engineers Paper No. 750765: Automatic and Adaptive Controls for Construction Equipment, Carter J. Ward, 1975.

A. PURPOSE

The purpose of the analysis is to investigate the RAM aspects (i.e. characteristics) of the earthmover automatic blade control system and prepare a plan to validate the Mean-Time-Between-Failures (MTBF) of the complete system (i.e. blade elevation and tilt angle controls, including the necessary hydraulic circuitry).

B. SCOPE

The RAM analysis encompassed reading, studying and learning the functional operation of the earthmover automatic blade control system. The following documents were used for this purpose.

(1) Blade elevation control hydraulic circuit diagram. (Located in Appendix C.)

(2) Blade tilt control electrical and hydraulic circuit diagram. (Located in Appendix C.)

(3) Society of Automotive Engineers Paper No. 750765: Automatic and Adaptive Controls for Construction Equipment, by Carter J. Ward, 1975. (SAE Transactions VOL. 84, 1975)

(4) Society of Automotive Engineers Paper No. 770551: Field Trials of Laser Surveying and of Experimental Earthmover Blade Control Kit, by Carter J. Ward and Preston S. Springton, April 1977.

(5) Hydraulic Control Designs for Retrofitting to Mobile Equipment by:

Dr. Carter J. Ward, Paper Number 4.3, Presented at the Mobile Hydraulic Design Symposium 13-15 May 1980.

Numerous conversations with CEL scientists and engineers and Spectra-Physics engineers provided additional information.

RAM textbooks, and current military standards and specifications were researched to provide the latest state-of-the-art techniques/methods in performing Failures Modes and Effects Analysis (FMEA), part stress analysis for operation and storage and developing Reliability Block Diagrams.

II. RAM

A. SUMMARY

Based upon a part stress analysis prediction, the reliability for the earthmover automatic blade control system is:

	MTBF (Hours)	Failure Rate Per 10^6 Hours	Reliablity Per Day	Reliability For 30 Days
Elevation Control	1050.9	951.6	0.9811	0.5649
Tilt Control	8576.3	116.6	0.9977	0.9323
Both Elevation and Tilt	936.2	1068.2	0.9788	0.5266

Design of new systems/equipment normally require an operational availability (Ao) of between 0.90 and 0.95 with 0.95 being the goal and 0.90 the threshold (i.e. minimum acceptable). Ao can be expressed mathematically as:

$$Ao^* = \frac{\text{MTBM} + \text{ready time}}{\text{MTBM} + \text{ready time} + \text{MDT}}$$

* Maintainability, Blanchard & Lowery McGraw-Hill Inc. 1969

where:

MTBM - Mean Time Between Maintenance includes both preventive and corrective maintenance.

Ready Time - includes the time the system/equipment is ready for use, but is not being operated.

MDT - Mean Downtime - Total time during which a system/equipment is not in condition to perform its intended function (includes time to repair, logistics and administrative delays).

For purposes of evaluating the Ao of the earthmover automatic blade control system, it is assumed that there will be no preventive maintenance required although there has been four hours allocated in the operational life profile. MTBM becomes Mean Time Between Failures (MTBF). The Operation Life Profile indicates a mission time of 20 hours with four hours available for scheduled (preventive) maintenance. With this type of mission and the inherent high reliability, it was concluded that ready time would have very little influence and, therefore, will not be included. Therefore, the Ao expression becomes:

$$Ao = \frac{MTBF}{MTBF + MDT}$$

For a Ao = 0.95 and MTBF = 936.2, the MDT for the blade control system is 49.27 hours. With proper logistics support (i.e. number of spares being readily available) the design of the blade control system should meet the Ao goal requirement of 0.95. It should be noted that the laser transmitter and receiver constitutes 85.9% of the total failure rate and both of these units can be easily replaced within 30 minutes. It is also estimated that the remaining 14.1% of the failures (i.e. by replacement) would not take longer than two hours. The composite of these two times equates to approximately 43 minutes which is well within the one hour allocated in the Operational Life Profile. To ensure meeting this Ao, an initial spare parts compliment should consist of at least one spare for every replaceable component with two spare laser transmitters and receivers for every 600 hours of operations.

It should be emphasized that these values are all predicted and that a test should be conducted to ensure a reliability design. It is recommended that the test duration be 936 hours in length with no failures requiring more than one hour MDT for each 24 hour time period.

Deep storage reliability for two years is 0.9737.

B. TECHNICAL APPROACH

The automatic blade control (both blade elevation and tilt) schematics and descriptions listed in the Scope were studied. A functional block diagram was developed and used to provide the basis for all subsequent RAM analyses. The automatic blade control system is illustrated schematically in Figure 1.

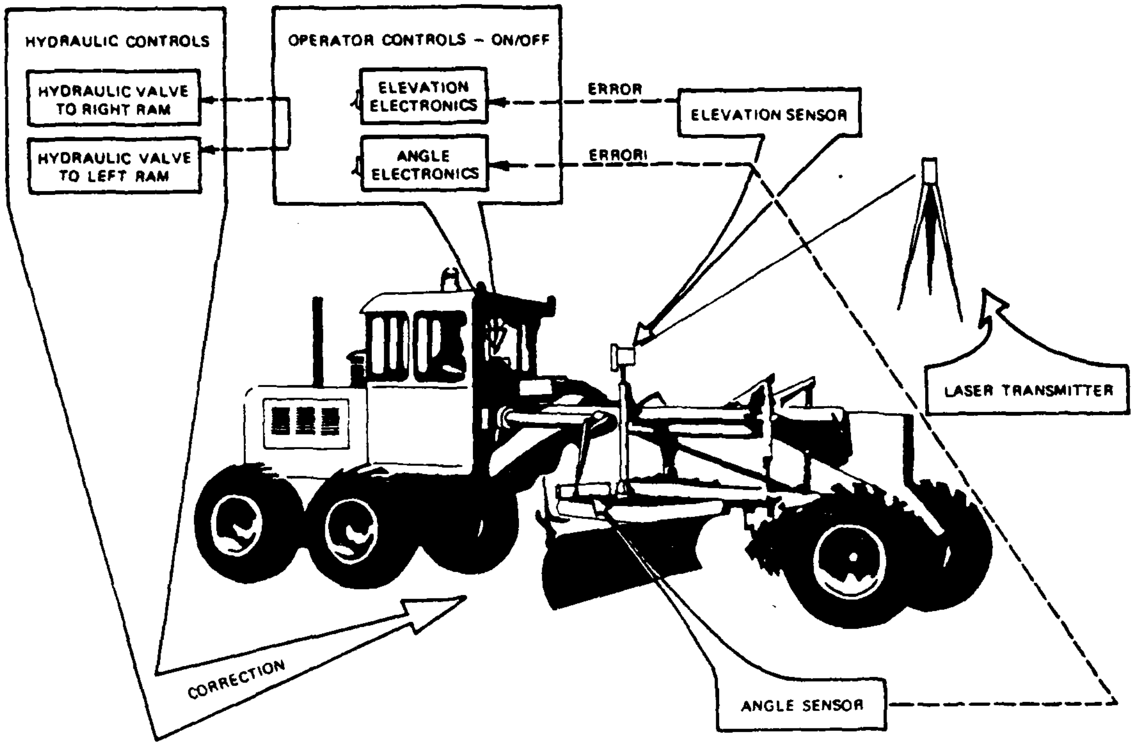


Figure 1 - Automatic Blade Control System Schematic

A reliability block diagram was developed from the functional block diagram using the guidance delineated in MIL-HDBK-217C, Appendix A.

A FMEA was performed on both blade elevation and tilt controls using the guidance of MIL-STD-1629.

A prediction (i.e. part stress analysis) was conducted on both the elevation and tilt controls using MIL-HDBK-217C and RADC TR-75-22 for operation.

Test requirements were determined using MIL-STD-471A and MIL-STD-781C as guidance.

The following paragraphs provide the detailed description and techniques/ methods of each of the analysis performed and subsequent results.

1. Functional Block Diagram

A functional block diagram was developed from the references listed in the Scope. The functional block diagram for the earthmover automatic blade control system is shown in Figure 2. The following provides a description of the operation of the automatic blade control system.

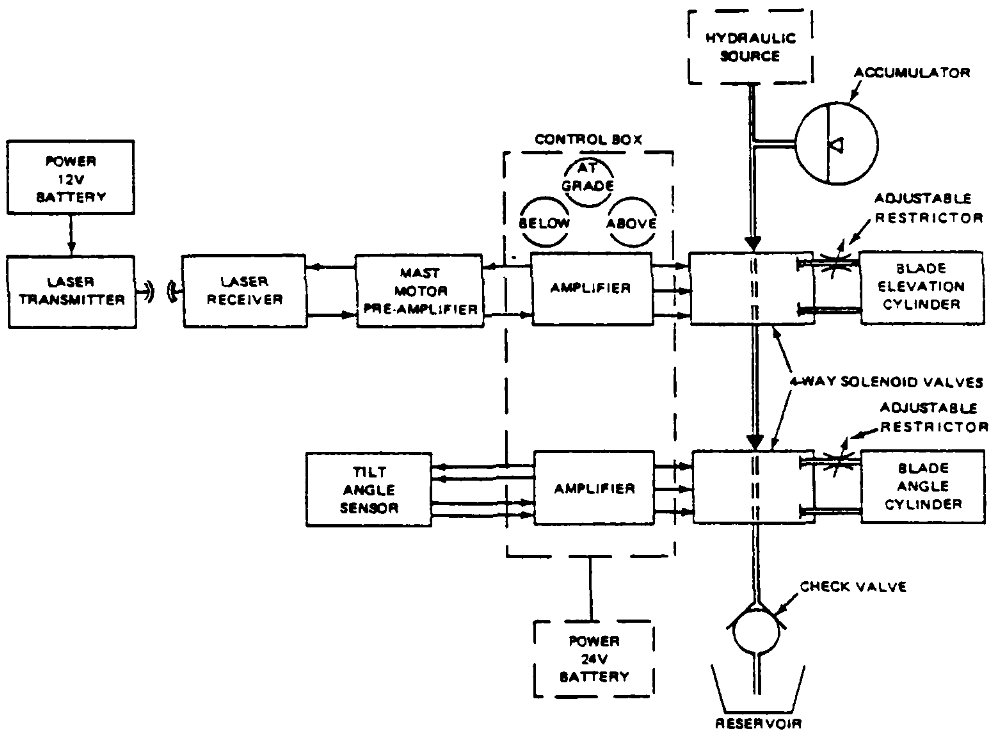


Figure 2 - Functional Block Diagram
Automatic Blade Control System

The rotating laser beam transmitter mounted on a tripod, with power supplied from an auxiliary 12V battery, establishes the elevation reference. A receiver mounted on the earthmover monitors the elevation of the blade. The receiver consists of 32 photocells, 4 banks of 8 photocells, each 90 degrees apart. The photocells work in pairs indicating whether the blade is below, at grade or above grade. Current generated by the pair of photocells is processed through a current to voltage amplifier. This amplifier signal is again amplified in the pre-amplifier located in the base of the mast. The signal is then processed by the main amplifier, which provides sufficient drive to operate the solenoid-actuated open-center valves, which controls the blade elevation cylinders. The hydraulic portion of the control is plumbed directly into the machine's existing hydraulic loop. The machine's pump is used to power the unit. The accumulator serves two purposes; reduce pressure shocks in the system and divide the flow input. The variable flow throttle valves inserted in the actuator lines help divide the flow between the accumulator and blade actuator. They restrict the flow of fluid into the actuator circuit and, as a result, play a role in how much fluid goes into the accumulator. The check valve pressurizes the line to ensure adequate pressure to actuate the solenoids. Power for the receiver, pre-amplifier and amplifier are provided from the machine's batteries.

The blade tile control system consists of a tilt angle sensor, amplifier, solenoid valve, and adjustable flow restrictor. The tilt angle sensor consists of a manometer tube made of glass and stainless steel, closed to eliminate fluid evaporation and contamination. A schematic of the angle sensor is shown in Figure 3.

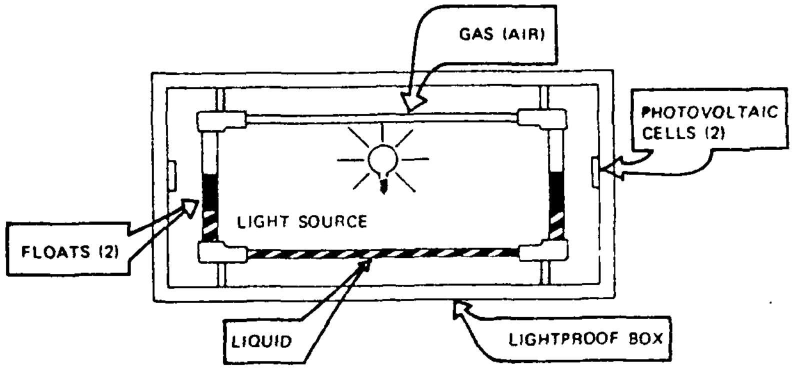


Figure 3 - Angle Sensor Schematic

The angle is sensed mechanically by the difference in float elevations supported by the fluid, and detected electrically by two photoelectric cells powered by the light source centered between them. Tilting of the sensor causes the floats to partially cover one photocell and uncover the other, generating a signal whose polarity indicates the direction and amount of tilt. The signal is then processed by an amplifier, which provides sufficient drive to operate the solenoid activated open-center valve, which controls the blade tilt cylinder.

2. Reliability Block Diagram

A reliability block diagram was developed from the functional block diagram and the guidance delineated in MIL-HDBK-217C Appendix A. The earthmover automatic blade control system is shown in Figure 4.

A prerequisite for developing the system level reliability block diagram is understanding the definition of the earthmover automatic blade control system as related to the definitions of reliability.

System reliability is defined as the probability of performing a specified function or mission under specified conditions for a specified time.

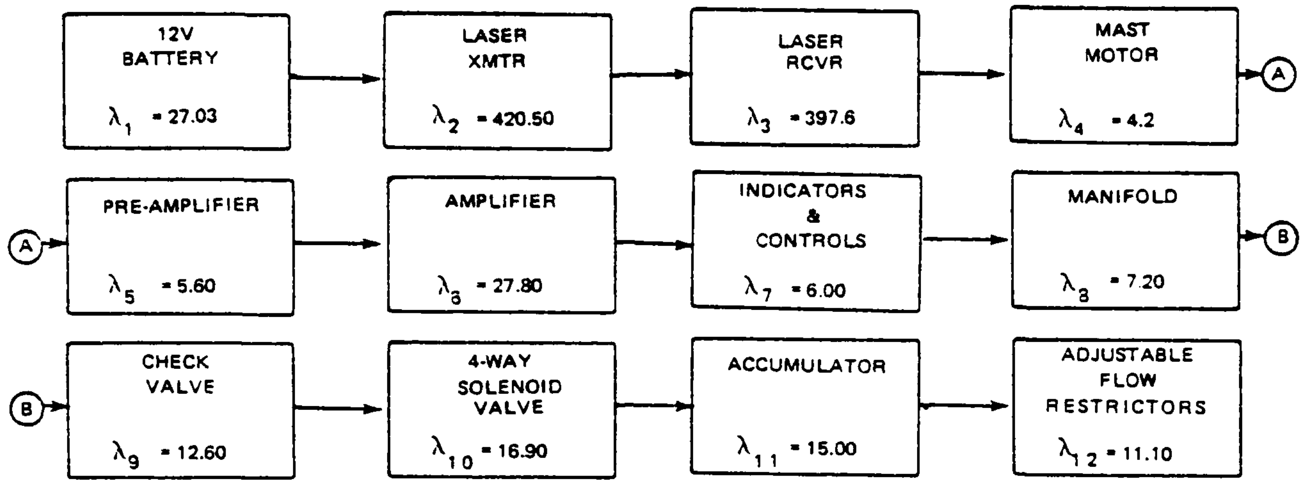
The reliability block diagram is a pictorial form of a statement of what is required for mission success. It provides the series and parallel paths depicting the equipment required for success.

An understanding of the operations, use and constraints of the automatic blade control system was acquired from developing the functional block diagram and supporting system description. It was determined for both elevation and angle controls that all the equipment (i.e. assemblies, units, components) for each control would be required for system success. There is some redundancy in the elevation control with the laser receiver and the four banks of eight (8) photocells, but the operation would be greatly reduced, therefore it was concluded that all four (4) banks would be required. Since all the equipment for each control system is required a series block diagram resulted.

The next step is to develop the reliability model (i.e. mathematical representation of the reliability block diagram).

Since all equipment is in series, the probability of system success for each control system is equal to the product of the probability of success for each of the individual equipment. Since reliability is a probability of success, the reliability for each block is determined and multiplied. The reliability for each block is determined from the expression;

ELEVATION CONTROL

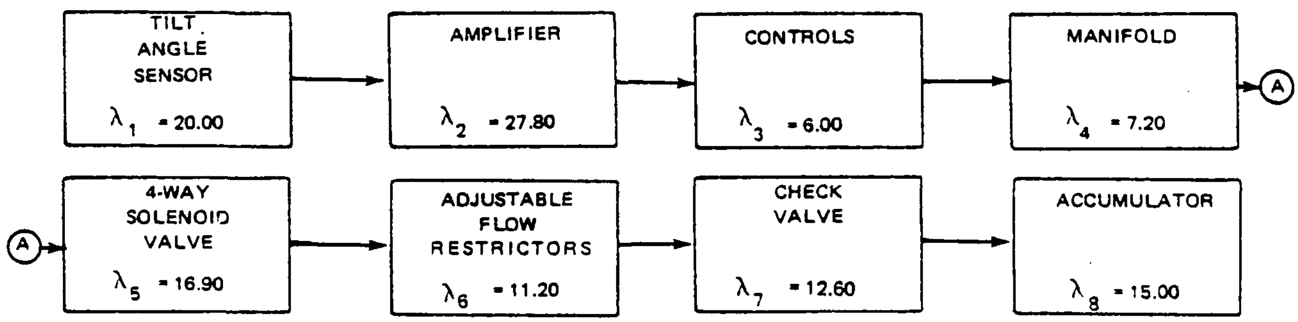


$R = e^{-\lambda t}$ $\lambda = \Sigma\lambda\text{'s} = 951.6$ FAILURES/ 10^6 HOURS

R(20 HOURS) = $e^{-(951.6)(20)(10^{-6})} = 0.9811$

R(600 HOURS) = $e^{-(951.6)(600)(10^{-6})} = 0.5649$

ANGLE CONTROL



$R = e^{-\lambda t}$ $\lambda = \Sigma\lambda\text{'s} = 116.7$ FAILURES/ 10^6 HOURS

R(20 HOURS) = $e^{-(116.7)(20)(10^{-6})} = 0.9977$

R(600 HOURS) = $e^{-(116.7)(600)(10^{-6})} = 0.9323$

$$R = e^{-\lambda t} \quad (\lambda t \text{ is an exponent}) \tag{1}$$

where

R = reliability (expressed as a decimal)

e = base of naperian log system (2.718)

λ = lambda or failure rate (normally expressed in failures/10^6 hours)

t = mission time (normally expressed in hours)

The expressions for probability of success for elevation control is;

$$Pec = R_1 \, R_2 \, R_3 \, R_4 \, R_5 \, R_6 \, R_7 \, R_8 \, R_9 \, R_{10} \, R_{11} \, R_{12} \tag{2}$$

where Pec - probability of mission success
R_1 - R_{12} - reliability of each block

The expression for probability of success for angle control is;

$$Ptc = R_1 \, R_2 \, R_3 \, R_4 \, R_5 \, R_6 \, R_7 \, R_8 \tag{3}$$

where:

Ptc - probability of mission success

R_1 - R_8 - reliability of each block

Since all major components for both elevation and angle control are in series, equations 2 and 3 can be simplified to determine the reliability. The individual failure rates are added to determine the total failure rate for the system. For elevation control, the failure rate is 951.6 failures/10^6 hours and for angle control, the failure rate of 116.7 failures/10^6 hours. By solving the expression $e - \lambda t$ where λ is the failure rate and t the mission time, the reliability is determined.

The failure rate (λ) for each block is determined by performing a part stress analysis on the components, subassemblies, assemblies and units that comprise each block. The techniques and methods used are discussed in paragraph 4, Predicted MTBF. The computation of the individual failure rates are also performed in paragraph 4. Each failure rate is annotated on the block.

The two mission times used were for 20 hours and for 600 hours (30 missions times 20 hours).

The computations using each of these mission times for each control system are shown below each reliability block diagram.

3. Failure Modes and Effects Analysis (FMEA)

A FMEA was performed on both the elevation and tilt controls. The FMEA evaluates the reliability of the design by postulating probable failure symptoms (modes) and determining the resulting effects of that failure. In addition, the basic cause of each failure and the design recommendations to circumvent or mitigate each are provided.

MIL-STD-1629 provided the basic format for the report.

A thorough understanding of the basic design and operation of the automatic control system is a prerequisite to conducting the system-level FMEA. The functional flow diagram and supporting system description in Section 1 provides the basis for the FMEA.

In performing the system-level FMEA and compiling the results on the attached worksheet, the following criteria were used. Each area discussed below refers to the identical column on the worksheet.

(1) Output Specification/Functional Description

General subsystem requirements were used to provide the output specification functional description for the system being analyzed.

(2) Failure Symptom

A serial number is provided for identification of the failure symptom and possible cause. The numbers are assigned sequentially. The failure symptom description indicates the different ways in which each output specification, or functional description deviates from the required performance.

(3) Possible Causes

This is the possible cause associated with each postulated failure symptom identified in 2.

(4) Failure Detection Method

The failure detection method is used to describe the features that are incorporated in the design through which occurrence of a failure mode is recognized. The word none indicates that there is no direct or indirect method of failure detection.

(5) Effect of Failure

The effect of failure will be the consequences of each assumed failure symptom on the operation, function, and/or status of the system being analyzed. The effect of failure describes the results of the failure symptom on the system being evaluated.

(6) Existing Compensation Provision

An existing compensation provision is an integral part of the design that either circumvents or mitigates the effect of the postulated failure. Compensating provisions include redundant items that allow continued and safe operation if one or more items fail, alternate modes of operation, and safety or relief devices.

(7) Classification of Failure

The following failure definitions were provided in the Statement of Work.

(a) Level 1 Minor. (Negligible) Failure mode characterized by the following condition:

(1) The automatic control system is more difficult to operate.

(b) Level 2 Major. (Maginal) Failure mode characterized by the following condition:

(1) The automatic blade tilt control inoperative.

(c) Level 3 Critical. Failure mode characterized by the following condition:

(1) The automatic elevation control system is inoperative.

(d) Level 4 Catastropic. Failure mode characterized by the following condition:

(1) Complete machine is inoperative.

(8) Failure Probability

Failure probability is provided for each possible cause for all postulated, identified failure symptoms. Failure probabilities are based on the complexity of the equipment, usage and application within the subsystem, and historial data. Generic terms such as very low, low, medium and high are used to describe each failure probability.

(9) Remarks

Recommended improvements are provided to either reduce the classification of failure or provide optimum compensating provision or to improve maintenance and operation procedures.

A FMEA has been performed on both the elevation and tilt control system. The results of the FMEA are contained on the following worksheets.

SYSTEM EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

SUBSYSTEM ELEVATION CONTROL

EQUIPMENT ____

DATE April 15, 1981

F M E A

FAILURE MODE AND EFFECT ANALYSIS

EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

1. OUTPUT SPECIFICATION FUNCTIONAL DESCRIPTION	2. FAILURE SYMPTOM SERIAL NUMBER	DESCRIPTION	3. POSSIBLE CAUSES	4. FAILURE DETECTION METHOD	5. EFFECT OF FAILURE	6. EXISTING COMPENSATING PROVISION	7. CLASS OF FAILURE	8. FAIL PROB	9. REMARKS
Provide for automatic control (up/down) of the blade on a grader.	001	Unable to provide automatic control.	1. Laser does not transmit. a. Laser tube dead. b. Dead battery.	Visual indication. Control box indicator lights. Audible indication from transmitter.	Loss of automatic control of blade.	Manual control.	Critical	Medium	As part of the Planned Maintenance System (PMS) ensure that the Battery and Laser Transmitter are inspected periodically.
			2. Laser transmitter does not spin.	Visual indication control box indicator lights.	Loss of automatic control of blade.	Manual control.	Critical	Medium	Perform a pre-operational check on the laser prior to operation.
			3. Laser transmitter out of alignment.	Observation blade does not follow control.	Cut will be contoured, not flat.	Manual control.	Critical	Very low	Perform a pre-operational check on the laser prior to operation.
			4. Laser receiver faulty (photocell and/or amplifier failure)	Observation blade does not follow control.	Loss of automatic control of blade.	Manual control or rotate receiver so that a good set of photocells face the transmitter.	Minor	Medium	As part of the PMS ensure that the receiver is inspected for cracks/breaks.

SYSTEM EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

SUBSYSTEM ELEVATION CONTROL

EQUIPMENT ______

F M E A

FAILURE MODE AND EFFECT ANALYSIS

EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

DATE April 15, 1981

1. OUTPUT SPECIFICATION FUNCTIONAL DESCRIPTION	2. FAILURE SYMPTOM		3. POSSIBLE CAUSES	4. FAILURE DETECTION METHOD	5. EFFECT OF FAILURE	6. EXISTING COMPENSATING PROVISION	7. CLASS OF FAILURE	8. FAIL PROB	9. REMARKS
	SERIAL NUMBER	DESCRIPTION							
Provide for automatic control (up/down) of the blade on a grader.	001 (con't)	Unable to provide automatic control.	5. Unable to raise mast.						
			a. Mast switch faulty. b. Motor faulty.	Visual observation.	Degraded automatic mode control.	Transmit requires adjustment each time reference (i.e. elevation) needs to be changed.	Minor	Low	Ensure that the quality of the motor and switch is the best available.
			6. Mast pre-amplifier faulty.	Control box indicator lights. Observation that blade does not follow control.	Loss of automatic control of blade.	Manual control.	Critical	Very low	Consider the use of a dual line pre-amplifier, where either line can be used to amplify the photocell signal.
			7. Power on-off switch faulty.	Observation no response and control box indicator lights do not illuminate.	Loss of automatic control of blade.	Manual control.	Critical	Low	Ensure that the switch is the best available for the application and provide for periodic inspection for loose terminals.

SYSTEM EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

SUBSYSTEM ELEVATION CONTROL

EQUIPMENT ____________

F M E A

FAILURE MODE AND EFFECT ANALYSIS

EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

DATE April 15, 1981

1. OUTPUT SPECIFICATION FUNCTIONAL DESCRIPTION	2. FAILURE SYMPTOM SERIAL NUMBER	DESCRIPTION	3. POSSIBLE CAUSES	4. FAILURE DETECTION METHOD	5. EFFECT OF FAILURE	6. EXISTING COMPENSATING PROVISION	7. CLASS OF FAILURE	8. FAIL PROB	9. REMARKS
Provide for automatic control (up/down) of the blade on a grader.	001 (con't)	Unable to provide automatic control.	8. Control box amplifier faulty.	Observation control box indicators show control command but no blade movement.	Loss of automatic control of blade.	Manual control.	Critical	Low	Ensure that the components that comprise the amplifier are MIL-STD and that they are conservatively stressed.
			9. Solenoid valve stuck closed.	Observation control box indicators show control but no blade movement.	Loss of automatic control of blade.	Manual control.	Critical	Very low	Ensure that the solenoid valve is the best available for the application. Provide for a manual control of the valve.
			10. Hydraulic subsystem failure. a. Broken lines. b. Accumulator faulty. c. Blocked manifolds d. Check valve sticks closed e. Solenoid valve stuck open	Visual indication of hydraulic fluid. Observation that controls are functioning properly, but no response of blade.	Loss of automatic control for the blade.	None.	Catastrophic	Very low	As part of the Planned Maintenance System (PMS) ensure that all hydraulic fittings and lines are inspected periodically for wear and early indication of leakage.

SYSTEM EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

SUBSYSTEM TILT CONTROL

EQUIPMENT

F M E A

FAILURE MODE AND EFFECT ANALYSIS

EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

DATE April 16, 1981

1. OUTPUT SPECIFICATION FUNCTIONAL DESCRIPTION	2. FAILURE SYMPTOM		3. POSSIBLE CAUSES	4. FAILURE DETECTION METHOD	5. EFFECT OF FAILURE	6. EXISTING COMPENSATING PROVISION	7. CLASS OF FAILURE	8. FAIL PROB	9. REMARKS
	SERIAL NUMBER	DESCRIPTION							
Provide for automatic control (tilt control) of the blade on a grader.	001	Unable to provide automatic control.	1. Angle sensor faulty. a. Photo-cells. b. Floats stick. c. Low fluid. d. Light source does not illuminate.	Visual indication blade not responsive. Open light replacement entry if off light is broken.	Loss of automatic tilt control of blade.	Manual control	Major	Low	Ensure as part of the Planned Maintenance System (PMS) that the sensor is periodically inspected. Consider a means to self test or periodically check the sensor.
			2. Control box amplifier faulty.	Visual indication blade not responsive.	Loss of automatic tilt control of blade.	Manual control	Major	Low	Ensure that the components that comprise the amplifier are MIL-STD and that they are conservatively stressed.
			3. Power on-off switch faulty.	Observation no response and control box indicator lights do not illuminate.	Loss of automatic tilt control of blade.	Manual control	Major	Very low	Ensure that the switch is the best available for the application and provide for periodic inspection for loose terminals.

SYSTEM EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

SUBSYSTEM TILT CONTROL

EQUIPMENT ______

F M E A

FAILURE MODE AND EFFECT ANALYSIS

EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

DATE April 16, 1981

1. OUTPUT SPECIFICATION FUNCTIONAL DESCRIPTION	2. FAILURE SYMPTOM SERIAL NUMBER	2. FAILURE SYMPTOM DESCRIPTION	3. POSSIBLE CAUSES	4. FAILURE DETECTION METHOD	5. EFFECT OF FAILURE	6. EXISTING COMPENSATING PROVISION	7. CLASS OF FAILURE	8. FAIL PROB	9. REMARKS
Provide for automatic control (tile control) of the blade on a grader.	001 (con't)	Unable to provide automatic control.	4. Solenoid valve stuck closed.	Observation blade not responsive.	Loss of automatic tilt control of blade.	Manual control	Major	Very low	Ensure that the solenoid valve is the best available for the application. Provide for a manual control of the valve.
			5. Hydraulic subsystem failure. a. Broken lines. b. Accumulator faulty. c. Blocked manifold. d. Check valve sticks closed or open (loss of back pressure) e. Solenoid value stuck open.	Observation visual indication of hydraulic fluid. Controls are functioning properly but no response of blade.	Loss of tilt control for the blade.	None	Catastropic	Very low	As part of the Planned Maintenance System (PMS) ensure that all hydraulic fittings and lines are inspected periodically for wear and early indication of leakage.

4. Predicted Mean Time Between Failures (MTBF)

To evaluate the design of the earthmover automatic blade control system for reliability aspects, the failure rate (λ) or MTBF (= $1/\lambda$) for each item (i.e. component, subassembly, assembly or unit) that comprise the system is required.

The MTBF or failure rate can be computed or determined in different ways. For equipments that have been in use for some time, actual data can be used to provide the failure rate data. For equipment that is new in design and has not been used extensively in the field, a part stress analysis (i.e. prediction technique) provides the best estimate of failure rate. The technique chosen for the blade control system was performing a part stress analysis. MIL-HDBK-217C and RADC TR-75-22 provides basic failure rates for individual components, subassemblies, assemblies and units that comprise the control system. MIL-HDBK-217C was used for all other electronic items. RADC TR-75-22 was used for all other items. Assumi a 50% electrical stress on all components and ambient temperature of 44^{o}C basic failure rates were extracted from tables in the above two references. These basic failure rates were multiplied by environmental and operational factors for each component within an assembly or unit. The failure rate of the assembly or unit was determined by adding all of the individual failure rates. The attached worksheet shows the basic component failure rate, application (environmental) modifiers and source of failure rates (remarks column) for each component that comprise the earthmover automatic blade control system. These are operational failure rates. That is, when the equipment is being operated.

PART STRESS ANALYSIS

ELEVATION CONTROL

EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

1. COMPONENT	2. PART #	3. Qty	4. BASIC FAILURE RATE	5. ENVIRONMENTAL FACTORS	6. ADJUSTED FAILURE RATE	7. TOTAL FAILURE RATE	8. REMARKS
12V BATTERY	COMMERCIAL VEHICLE	1	27.027	Ground Mobile	27.027	27.027	Rome Air Development Center (RADC) NON-ELECTRONIC RELIABILITY NOTEBOOK RADC-TR-75-22 (p.2-34)
LASER XMTR	SPECTRA-PHYSICS	1	420.5	Ground	420.5	420.5	MIL-HDBK-217C Section 2.4 Lasers $\lambda = {}^{\pi}E^{\lambda}$ Media $+ {}^{\pi}E^{\lambda}$ Coupling $= (5)(84) + (5)(0.1)$
LASER RCVR	32 photocells plus 16 amplifiers	1	397.64	Ground	397.64	397.64	Reliability Technology By Green/ Bourne p.566 (15 x 0.75)(32)=360 photocell MIL-HDBK-217C (2.35 x 16)= 37.6 Amplifier
MAST MOTOR	1/4 HP SPECTRA-PHYSICS	1	4.2	Ground Mobile	4.2	4.2	RADC-TR-75-22 (p.2-171)
PRE-AMPLIFIER	SPECTRA-PHYSICS	1	5.56	50% Stress MIL-STD Components	5.56	5.56	Purchased Item-Estimated part count; 6 diodes, 4 capacitors, 2 resistors, 1 varistor. MIL-HDBK-217C Section 3.0
AMPLIFIER	SPECTRA-PHYSICS	1	27.8	50% Stress MIL-STD Components	27.8	27.8	Estimated Part Count; 38 resistors, 3 capacitors, 4 transistors, 8 diodes, 5 operational amps, 1 amps, 1 IC. MIL-HDBK-217C Section 3.0
INDICATORS & CONTROLS	SPECTRA-PHYSICS	-	6.0	Ground Mobile	6.0	6.0	Purchased Item-Estimated part count; 3 switches, 3 lamps. MIL-HDBK-217C Section 3.0
MANIFOLD		1	7.22	Ground Mobile	7.22	7.22	RADC-TR-75-22(p2-140)
CHECK VALVE		1	12.6	Ground Mobile	12.6	12.6	RADC-TR-75-22(p2-188)
4-WAY SOLENOID VALVE		1	16.95	Ground Mobile	16.95	16.95	RADC-TR-75-22(p2-277)
ACCUMULATOR		1	14.99	Ground Mobile	14.99	14.99	RADC-TR-75-22(p2-21)
ADJUSTABLE RESTRICTORS		2	5.55	Ground Mobile	5.55	11.10	RADC-TR-75-22(p2-292)

* FAILURES PER 10^6 HOURS

$\Sigma = 951.6$

PART STRESS ANALYSIS

TILT CONTROL

EARTHMOVER AUTOMATIC BLADE CONTROL SYSTEM

1. COMPONENT	2. PART #	3. Qty	4. BASIC FAILURE RATE	5. ENVIRONMENTAL FACTORS	6. ADJUSTED FAILURE RATE	7. TOTAL FAILURE RATE	8. REMARKS
TILT ANGLE SENSOR	CEL DESIGN	1	20	Ground Mobile	20	20	ESTIMATED - Component Complexity
AMPLIFIER	CEL DESIGN	1	27.8	50% STRESS MIL-STD COMPONENTS	27.8	27.8	ESTIMATED PART COUNT; 38 resistors, 3 capacitors, 4 transistors, 8 diodes, 5 operational amps, 1 IC. MIL-HDBK-217C Appendix B
CONTROLS		-	6.0		6.0	6.0	Purchased item. Estimated part count; 3 switches, 3 lamps. MIL-HDBK-217C Appendix B.
MANIFOLD 4-WAY		1	7.22		7.22	7.22	RADC-TR-75-22(p2-140)
SOLENOID VALVE		1	16.95		16.95	16.95	RADC-TR-75-22(p2-277)
ADJUSTABLE FLOW RESTRICTORS		2	5.55		5.55	11.10	RADC-TR-75-22(p2-292)
CHECK VALUE		1	12.6		12.6	12.6	RADC-TR-75-22(p2-188)
ACCUMULATOR		1	14.99		14.99	14.99	RADC-TR-75-22(p2-21)

$\sum = 116.64$

* FAILURES PER 10^6 HOURS

5. Test Regime

In accordance with MIL-STD-781C, a fixed length test plan provides the best estimate of true MTBF and provides the means to determine if the reliability requirements have been met. The predicted MTBF is 936 hours and is considered an average value and an estimate of the true value. With application of confidence limit or confidence interval, a measure of the closeness of the estimate to the true value is determined. The majority of the individual test times to failure of the components used in the blade control system are exponentially distributed and calculations of confidence limits are based on chi-square distribution.

Assuming that the predicted value, MTBF=936 hours, is what is required, this value establishes the lower one-sided MTBF requirements. Using the chi-square distribution, for 90 per cent confidence, the equipment must be tested for the following hours with associated failures.

0 Failure - 2155 hours
1 Failure - 2155 hours
2 Failures- 3640 hours

Testing is expensive, therefore it's desirable to minimize the amount of testing required and still ensure a reliable product.

Assuming that the predicted MTBF of 936 hours is what is required and is the time duration for testing; zero failures would produce a 90 per cent confidence that the MTBF will be 406.5 hours.

The operational profile allows for one hour of corrective maintenance per day. The majority of failures (laser transitter and receiver) are easily replaceable within the one hour time limit. In addition, an adequate supply of spare parts would ensure that the majority of all failures be easily corrected within one hour. Therefore, it is recommended that the automatic blade control system be tested for 936 hours without failures to ensure a 90% confidence that the MTBF will be at least 406.5 hours.

APPENDIX A OPERATIONAL LIFE PROFILE

The following anticipated operational life profile for the automatic blade control system is:

1. Warehouse storage; - 50^{o}C to +72^{o}C for two years and no maintenance.
2. Transporation; - 50^{o}C to +72^{o}C, 6g shock, maintenance consists of only that required to acquire operational stature at delivery.
3. Mission time - 20 hours, outside environment, - 50^{o}C to +44^{o}C, light rain/snow and fog to clear and sunny , 4 hours for scheduled maintenance per day, 1 hour per day for corrective maintenance.
4. Mission repeats every 24 hours for 30 missions total.

APPENDIX B TASKS

1. Task 1. Establish the most cost-effective reliability and maintainability requirements to meet availability probabilities to 90 to 95% for operational availability and 85% for storage availability of the complete automatic blade control system.
2. Task 2. Produce a functional block diagram of the automatic blade control system.
3. Task 3. Produce a reliability block diagram and mathematical model of the automatice blade control system.
4. Task 4. Develop a failure modes and effects analysis (FMEA) for the automatic blade control system.
5. Task 5. Formulate predicted MTBF for the automatic blade control system.
6. Task 6. Use the predicted MTBFs in the mathematical model to evaluate the the probabilities of successfully meeting the requirements of the operational life profile.
7. Task 7. Develop test regime to validate both operational and storage MTBFs. Provide a range of options in terms of lower MTBF confidence level, number of units, number of failures, and total test time anticipated. Include at least one test plan that is the most cost effective in compliance with MIL-STD-781C and MIL-STD-471A for the demonstration and verification of reliability and maintainability.
8. Task 8. Submit four (4) copies of a progress report by the fifteenth (15th) day of each month after contract award for the duration of the contract. The progress report shall be inexpensively prepared in the form of a letter and shall include a brief statement of the following:
    a. Confirmation of any agreements or understandings reached as a result

of technical meetings or discussions with Government technical personnel.

b. Work accomplished during the reporting period.

c. Special problems encountered and unsolved.

d. Percentage of work completed on each task.

e. Plans for the following month.

9. Task 9. Submit one (1) original and five (5) copies of a report documenting the results of the efforts. This report shall clearly summarize all work performed and shall contain the following information:

a. Table of Contents

b. Brief summary of all work done, including that yielding negative results or positive results not used. All information shall be discussed in detail.

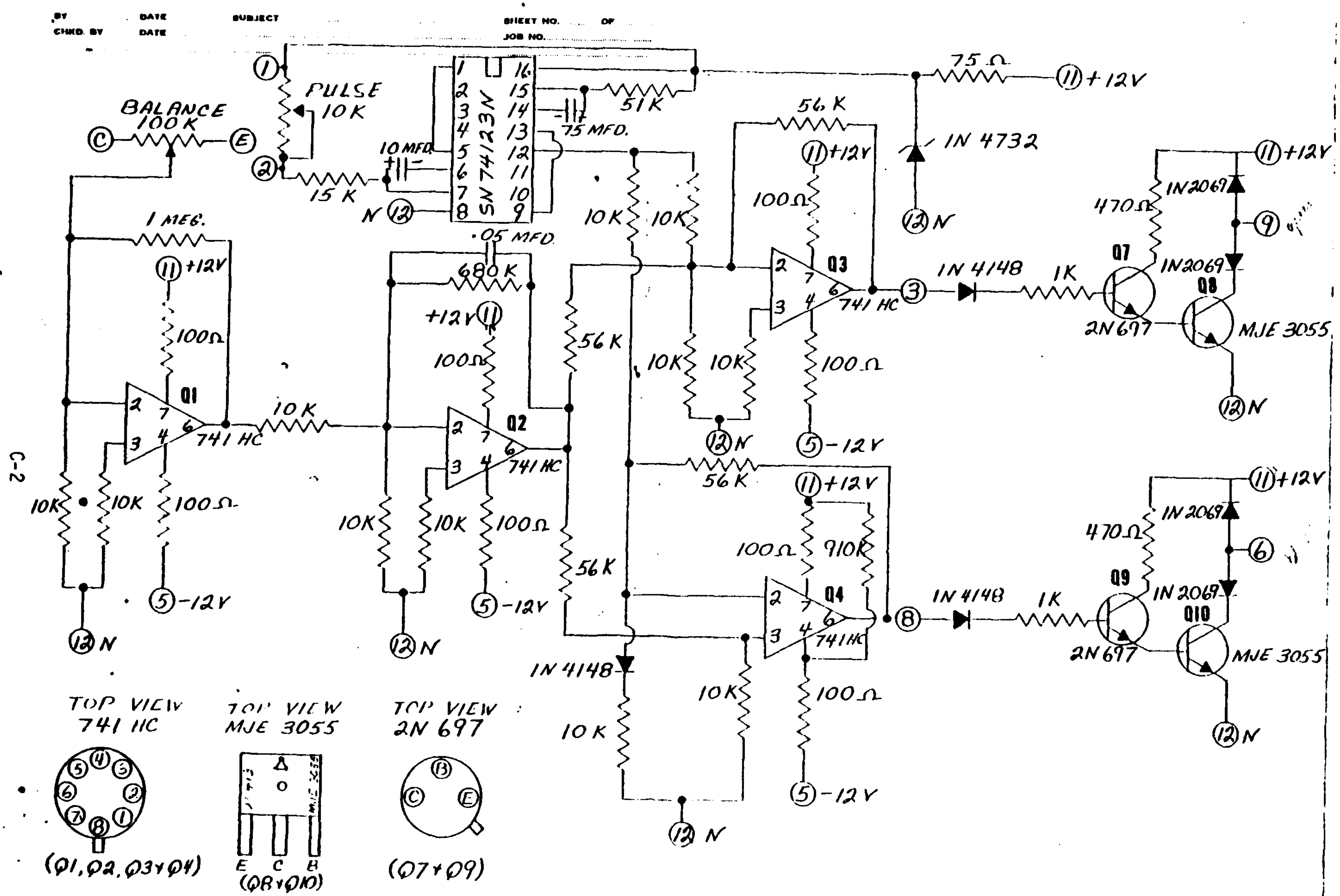
c. The body of the report shall describe all work done under the contract, as applicable.

d. Discussion of results, conclusions and recommendations.

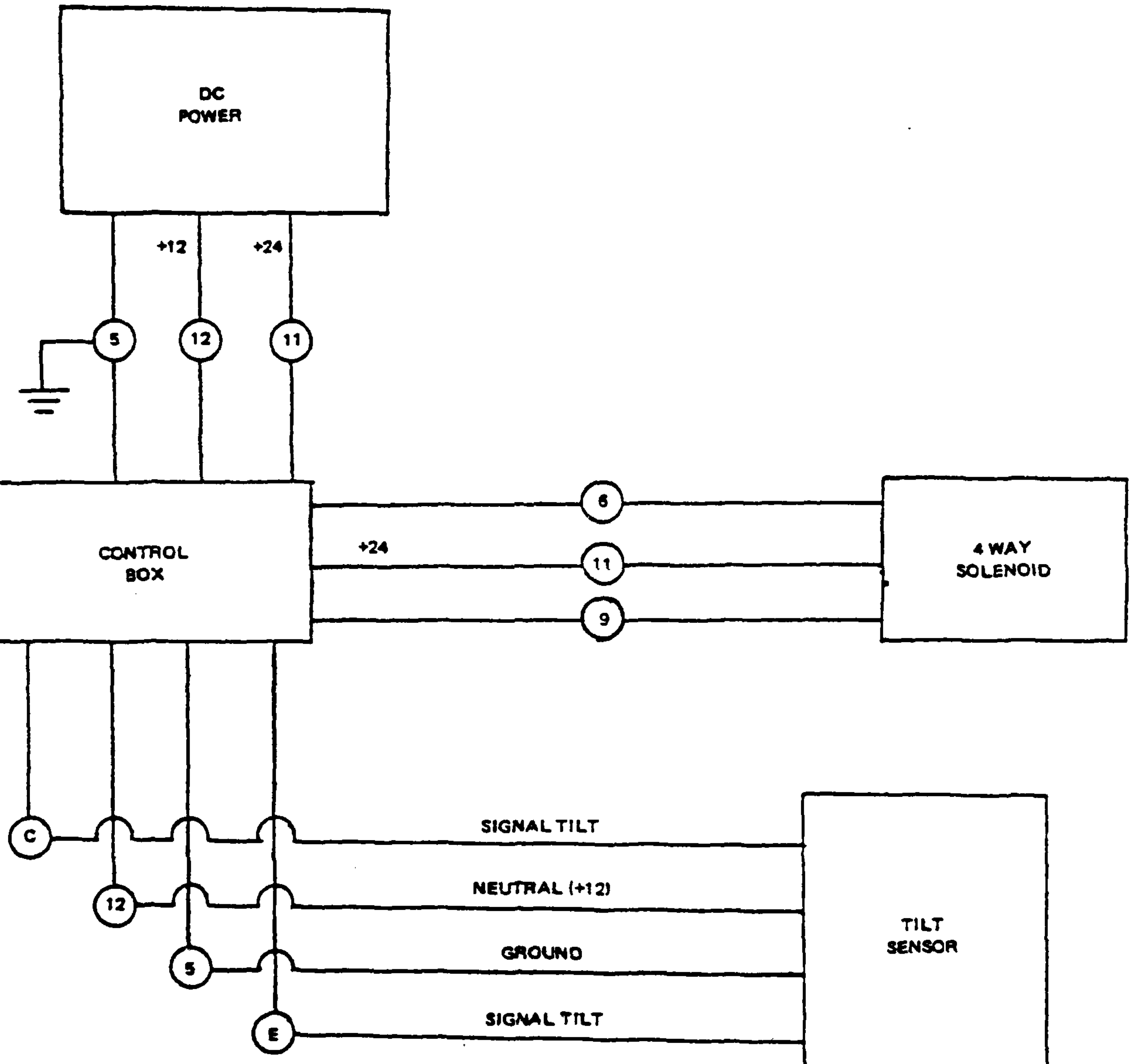
APPENDIX C

HYDRAULIC/ELECTRICAL SCHEMATICS

REFERENCE MATERIAL



AMPLIFIER ELECTRICAL SCHEMATIC



TILT ANGLE ELECTRICAL SCHEMATIC

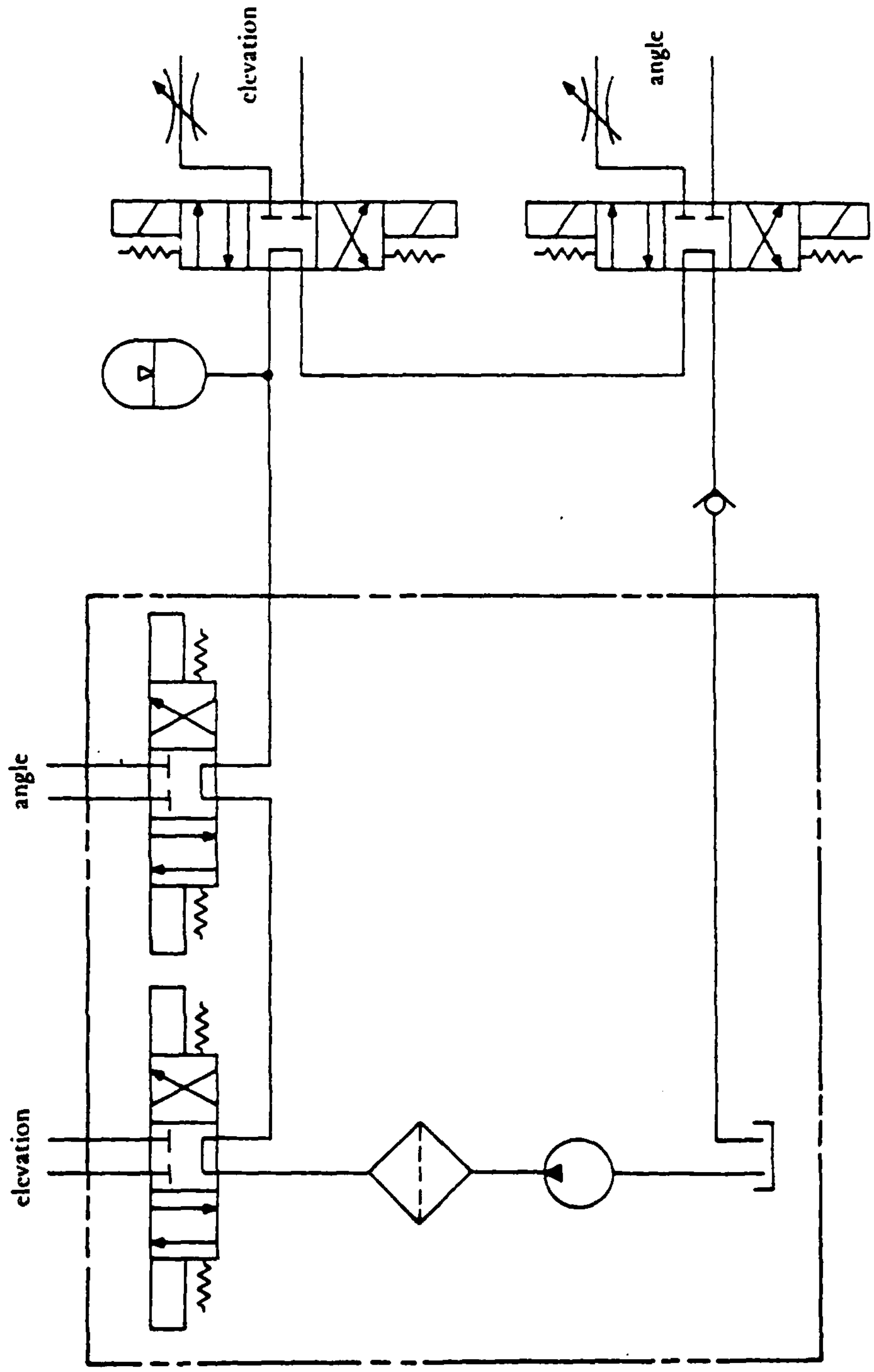


Figure 4.3.3. System Three: solenoid actuated open-center control circuit, pilot pressurized with in-line check valve (phantom line encloses machine's original components, i.e., manual controls, pump, filter and reservoir).

HYDRAULIC SCHEMATIC - BLADE CONTROL SYSTEM

APPENDIX D

DEEP STORAGE

A storage reliability prediction was performed on the elevation and tilt control. RADC LC-78-1 Storage Reliability provided the basic part failure rates. The following is the results of the storage prediction.

A. Elevation Control

	Component	Qty.	Failure Rate 10-9 Hours	Reference RADC LC-78-1
1.	12 V Battery	1	-----	2-22
2.	Laser transmitter	1	TBD	2-29
3.	Laser receiver	1	342.4	2-18
4.	Mast Motor	1	34.4	2-20
5.	Amplifier	1	245.6	2-10 to 2-18
6.	Pre-amplifier	1	61.9	2-10 to 2-18
7.	Indicator & Controls	1	191.7	2-18, 2-20
8.	Manifold	1	----	
9.	Check valve	1	22.9	
10.	Solenoid	1	8.53	
11.	Accumulator	1	32.6	
12.	Adjustable restrictor	2	11.10	
			Σ = 951.13	

B. Tilt Control

	Component	Qty.	Failure Rate 10-9 Hours	Reference RADC LC-78-1
1.	Tile angle sensor	1	60.0	Estimate
2.	Amplifier	1	245.6	2-10 to 2-10
3.	Controls & Indicators	1	191.7	2-18, 2-20
4.	Manifold	1	---	
5.	Solenoid valve	1	8.53	2-26
6.	Check valve	1	22.9	2-26
7.	Accumulator	1	32.6	2-22
8.	Adjustable restrictor	2	11.1	2-26
			Σ = 572.43	

After two years of storage the probability of the elevation and tilt controls operating are determined by solving the equation $R = e-\lambda t$ where λ is the above failure rates and t is 2 years.

$$R\ elevation = e - (951.31)(10-9)(17520) = .98347$$

$$R\ tilt = e - (572.43)(10-9)\ (17520) = .99002$$

DAT

FILM