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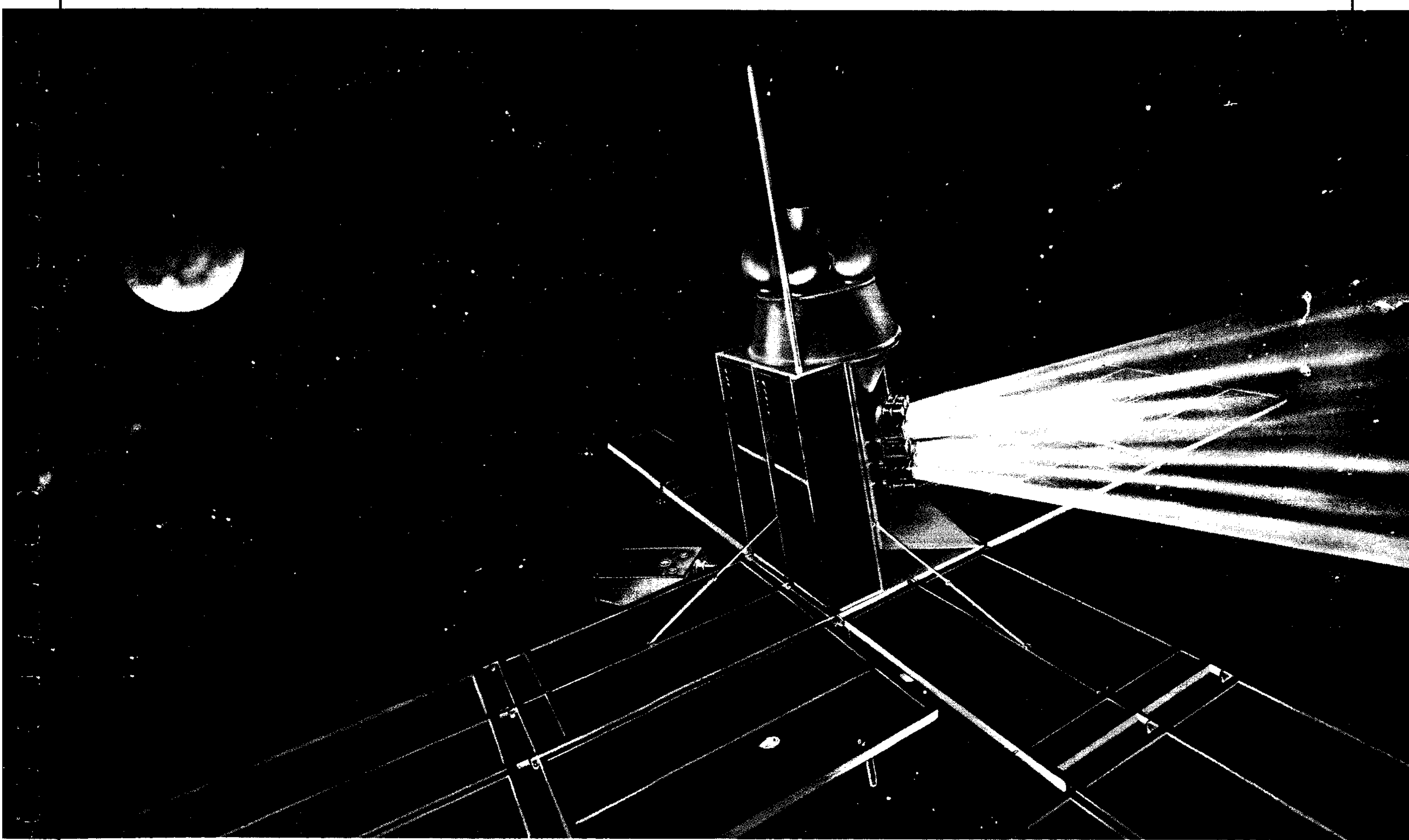
RELIABILITY ANALYSES OF MODULAR POWER CONDITIONING AND CONTROL SYSTEMS FOR ION ENGINES



SOLAR POWERED ELECTRIC PROPULSION PROGRAM

RELIABILITY ANALYSES OF MODULAR POWER CONDITIONING AND CONTROL SYSTEMS FOR ION ENGINES

Project Final Report

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JPL Contract No. 951144/October 1966

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Dr. D. Young	Mathematical Model Development
Mr. W. J. Muldoon	System Design

SECTION I

SUMMARY

This document is the Final Report of a reliability analysis of a thermal-vacuum prototype power conditioning and control system developed during the hardware phase of JPL Contract No. 951144. The system which makes use of modularized power conditioning techniques employs partial redundancy where increased reliability is required.

The reliability analysis of this system (with no modifications from the prototype configuration) results in a total probability of success of 0.85 for a 10,000 hour mission. This analysis has helped define areas of the system where substantial reliability improvements can be made with only minor changes in circuit design and virtually no penalty in system weight. The application of these improvements to a proposed flight model optimized for SERT II requirements has yielded the substantially higher reliability of 0.96 for the complete system for a 10,000 hour mission.

The analysis has been based on appropriate mathematical models, the best available sources of failure rate data, and detailed component stress calculations. Every attempt has been made to make this study as thorough and exact as possible.

AUTHOR

SECTION II

INTRODUCTION

A program was initiated at Hughes Aircraft Company in February 1965 under contract to the Jet Propulsion Laboratory to determine the feasibility of solar-electric propulsion for unmanned interplanetary missions.[1] Included in this program was the development and test of a prototype ion engine system[2] including thruster, feed system, and power conditioning and controls.

The power conditioning and control system employed made use of a unique modular approach in which, the electrical outputs of the various supplies required to operate the ion engine and feed systems were generated by adding the outputs of individual low power, low voltage modules. This approach was chosen over the more conventional techniques because it offered promise of lighter weights and higher efficiencies, and because it appeared more acceptable to the requirements of power and voltage matching which are unique to solar powered electric propulsion missions. Upon cursory evaluation, one seeming disadvantage of the modular approach was the larger total number of components required resulting in an apparent lower system reliability. However, a more detailed analysis indicated that any disadvantage associated with the greater number of components was more than offset by the ability to provide partial redundancy where necessary. Thus, it was felt that the increasing of total system reliability to levels consistent with space systems could be accomplished with the modular approach at weight penalties far less than would be incurred with the more conventional types of power conditioning.

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[1] Solar Powered Electric Propulsion Spacecraft Study, Final Report, JPL Contract No. 951144, December 1965.

[2] Development and Test of an Ion Engine System Employing Modular Power Conditioning, Final Report, JPL Contract No. 951144 September 1966.

This report details the results of a reliability analysis of two ion engine power conditioning and control systems designed to operate a 15 cm Hg bombardment thruster and its associated feed system. These systems are: (1) a thermal-vacuum prototype developed and tested under JPL contract and (2) a proposed optimized flight configuration for a 1.2 kW SERT II engine.

It is important to note that the thermal-vacuum prototype was designed to meet two mission objectives (first, interplanetary applications and, secondarily, SERT II requirements) and therefore was not optimized for a specific mission. The primary consideration in the design was the demonstration of all circuit techniques which might be required to operate ion propulsion systems which were suitable for Solar-Electric spacecraft and which might employ individual thrusters with power levels up to six kilowatts. In order to satisfy this design objective, the total number of power conditioning modules employed were greater than that actually required to operate the thruster (originally a 20 cm Hughes engine which was subsequently replaced with a 15 cm LeRC engine) used during the hardware development and test program. However, this "over capability" made possible the demonstration of circuit techniques such as dc adding, ac adding, incremental regulation, continuous regulation and control, redundancy, compensation for solar voltage changes in transit, power matching to solar array, etc.

A second objective of the prototype system was to provide power for the 15 cm LeRC engine under simulated earth-orbit conditions. The solar array output voltage level was thus established at between 40 and 60 volts rather than the 60 to 100 volt range considered desirable for an interplanetary mission. Also, extensive overrides were provided in the control circuitry designed to protect the engine and keep it running even if not at maximum performance. This control mode is in contrast to the optimizing of engine performance which would be required for an interplanetary mission.

In contrast to the prototype system, (with its overdesign for the 15 cm engine and contradictory constraints of an interplanetary mission and an earth orbit application) the optimized system has been designed to supply the 1200 watts now known to be maximum for the 15 cm engine. The new system uses a grounded feed system, a minimum number of modules, and additional feed system and control circuitry redundancy. The substantial increase in reliability (96% versus 85%) of the optimized system has been obtained primarily as a result of additional redundancy in the feed system and the control circuitry. At the same time, the weight of the system has been reduced primarily through the use of fewer modules.

The reliability analysis of both systems has been made for a mission duration of 10,000 hours, such as required for a Mars transit, and has been made with a "worst-case" assumption of system failure in event of any telemetry failure or any loss in regulation or control. Since telemetry represents a significant fraction of the total circuitry, and since there are many parallel information paths to obtain data on essential engine performance, the resultant figure is quite conservative. Similarly, satisfactory, if not optimum, performance may be obtained from the engine in spite of loss of regulation in several supplies. Thus, any degraded mode has been defined (for analysis purposes) as a system failure again providing a conservative estimate of system reliability.

The approach to the study presented in this report is in keeping with standard (and accepted) reliability analyses. First, functional diagrams of each of the power supplies are presented along with an evaluation of all possible failure modes; second, mathematical models, which combine the elements of the functional diagrams in such way that the failure modes can be quantitatively assessed, are developed for each supply; third, failure rates for all components employed are established and, finally, a numerical evaluation of the reliability of the complete system is made. The sections which follow present the details of each of these steps.

SECTION III

RELIABILITY ANALYSIS/THERMAL-VACUUM PROTOTYPE

For the purpose of this analysis the power conditioning and control system was divided into seven basic subsystem blocks as shown in Fig. 1. Each of these subsystems was in turn subdivided into circuit block diagrams which specified in detail the various functions provided by that particular subsystem. From these functional circuit diagrams, the failure modes associated with a given subsystem were established. Based on these failure modes, reliability block diagrams were drawn and, subsequently, appropriate mathematical models were developed. By inserting into the resulting mathematical expressions established failure rates for the components employed in the circuitry, numerical results were finally obtained for the reliability of the complete system.

Each of the steps of the reliability analysis outlined above will be described in detail in the following paragraphs. However, prior to this detailed description, a general discussion of the development of the mathematical models and the establishment of component failure rates will be presented.

A. GENERAL DISCUSSION

Since there is a choice to be made in the approaches employed in developing the mathematical models and in establishing component failure rates, a brief discussion of these areas is appropriate before proceeding with the over-all analysis.

1. Mathematical Models

The mathematical models from which the reliability of the system can be quantitatively determined can be derived rigorously (i.e. exact models) or approximate solutions can be found. The advantages to using the approximate models are threefold: (1) the development of each model is less complex, (2) each term in the expression represents a given failure mode providing a more obvious correlation between the mathematics and the physical situation (also facilitating

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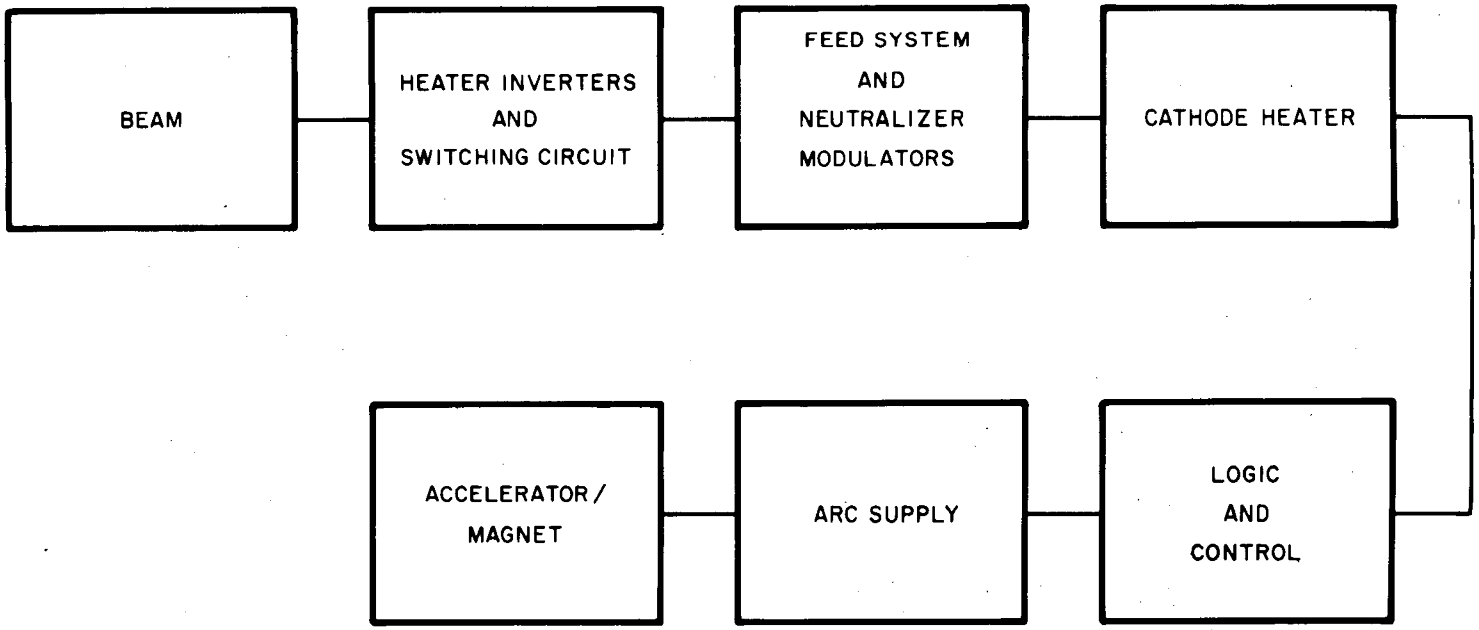

Fig. 1. Power conditioning and control system block diagram.

alteration of the expression itself, if circuit changes are made), and (3) in general, the final expression is minimized in length and complexity thereby simplifying the numerical calculations. However, if this approach is to be used, the validity of the approximation must be established.

During this study exact mathematical models were derived for each of the seven subsystem blocks. The resulting expressions are given in Appendix A. Subsequent to the development of these rigorous models, approximate expressions were sought which would yield essentially the same numerical results. To establish the validity of the approximate method employed, the redundant portions of the Beam Supply and the Cathode Heater were chosen as test cases. These supplies typify the two types of redundancy used throughout the system. Upon substitution of failure rates in the exact and approximate expressions, the reliabilities of these subsystems were found to be:

<u>Beam Supply</u>

R = 0.9996 - exact expression

R = 0.99956 - approximate expression

<u>Cathode Heater</u>

R = 0.9998 - exact expression

R = 0.9999 - approximate expression.

Note that the numerical results quoted are intended to apply only to the redundant inverters and their failure sensing and switching mechanisms.

The numerical results above indicate disagreement by only one part in the fourth decimal place. This magnitude of difference is clearly insignificant in the final combination of the numerical results. For this reason, it was concluded that approximate redundancy expressions could be used in the numerical evaluation process. These expressions are developed along with the discussion of the individual subsystem blocks in the following sections.

The principal factor not included in the derivation of the approximate expressions is the possibility of failure of the standby elements during the time they are standing by waiting for use. The closeness of the numerical results obtained by the two methods indicated that consideration of this factor was not essential here.

2. Component Failure Rates

The mathematical models discussed above are composed of elements which represent the probability of certain modes of failure occurring. In general, each of these elements concerns itself with some group of components. As such, the probability number for that element is computed directly from a tabulation of the failure rates for that group of components. Calculations of this type require that each component be individually examined to determine its operating stress level. The stress level is then used to derate the basic failure rate if required. Failure rates and stress sheets for each element of the mathematical models have been prepared and are presented in Appendix B. Thus, every component in the system has been analyzed and a failure rate determined for each. In addition, failure rates based on the number of solder connections and external connectors (where used) have been determined and entered into the calculation.

In some instances, it has been necessary to consider more than one failure mode of an individual component. Since only total failure rates are available from the various data sources, some engineering judgement is required here. For example, experience indicates that diodes fail short more often than they fail open. Thus, the total failure rate has been divided into 75% for the shorted case and 25% for the open case. In some cases where it is not so easy to draw on experience and yet it is necessary to consider two possible failure modes, the most conservative approach of assigning the total failure rate to both modes has been used.

A multiple failure mode case which is worthy of discussion is that of the high voltage transformers failing on insulation breakdown. Here, a total failure rate is available for the transformer and the question arises as to what fraction of this rate should be used to assess the insulation failure mode. A Beam Supply transformer has four separate windings and an open or short failure of any of these windings or an insulation failure between any two of these windings is a possible failure mode. In addition, a very conservative safety factor was used in the amount of high voltage insulation provided. Destruction hi-pot tests performed on two of these transformers indicated that insulation breakdown occurred at 15 kV and at 17 kV for the test samples. Since the maximum operating voltage is only 3.5 kV (the average for the Beam Supply string is approximately 2 kV), it can be seen that a large safety factor exists. Considering that high voltage insulation failure was only one of several possible transformer failure modes and that extra conservative design had been used in the amount of insulation, it was estimated that this failure mode should be evaluated using 1/10 of the total transformer failure rate. In order to provide one more degree of conservatism, the final value of 1/7 of the total rate was used in the calculation.

Thus, the various system failure modes are quantitatively assessed primarily by tabulating total component failure rates with those instances where multiple component failure modes are concerned being treated as described above.

B. INDIVIDUAL SUBSYSTEM ANALYSIS

The quantitative evaluation of the reliability of each of the major subsystems were based on the approximate mathematical models developed below and the failure rates and Stress Sheets provided in Appendix B. The reliability block diagrams used throughout this Section were developed simply by considering the various failure modes associated with each subsystem. From these diagrams, the mathematical models are derived.

The numerical results of the reliability analysis are summarized in Fig. 2. Total system probability of success for a 10,000 hour mission was found to be approximately 0.85 for the thermal-vacuum prototype. Further analysis has shown that, for a flight system, this number may be improved to greater than 0.96 with no penalty in size and weight. This improvement is discussed in Section IV.

1. Beam Supply

The function and outputs provided by the Beam Supply subsystem are as follows:

Function

- Provide power to ion beam at +3500 VDC

Outputs

- +3500 VDC beam power output
  +5 VDC voltage telemetry
  +5 VDC current telemetry

The functional circuit diagram of the Beam Supply is given in Fig. 3. The seven operating plus two standby modules (nine total) are shown with their outputs added in a series string. Each output is effectively shunted by diodes so that a closed path is always available even though the inverter module has failed. The logic system is indicated as being contained in the

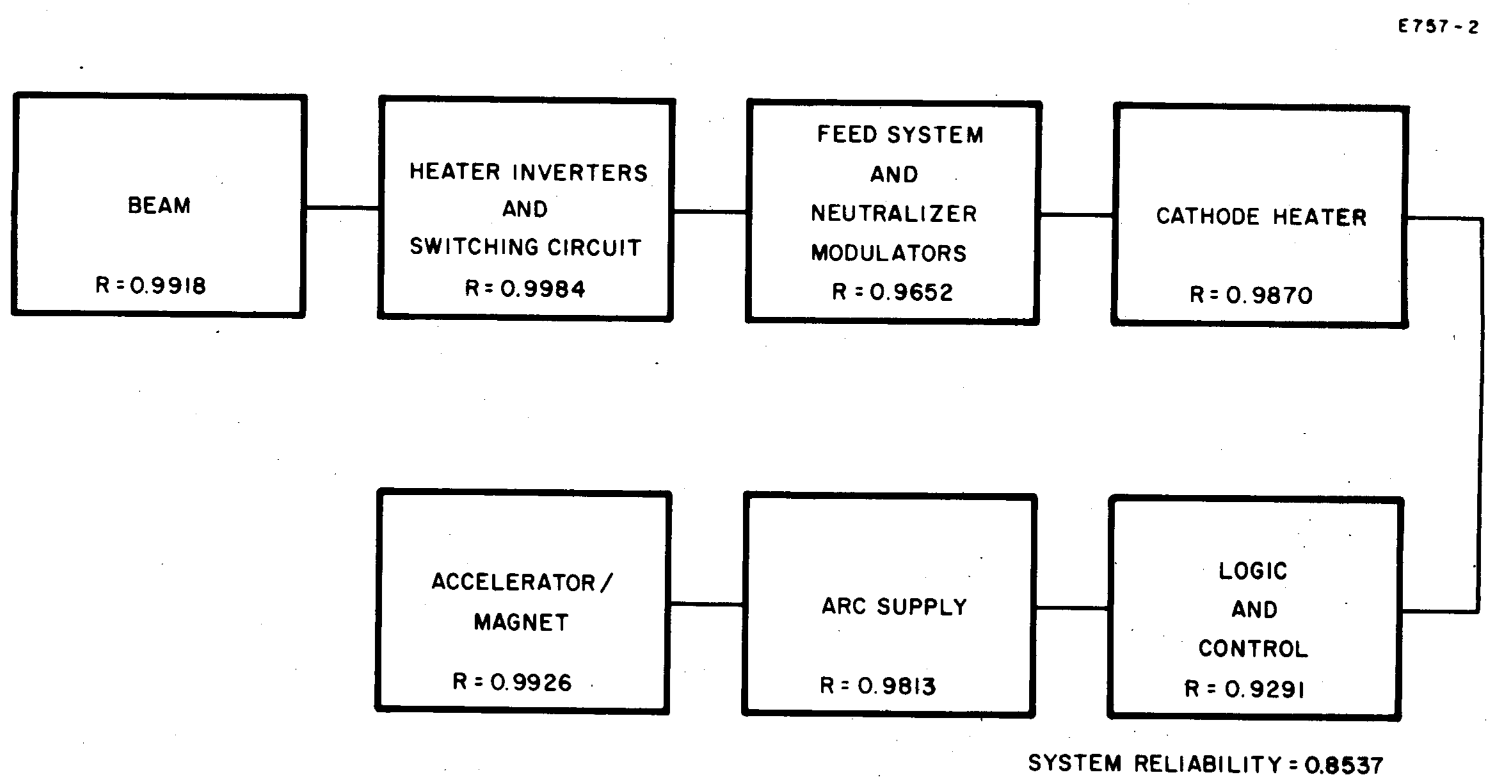

Fig. 2. Thermal vacuum prototype power conditioning and control system reliability summary.

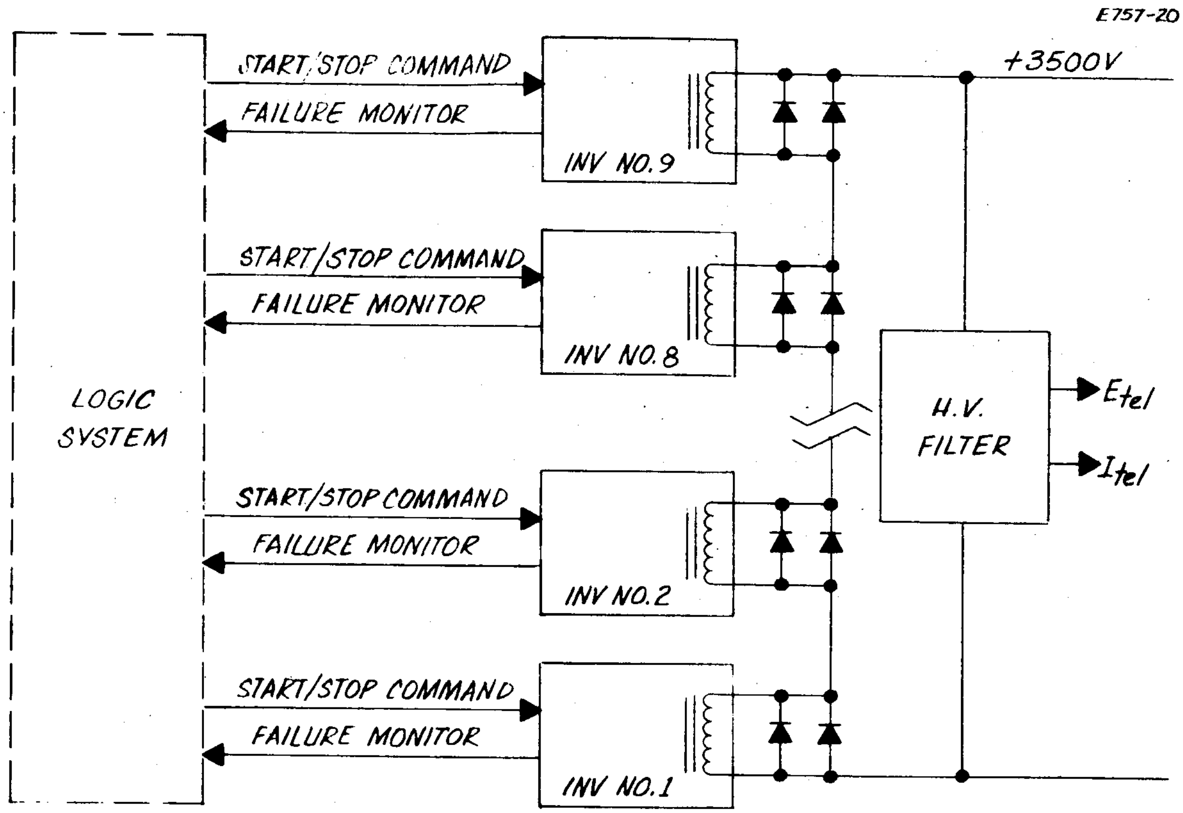

Fig. 3. Beam supply functional diagram.

dashed line since this system is located elsewhere. Each inverter module produces a low level logic signal for failure monitoring and these signals are used by the logic system to command the standby modules. The logic system also commands the modules during initial start up, overload trip, and reset. (The logic system is considered separately in the analysis and is presented in a later section.) A high voltage filter is connected across the total output to provide ripple smoothing and to provide voltage and current telemetry.

The failure modes associated with the Beam Supply Subsystem as well as the effect of these failures are given in Table I.

TABLE I

Beam Supply Failure Modes

TYPE OF FAILURE	RESULT
1. Inverter module failure	1. Standby module inserted
2. Component failure of any type in high voltage filter	2. Beam short to ground, loss of telemetry, or increased ripple
3. Transformer high voltage insulation breakdown	3. Beam short to ground
4. Series string connections mechanical failure or short to ground	4. No beam output
5. Failure monitor failure a. Indicates no failure when one has occurred b. Indicates failure when one has not occurred	5. Beam voltage change a. Standby not inserted - beam voltage too low b. Standby inserted - beam voltage too high

Item 1 in Table I does not represent a system failure since a standby module would automatically be inserted. Items 2 through 5, however, are assumed in this analysis to be failure modes which result in a loss of the system.

This assumption is an example of the conservative approach used throughout the analysis since, for example, a change in beam voltage or a loss of telemetry need not necessarily be considered catastrophic.

By considering the various failure modes listed in Table I, it is possible to derive an approximate mathematical model from which the reliability of the Beam Supply Subsystem can be quantitatively determined. In order to aid in the derivation of the model, the reliability block diagram shown in Fig. 4 was constructed. This diagram shows the relationships, from a reliability standpoint, among the failure modes associated with the Beam Supply Subsystem. It also serves to clearly point out the areas of redundancy incorporated in the subsystem design.

Referring to the reliability block diagram in Fig. 4, it can be seen that the Beam Supply Subsystem is made up of series and standby redundant elements. Since the reliability of a series system is simply the product of the reliabilities of each of the elements, the Beam Supply Subsystem reliability is given by

$$R(t) = R^1 \cdot R_6 \cdot R_7 \cdot R_8 \cdot R_9 \qquad (1)$$

where R^1 is the reliability of the redundant portion and the remaining R_i's are the series elements as designated.

It can be shown that the reliability of a redundant system consisting of m operating and N standby modules is given by

$$R^1 = e^{-m\lambda t} \sum_{r=0}^{N} \frac{(m\lambda t)^r}{r!} \qquad (2)$$

where λ is the total failure rate of an individual module (i.e., the sum of the failure rates of all the components within a single module). In order to

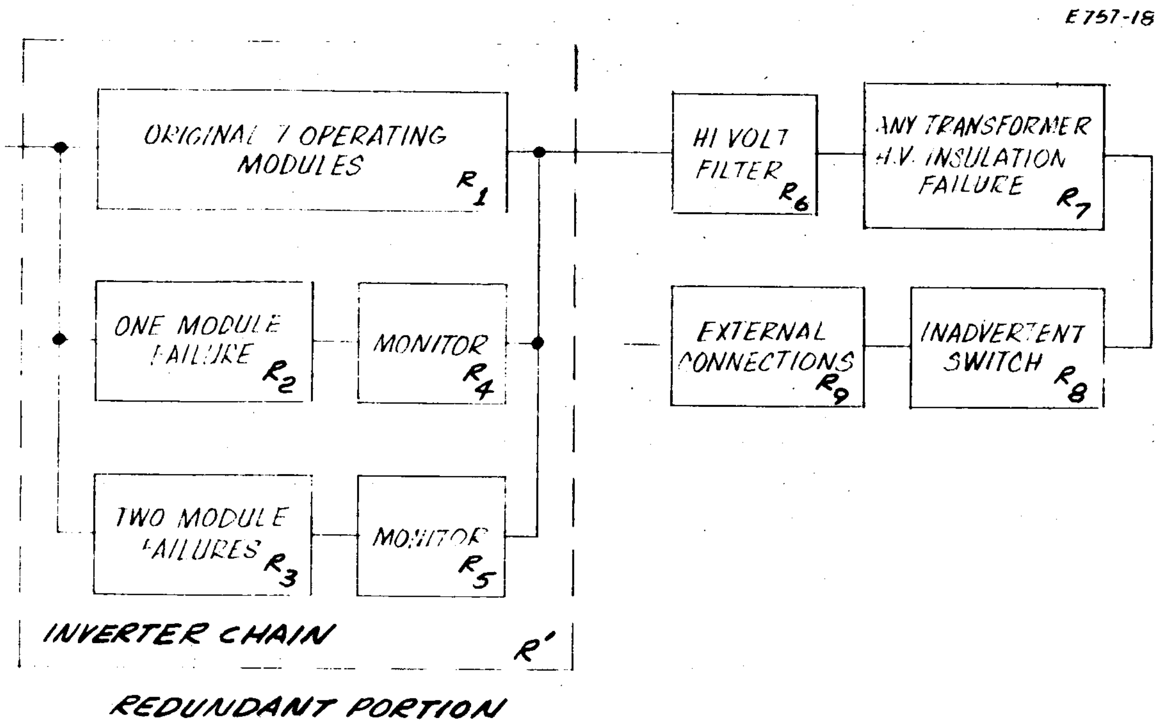

Fig. 4. Beam supply reliability block diagram.

generalize Eq. 2 to include the failure monitors and switching circuits associated with each standby, assume that these units are series elements with the redundant modules. Therefore, Eq. 2 becomes

$$R^{1} = e^{-m\lambda t}\sum_{r=0}^{N}\frac{(m\lambda t)^{r}}{r!}e^{-\ell\lambda_{M}t} \tag{3}$$

where $\ell = 0$ when $r = 0$,

$\ell = 1$ when $r = 1, 2 \ldots N$, and

λ_M is the total failure rate of an individual monitor and switching circuit.

By expanding Eq. 3, the reliability of the redundant portion can be written in terms of the R_i's shown in Fig. 4 as follows

$$R^{1} = R_1 + R_2 R_4 + R_3 R_5$$

where by definition

$$R_1 = e^{-7\lambda t}$$

$$R_2 = e^{-7\lambda t}(7\lambda t)$$

$$R_3 = e^{-7\lambda t}\frac{(7\lambda t)^2}{2}$$

$$R_4 = R_5 = e^{-\lambda_M t} \quad .$$

Thus the total Beam Supply reliability is, in terms of the R_i's,

$$R(t) = (R_1 + R_2 R_4 + R_3 R_5) \cdot R_6 \cdot R_7 \cdot R_8 \cdot R_9$$

The numerical evaluations of the R_i's and R(t) can now be obtained by employing the appropriate Stress Sheets and Table B-I provided in Appendix B as follows:

$\underline{R_1}$ — From the Beam Module Stress Sheets the total failure rate of this element is

$$\lambda = 0.1625\%/1000 \text{ hrs}$$

so that

$$7\lambda = 1.138\%/1000 \text{ hrs}$$

and

$$7\lambda t = 0.01138/1000 \text{ hrs} \times 10{,}000 \text{ hrs} = 0.1138 .$$

Finally

$$R_1 = e^{-7\lambda t} = 0.8925 .$$

$\underline{R_2}$ — Similarily,

$$R_2 = e^{-7\lambda t}(7\lambda t) = 0.1016$$

$\underline{R_3}$ — and

$$R_3 = e^{-7\lambda t}\frac{(7\lambda t)^2}{2} = 0.0058 .$$

$\underline{R_4}$ – From the Beam Fail Sensing Stress Sheets the total failure rate of this element is

$$\lambda = 0.0195\%/1000 \text{ hrs}$$

and

$$\lambda t = 0.000195/1000 \text{ hrs} \times 10,000 \text{ hrs} = 0.00195$$

so that

$$R_4 = e^{-\lambda t} = 0.9980$$

$\underline{R_5}$ – and

$$R_5 = R_4 = 0.9980 \quad .$$

The reliability of the redundant portion of the Beam Supply is then

$$R^1 = R_1 + R_2 R_4 + R_3 R_5 = 0.9996$$

$\underline{R_6}$ – From the Beam High Voltage Filter Stress Sheets, the total failure rate of this element is

$$\lambda = 0.0258\%/1000 \text{ hrs}$$

so that

$$R_6 = e^{-\lambda t} = 0.9974$$

$\underline{R_7}$ — Referring to the earlier general discussion on component failure rates, the failure rate of the Beam transformer is

$$\lambda = \frac{1}{7}\lambda \text{ transformer from Table B-I}$$

where

$$\lambda_{transformer} = 0.02\%/1000 \text{ hrs}$$

and, therefore,

$$\lambda = \frac{0.02\%/1000 \text{ hrs}}{7} = 0.0029\%/1000 \text{ hrs}$$

Since there are nine transformers, the total failure rate of this element is

$$9\lambda = 0.026\%/1000 \text{ hrs}$$

Finally

$$R_7 = e^{-9\lambda t} = 0.9973$$

$\underline{R_8}$ — The probability of obtaining an open circuit (logical high) in the Monitor (causing an inadvertent switch) has been assessed at 0.003%/1000 hrs. Since normally there are seven operating modules, the total failure rate for this failure mode is

$$7\lambda = 0.021\%/1000 \text{ hrs}$$

and

$$R_8 = e^{-7\lambda t} = 0.9979$$

$\underline{R_9}$ — From Table B-I, the failure rate of external connections is 0.0001%/1000 hrs. Since there are forty external connections, the total failure rate for this element is

$$40\lambda = 0.004\%/1000 \text{ hr}$$

and

$$R_9 = e^{-40\lambda t} = 0.9996 .$$

Finally the total Beam Supply reliability is

$$R = R^1 \cdot R_6 \cdot R_7 \cdot R_8 \cdot R_9 = 0.9918$$

2. Heater Inverters and Switching Circuits

The functions and outputs provided by the Heater Inverters and Switching Circuits are as follows:

Functions

- Provide AC power to modulator and cathode heater driven inverters
- Provide low DC voltage to system logic and control functions

Outputs

- 80 V, 5 KC square wave power output
- +6 VDC logic and control power
- +12 VDC logic and control power
- -12 VDC logic and control power

The functional circuit diagram of the Heater Inverters and Switching Circuit is given in Fig. 5. The single operating plus one standby module (two total) are shown with the main AC power output being selected by the relay. The relay is operated any time the standby inverter is running. The heater inverter is started by ground command and initiates the engine warm up cycle. The failure sensing and automatic switching circuit provides a start command to the standby inverter in the event that the main inverter fails.

In addition to supplying AC power to the system, the heater inverters also supply the low voltage DC power which is required by the logic and control system. Since the failure sensing circuit only examines the main inverter, a failure could occur at a point in the low voltage DC system which would not be detected. Rather than provide a more sophisticated and complex failure sensing circuit, this contingency is provided for by including a ground command link to the standby inverter. This addition then provides a redundant means for starting this module.

The failure modes associated with the Heater Inverter and Switching Circuits subsystem as well as the effect of these failures are given in Table II.

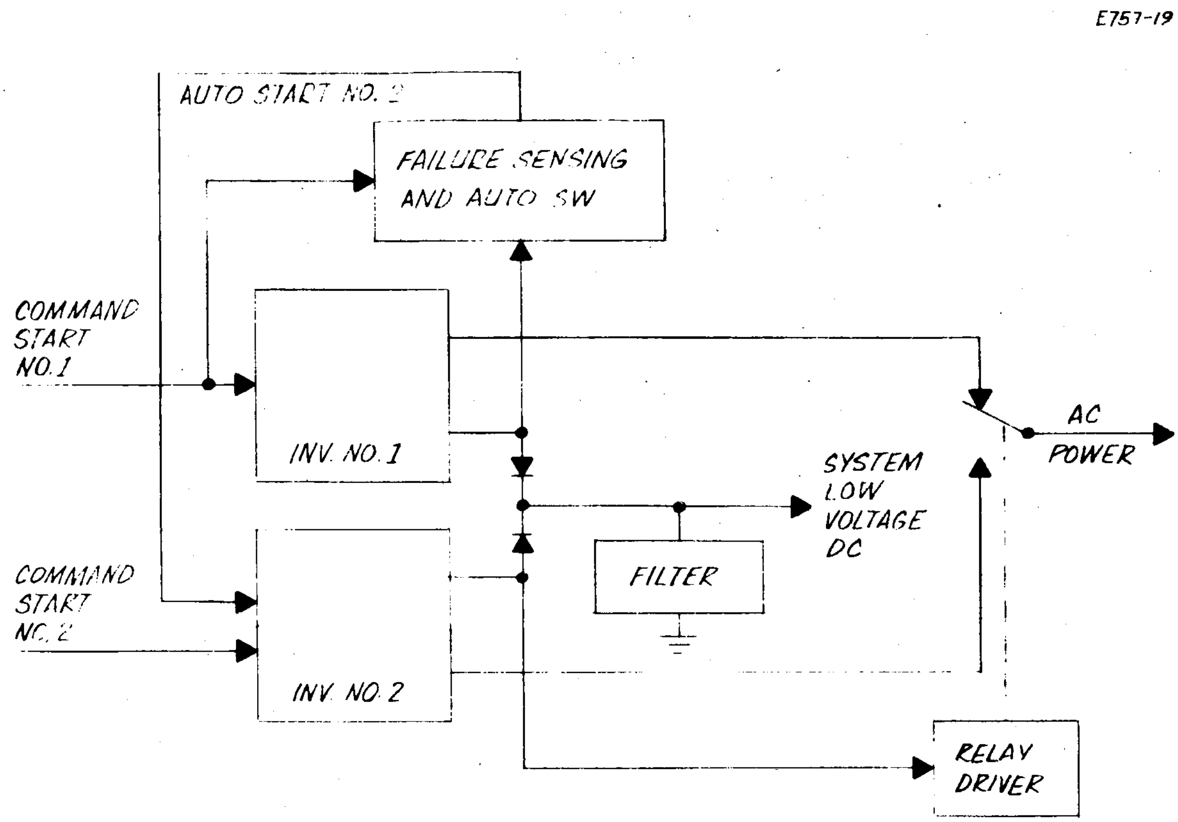

Fig. 5. Heater inverters and switching circuit functional diagram.

TABLE II

Heater Inverters and Switching Circuits Failure Modes

TYPE OF FAILURE	RESULT
1. Inverter module failure	1. Standby module inserted
2. Relay failure a. Operates inadvertently and in addition inverter No. 2 does not operate b. Fails to operate and in addition inverter No. 1 does not operate	2. Switch AC power a. AC power output connected to a non-operating inverter b. AC power output connected to a non-operating inverter
3. Low voltage rectifier fails short or filter fails short to ground	3. Loss of low voltage
4. Command start No. 1, auto start No. 2, and command start No. 2 all fail	4. Neither inverter operates
5. Fail sense and auto switch fails and in addition inverter No. 1 and Command Start No. 2 both fail	5. Standby module not started after inverter No. 1 fails
6. Inadvertent auto start No. 2 and in addition inverter No. 2 fails	6. No operating inverter

Again item 1 in Table II does not represent a system failure since a standby module would automatically be inserted. Items 2 through 6, however, do result in an over-all system failure.

The reliability block diagram of the Heater Inverters and Switching Circuit is given in Fig. 6. It can be seen from this diagram that from a reliability standpoint this subsystem consists of standby, parallel, and series elements. In this case the standby redundant elements have unequal failure rates so that the reliability of the redundant portion is given by

$$R^1 = \frac{\lambda_2 e^{-\lambda_1 t} - \lambda_1 e^{-\lambda_2 t}}{\lambda_2 - \lambda_1} \tag{4}$$

where λ_1 and λ_2 are the failure rates of the respective elements. The reliability of a parallel system is given by

$$R = 1 - (1 - R_1)(1 - R_2) \ldots (1 - R_n)$$

where R_1, R_2, ... R_n are the reliabilities of the elements in parallel.

From the appropriate Stress Sheets the R_i's of the blocks shown in Fig. 6 can be determined with the following results:

$$R_1 = R_1' = R_1'' = 0.9846$$

$$R_2 = R_2' = 0.9988$$

$$R_3 = 0.9984$$

$$R_4 = R_4' = 0.9999 \ (t = 120 \text{ hrs})$$

$$R_5 = R_5' = 0.9904$$

$$R_6 = 0.9997 \quad .$$

Consider next the various groupings of the blocks as represented by the R_i's:

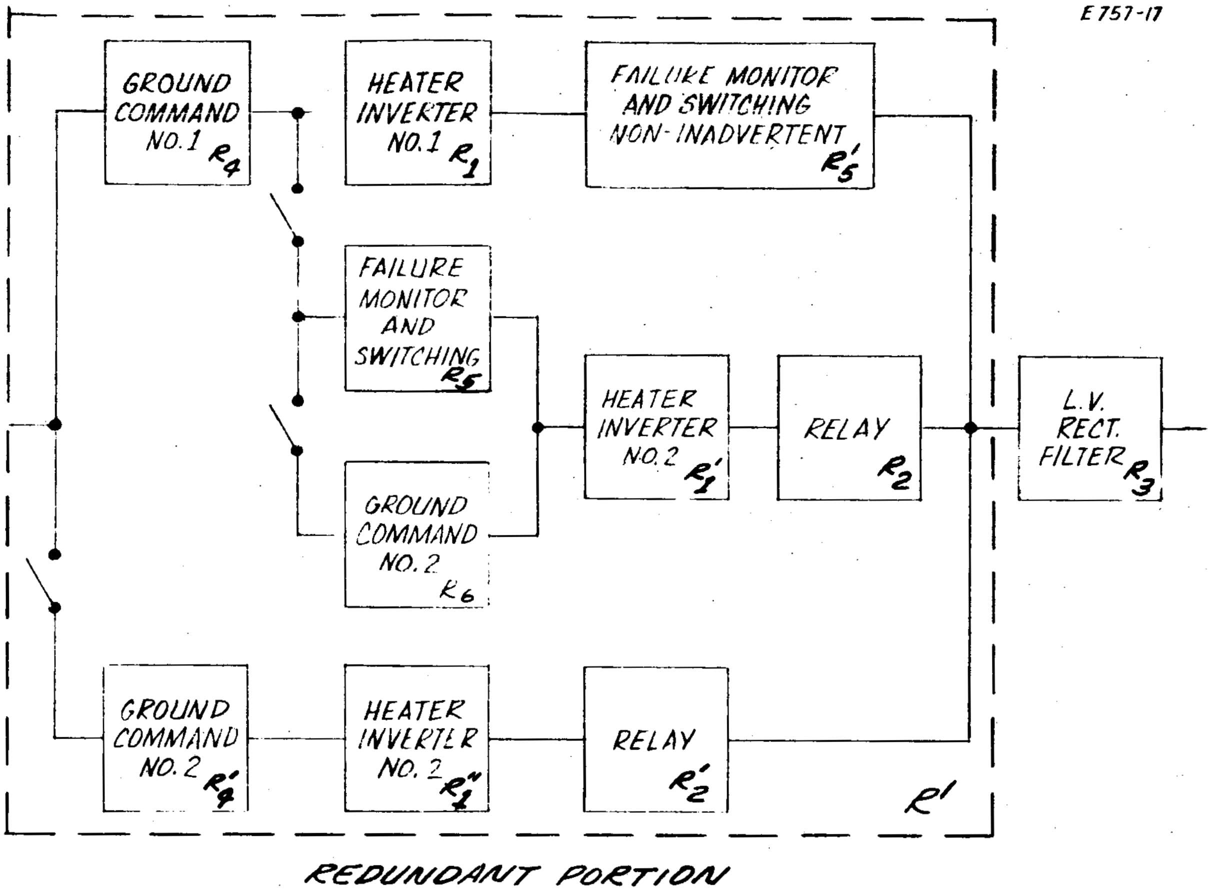

Fig. 6. Heater inverter and switching circuits reliability diagram.

$\underline{R_5, R_6}$ — Parallel group with reliability R_7

where $R_7 = 1 - (1-R_5)(1-R_6)$

$\underline{R_7, R_1', R_2}$ — Series group with reliability R_8

where $R_8 = R_7 \cdot R_1' \cdot R_2$

$\underline{R_1, R_5'}$ — Series group with reliability R_9

where $R_9 = R_1 \cdot R_5'$

$\underline{R_8, R_9}$ — Parallel group with reliability R_{10}

where $R_{10} = 1 - (1-R_8)(1-R_9)$

$\underline{R_{10}, R_4}$ — Series group with reliability R_{11}

where $R_{11} = R_{10} \cdot R_4 = 0.9996$

yielding an effective failure rate for 10,000 hrs for these elements of

$$\lambda_1 t = 0.00042$$

$\underline{R_4', R_1'', R_2'}$ — Series group with reliability R_{12}

where $R_{12} = R_4' \cdot R_1'' \cdot R_2' = 0.9832$

yielding an effective failure rate for 10, 000 hrs for these elements of

$$\lambda_2 t = 0.1684$$

R_{11}, R_{12} — Standby redundant group with failure rates λ_1 and λ_2, respectively. Using Eq. 4 the reliability R^1 of the standby redundant group is

$$R^1 = \frac{\lambda_2 R_{11} - \lambda_1 R_{12}}{\lambda_2 - \lambda_1} = 0.9999$$

R_3, R^1 — Series group which provides the total reliability R of the Heater Inverters and Switching Circuit subsystem where

$$R = R^1 \cdot R_3 = 0.9984 \quad .$$

3. Feed System and Neutralizer Modulators

The function and outputs provided by the Feed System and Neutralizer Modulators subsystem are as follows:

Functions

- Provide power to feed system and neutralizer

Outputs

- 3 VAC neutralizer power output
  +5 VDC voltage telemetry
  +5 VDC current telemetry
- 5 VAC vaporizer power output (isolated for + 3. 5 KV)
  +5 VDC voltage telemetry
  +5 VDC current telemetry
- 5 VAC pressurizer power output (isolated for +3. 5 KV)
  +5 VDC voltage telemetry
  +5 VDC current telemetry
- +10 VDC valve power output (isolated for +3. 5 KV)

The functional circuit diagram of the Modulator subsystem is shown in Fig. 7. This subsystem performs several functions but is physically small and is all contained in a single module. AC power is received from the Heater Inverter and modulated by the various regulators as shown. The feed system outputs are isolated for high voltage in this design.

Since there is no redundancy employed, the failure modes associated with the Modulators subsystem are simply the failure of any component. The reliability block diagram of this subsystem would therefore consist of a single series element.

The reliability of the Feed System and Neutralizer Modulators is given by

$$R = e^{-\lambda t} \tag{5}$$

where λ is given in the Modulator Stress Sheet as 0.3538%/1000 hrs. Therefore,

$$R = e^{-0.03538} = 0.9652 \quad .$$

4. Cathode Heater Supply

The function and outputs provided by the Cathode Heater subsystem are as follows:

Functions

- Provide AC power to the cathode heater

Outputs

- 3 VAC square wave power output (isolated for +3.5KV)
  +5 VDC voltage telemetry
  +5 VDC current telemetry

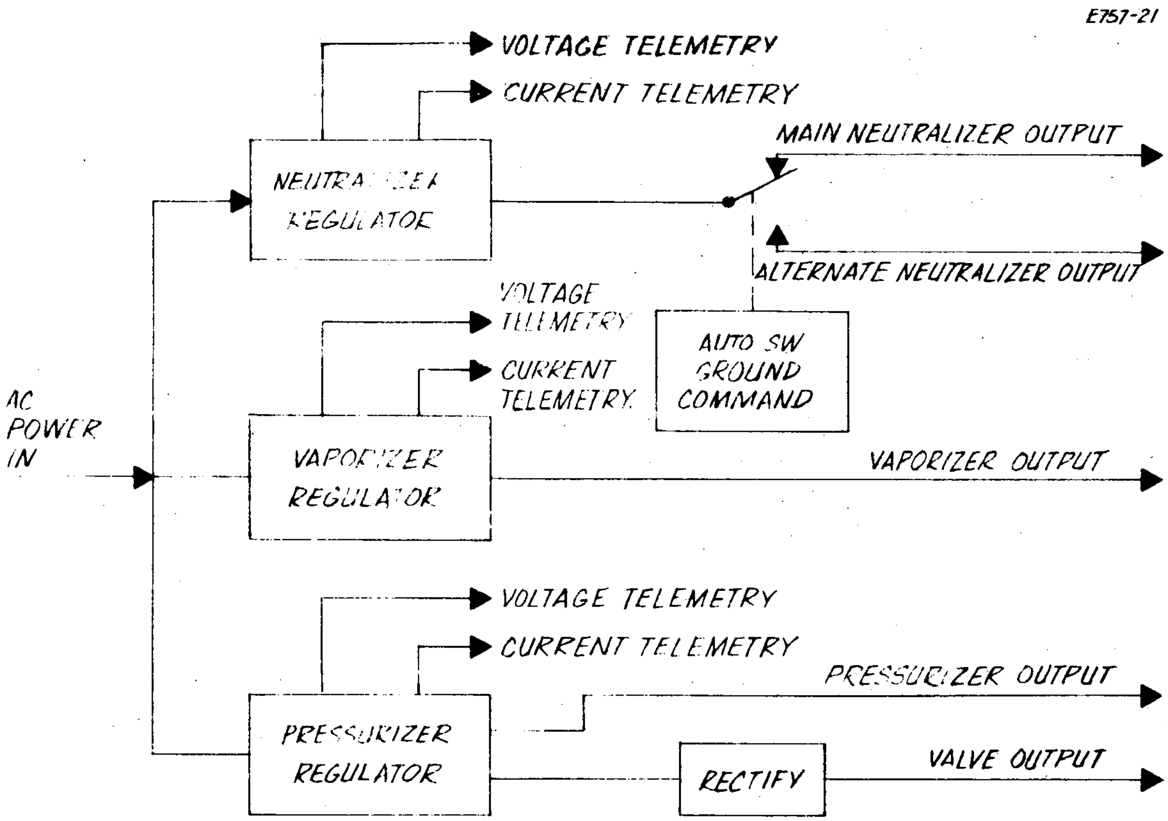

Fig. 7. Modulator subsystem functional diagram.

The functional circuit diagram of the Cathode Heater supply is presented in Fig. 8. The single operating and one standby module (two total) are shown with the output relay switch which supplies prime DC power to the operating module and also connects the AC output from the operating module to the output transformer. The fail sense and switching circuit operates the output relay switch in the event of a failure of the main inverter. The inverter modules used here are driven inverters with the AC drive being received from the Heater Inverters.

The output transformer, the telemetry circuits, and the regulator circuit are contained in a separate module called the Cathode Controller. (In actual practice, the output transformer was mounted at the engine to minimize transmission line drop.) The regulator measures the output RMS current, compares this to the desired value (commanded by the analog control system), and provides an error signal to the pulse-width modulator in the inverter. Redundancy is not provided for the circuitry in the Cathode Controller module.

The failure modes associated with the Cathode Heater subsystem as well as the effect of these failures are given in Table III.

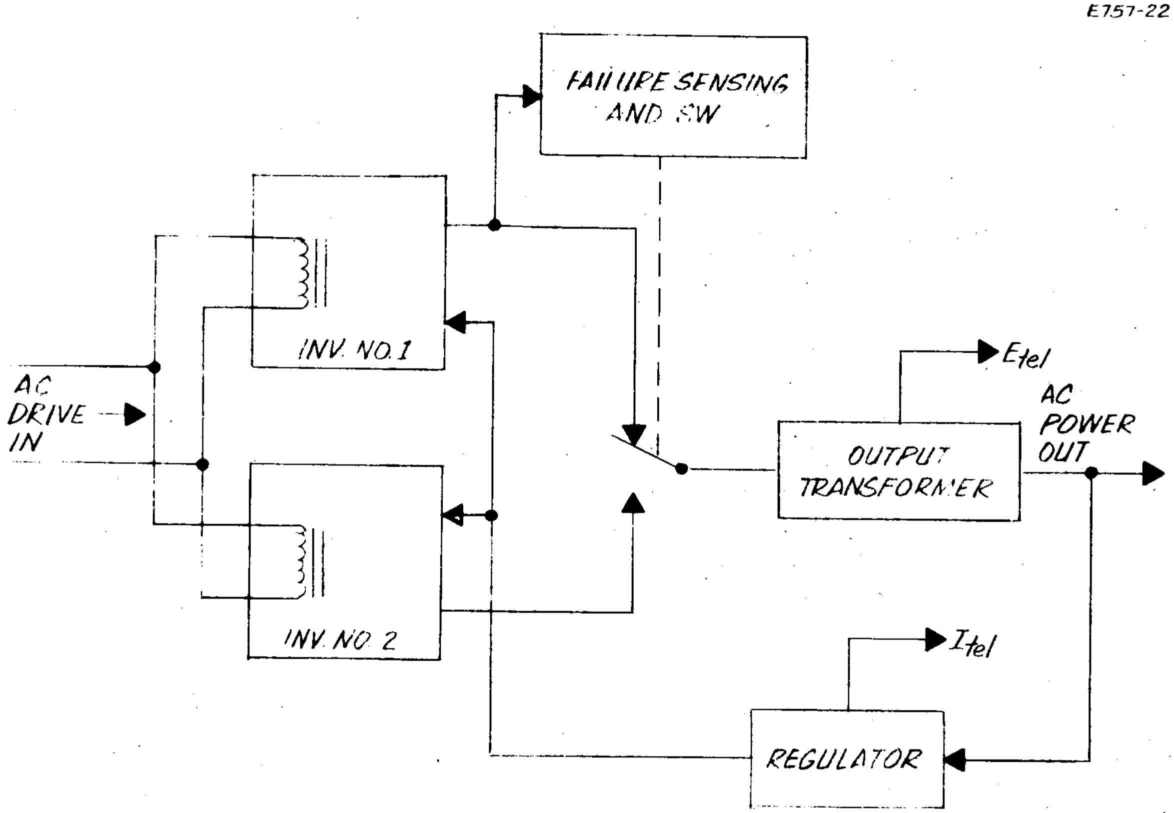

Fig. 8. Cathode heater supply functional diagram.

TABLE III

Cathode Heater Failure Modes

TYPE OF FAILURE	RESULT
1. Inverter module failure	1. Standby module inserted
2. Input transformer fails short or short to ground	2. Overloads AC driven source (heater inverter)
3. Relay or driving circuit failure a. Operates inadvertently and in addition inverter No. 2 malfunctions b. Fails to operate and in addition inverter No. 1 malfunctions	3. Switch AC power a. AC power out connected to non-operating inverter b. AC power out connected to a non-operating inverter
4. Regulator or transformer failure	4. Loss of output

Item 1 in Table III does not represent a system failure since the standy module is automatically inserted. Items 2, 3, and 4 do, however, result in a loss of the system.

The reliability block diagram of the Cathode Heater is given in Fig. 9. This sybsystem consists of standby and series elements. Although physically only one failure sense and switch is imployed, from a reliability point of view two possible failure modes exist for this element: (1) inadvertent switching (λ_a) and (2) complete failure (λ_b). For the sake of conservatism assume λ_a is equal to λ_b.

From the appropriate Stress Sheets, the R_i's of the blocks shown in Fig. 9 can be determined as follows

$$R_1 = 0.9880$$

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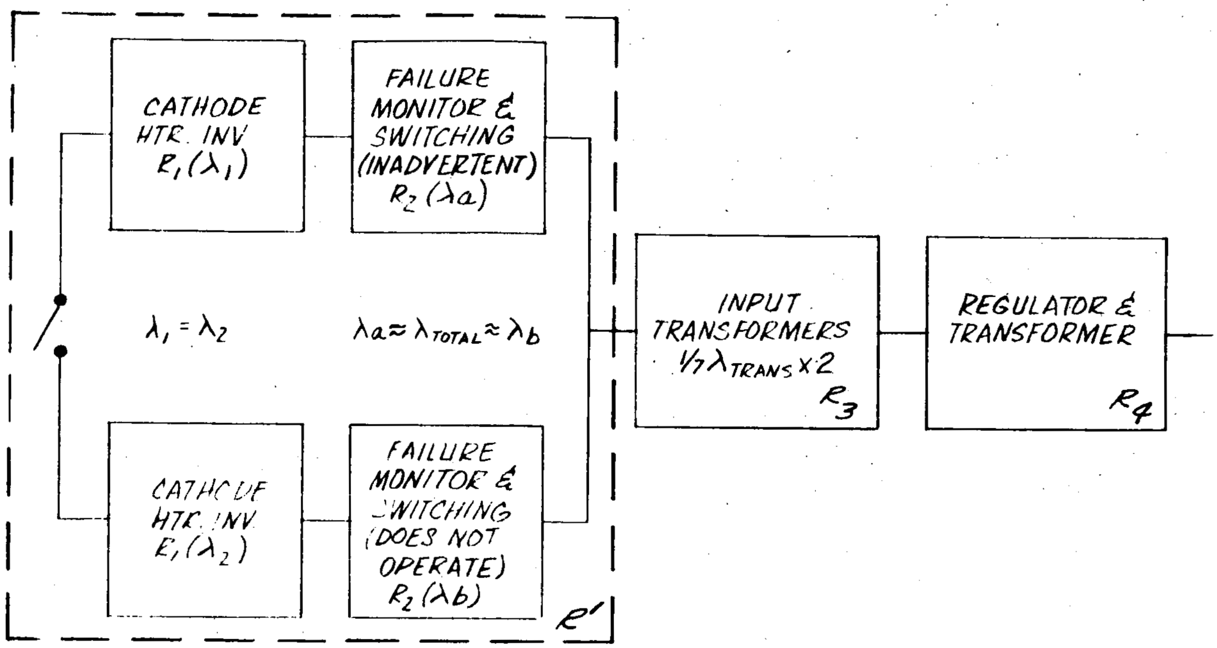

Fig. 9. Cathode heater supply reliability diagram.

$$R_1 = 0.9880$$

$$R_2 = 0.9978$$

$$R_3 = 0.9996$$

$$R_4 = 0.9875$$

Consider now the various groupings of blocks as represented by the R_i's:

$\underline{R_1, R_2}$ — Two series groups each with reliability R_5

where $R_5 = R_1 \cdot R_2 = 0.9858$

$\underline{R_5, R_5}$ — Standby redundant group with equal failure rates so that

$$R^1 = R_5 (1 - \lambda t) = 0.9999$$

$\underline{R^1, R_3, R_4}$ — Series group which provides the total reliability of the Cathode Heater subsystem

$$R = R^1 \cdot R_3 \cdot R_4 = 0.9870 \quad .$$

5. Logic and Control

The functions and outputs provided by the Logic and Control subsystem are as follows:

Functions

High power control logic

- Provides turn on/off and redundant switching commands to Beam, Accel/Magnet, and Arc Supplies
- Provides for Beam voltage reduction at high line voltages

System timing and control

- Provides timing for start pulses, trip sampling, and vaporizer delay

- Provides interface for system turn on/off
- Provides trip level sensing and generation of overload turn off commands

Analog control system

- Derives desired control characteristics from system parameter inputs
- Provides linear control signals to variable supplies based on derived control characteristics

Outputs

- Low level logic commands
- Low level analog control signals.

The functional circuit diagram of the Logic and Control subsystem is shown in Fig. 10. This subsystem may be logically divided into two basic sections of analog circuitry and digital circuitry. The digital portion may be further divided into a timing and control section and a control logic section. The functions of these individual sections are summarized in Fig. 10. Although a large number of operations are being performed by this system, it is physically small and is all contained in a single module. The major portion of the circuitry (both the analog and digital sections) is mechanized with integrated microcircuits in order to achieve small size and weight and high reliability.

There is no redundancy employed in this subsystem and as such the mathematical model reduces to a series element and the reliability calculation is based on component failure rate tabulation. For convenience of calculation the Logic and Control is divided into three series blocks, namely; (1) system timing and control function, R_1; (2) high power control logic, R_2; and (3) analog control system, R_3. From the Stress Sheets in Appendix B, the numerical values of the R_i's are as follows:

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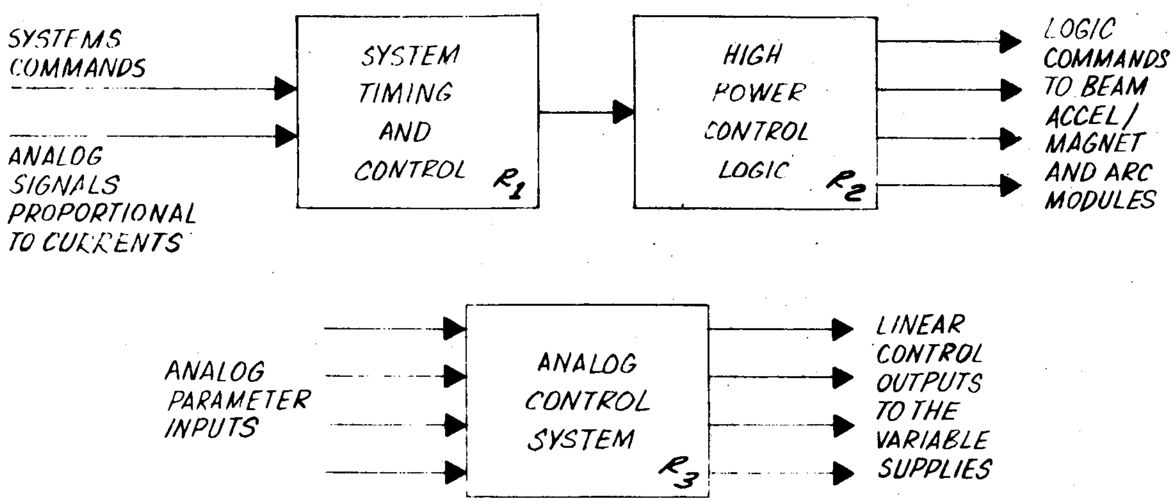

Fig. 10. Logic and control subsystem functional diagram.

$$R_1 = 0.9748$$

$$R_2 = 0.9807$$

$$R_3 = 0.9718 \quad .$$

The total Logic and Control subsystem reliability is then

$$R = R_1 \cdot R_2 \cdot R_3 = 0.9292 \quad .$$

6. Arc Supply

The function and outputs of the Arc Supply subsystem are as follows:

Function

- Provide DC power to the arc discharge

Outputs

- +36 VDC discharge power output (isolated for +3.5 KV)
- +108 VDC boost at $I_{arc} \leq 10$ mA

  +5 VDC voltage telemetry

  +5 VDC current telemetry .

The functional circuit diagram of the Arc supply is shown in Fig. 11. The two operating plus one standby modules (three total) are shown with their outputs AC added in a series string. In this case, a module which is turned off or has failed must reflect a short circuit since diode shunting cannot be used. The short is reflected by shorting the output transformer primary with a relay as shown in the diagram. The modules used here employ driven inverters with the AC drive being received from the Accel/ Magnet inverters (see next section). The AC power out of the series string is supplied to the rectifier, filter, and regulator circuitry which is located

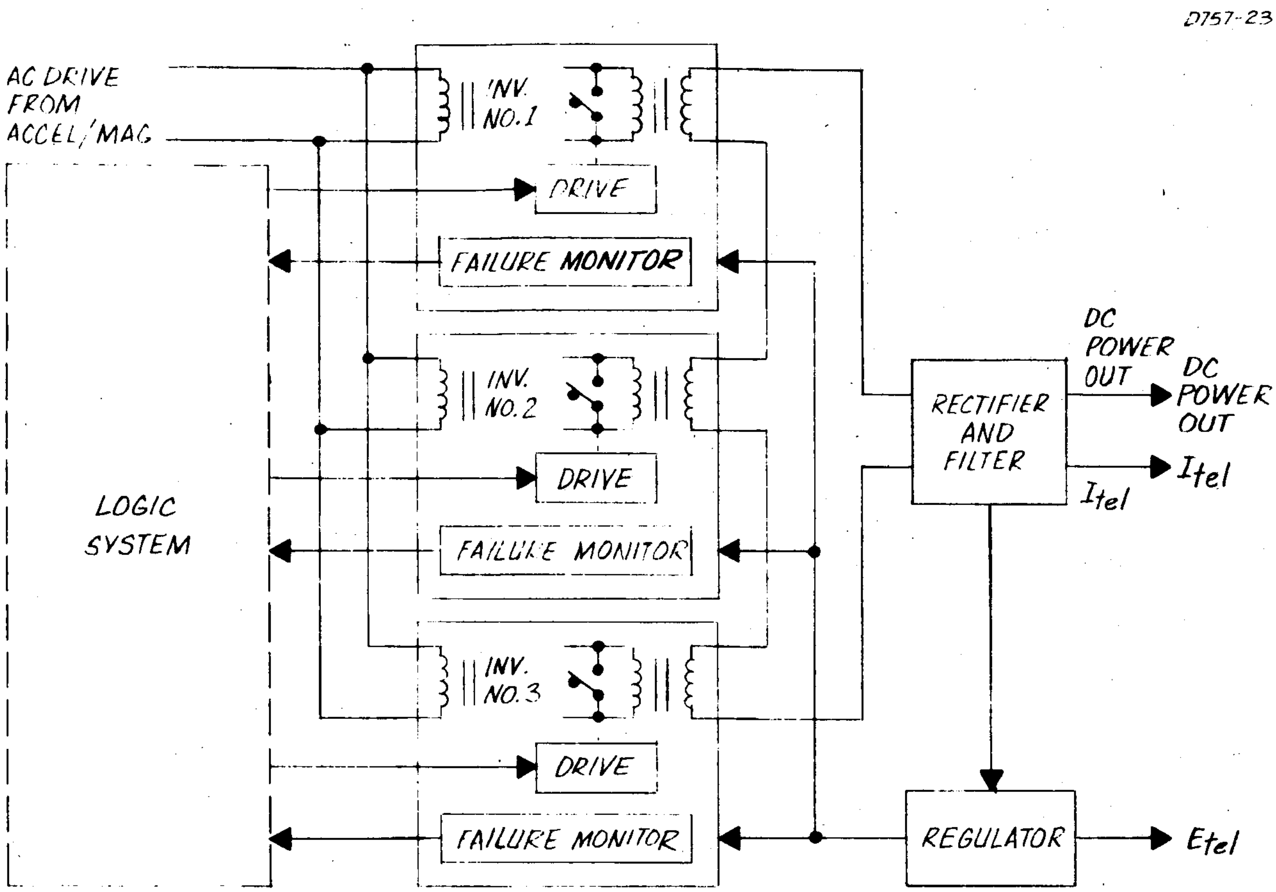

Fig. 11. Arc supply functional diagram.

in a fourth module called the Arc Rectifier Filter. The regulator measures the output DC voltage, compares this to the desired value (commanded by the analog control system), and provides an error signal to the pulse-width modulators in the inverters. Redundancy is not provided for the circuitry in the Arc Rectifier Filter module.

The failure modes associated with the Arc Supply subsystem are summarized in Table IV along with their effect on the system. Some explanation is necessary for Item 3. It can be seen that the failure mode listed covers the possibility that the relay (this includes driving circuitry) would fail to short the primary in the event of a module failure. It will be noticed that no mention is made of the possibility of the relay in the standby module failing in such a way that it opens the primary and energizes the module. If this should occur, then all three modules would be simultaneously operating. However, since this is a regulated supply, and the three operating inverters would be cut back such that they produced the normal output. Thus, this relay failure mode does not represent a system failure and although it changes the configuration slightly, this change has negligible effect on the reliability calculation. Hence, this mode is not listed on the drawing.

TABLE IV

Arc Supply Failure Modes

TYPE OF FAILURE	RESULT
1. Inverter Module Failure	1. Standby Module Inserted
2. Failure monitor failure	2.
a. Indicates no failure when one has occurred	a. Standby not inserted therefore output too low
b. Indicates failure when one has not occurred	b. Standby inserted and indicated failed module removed
3. Relay fails in such a way that it does not short the module primary when a failure has occurred in that module	3. Series string open
4. Input transformer fails short to ground	4. AC Drive overloaded
5. Output transformer fails short to ground or open secondary (may be reflected)	5. Short placed on 3.5 KV bus or series string opens
6. Rectifier-filter or Regulator failure	6. Loss of output
7. Series string connections mechanical open or short to ground	7. Short placed on 3.5 KV bus or series string opens

As indicated Items 1 and 2b in Table IV do not result in a system failure. Items 2a and 3 through 7 do, however, affect a loss of the system.

The reliability block diagram of the Arc Supply (see Fig. 12) shows that this subsystem consists of standby and series elements. The reliability of the standby redundant portion which consists of the blocks designated by R_1 through R_4 can be determined by

$$R^1 = e^{-m\lambda t}(1 + m\lambda t) \tag{6}$$

From the Stress Sheets the failure rates of the arc inverter, fail sense, and switching (these latter two being the monitor and relay) are 0.1308%/1000 hrs, 0.0123%/1000 hrs, and 0.0063%/1000 hrs, respectively. Thus, since these three elements are in series, the failure rate in Eq. 6 is given as

$$\lambda = 0.1308\%/1000 \text{ hrs} + 0.0123\%/1000 \text{ hrs} + 0.00635/1000 \text{ hrs}$$

$$= 0.1495\%/1000 \text{ hrs}$$

$$m\lambda t = 2 \times 0.1495\%/1000 \text{ hrs} \times 10,000 \text{ hrs} = 0.0299$$

and

$$R^1 = 0.9991 \ .$$

Since R^1 is in series with R_5, R_6, R_7, and R_8, the total reliability of the Arc Supply is given by

$$R = R^1 \cdot R_5 \cdot R_6 \cdot R_7 \cdot R_8 = 0.9813 \ .$$

From the appropriate Stress Sheets in Table B-I the remaining R_i's of the blocks shown in Fig. 12 can be determined with the following results

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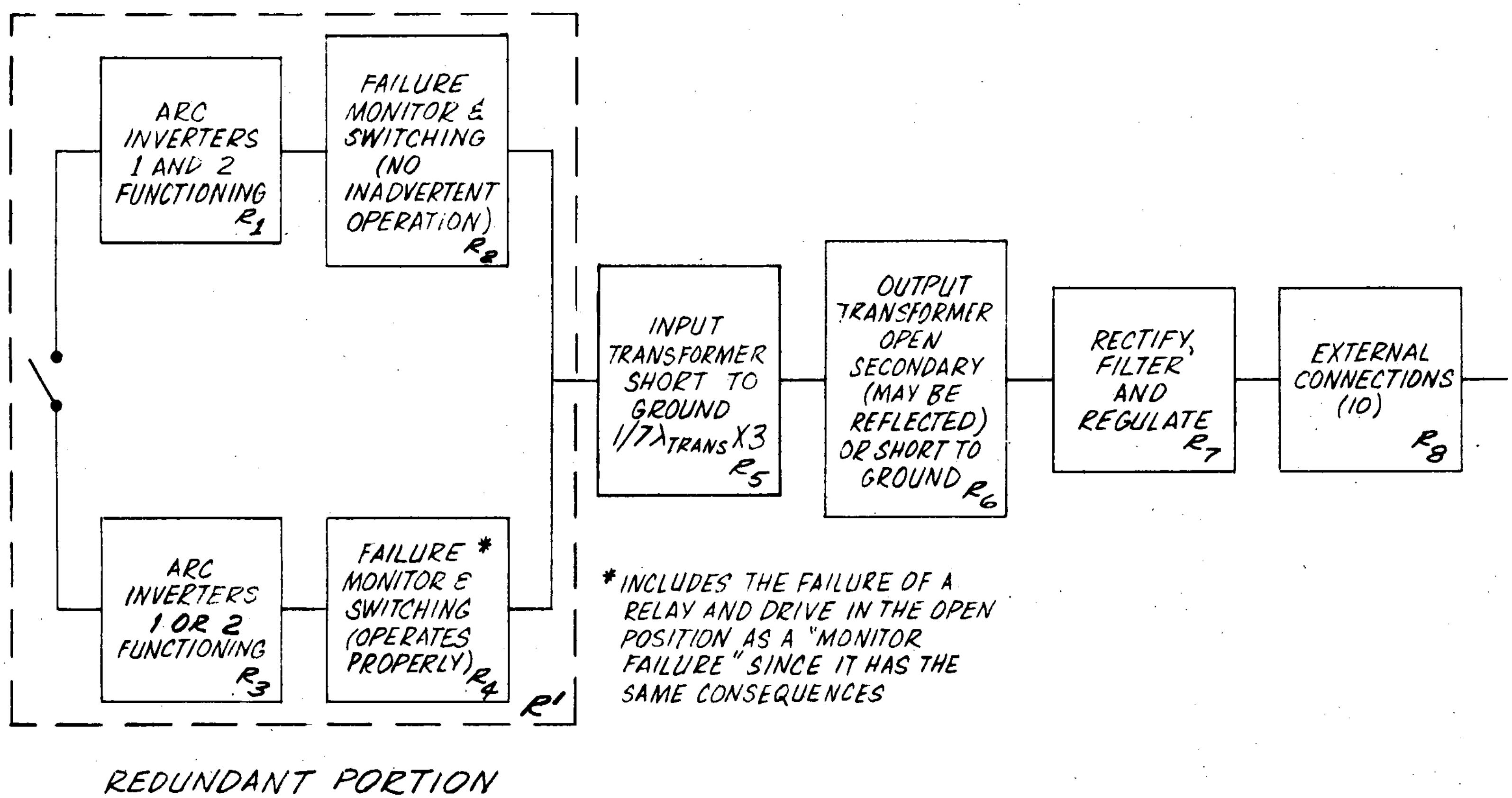

Fig. 12. Arc supply reliability diagram.

R_5 = 0.9994 (3 transformers, 1 failure mode)

R_6 = 0.9982 (3 transformers, 2 failure modes)

R_7 = 0.9837

R_8 = 0.9998 (10 connections) .

7. Accelerator/Magnet Supply

The functions and outputs provided by the Accelerator/Magnet Supply subsystem are as follows:

Functions

- Provide DC power to the magnet
- Provide DC power to accelerator at -2000 VDC
- Provide AC drive to arc inverters

Outputs

- +4 VDC magnet power output
  +5 VDC current telemetry No. 1
  +5 VDC current telemetry No. 2
- -2000 VDC accelerator power output
  +5 VDC voltage telemetry
  +5 VDC current telemetry
- 20 VAC push-pull drive for arc supply .

The functional circuit diagram of the Accelerator/Magnet supply is shown in Fig. 13. One operating inverter plus one standby inverter are employed (total of two). The major portion of the inverter output power supplies the Magnet rectifiers. A smaller amount of power supplies the Accelerator high voltage transformers whose outputs are DC added in a

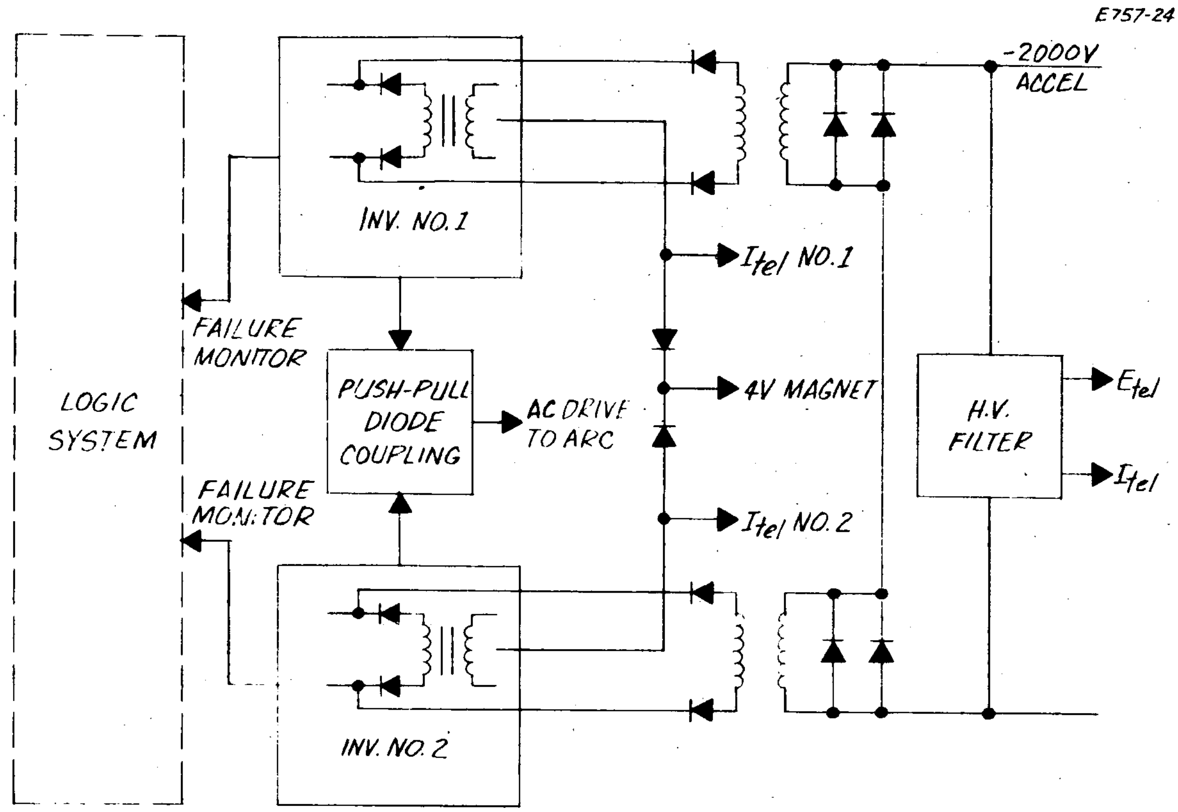

Fig. 13. Accelerator-magnet supply functional diagram.

manner similar to that of the Beam Supply. In addition, AC drive is supplied to the Arc inverters. The Magnet rectifiers and the Accelerator high voltage transformers and associated circuits are located in a third module called the Accel/Magnet Rectifier.

The failure modes associated with the Accelerator/Magnet subsystem as well as their effect on the system are given in Table V.

TABLE V

Accelerator/Magnet Supply Failure Modes

TYPE OF FAILURE	RESULT
1. Inverter module failure	1. Standby module inserted
2. Failure monitor failure	2.
a. Indicates no failure when one has occurred	a. Standby not inserted — output too low
b. Indicates failure when one has not occurred	b. Standby inserted and indicated failed module removed
3. Magnet rectifiers fail short	3. Overload inverters
4. Magnet transformers or Accel transformers fail short to ground	4. Short on + 3.5 KV bus or short on - 2 KV bus
5. Component failure of any type in Accel filter	5. Accel short to ground, loss of telemetry, poor ripple
6. External connections mechanical open or short to ground	6. Loss of Magnet or Accel output

All items in Table V, except 1 and 2b, result in a system failure.

The reliability diagram of the Accelerator/Magnet is given in Fig. 14. It can be seen from this diagram, that Accelerator/Magnet subsystem consists of standby and series elements.

With the exception of R_3 (i.e., the reliability of the Failure Monitor function) the R_i's can be obtained from the appropriate Stress Sheets in Appendix B. The failure monitor in this subsystem is limited to detecting failures in the inverters (i.e. R_1). Thus, should a failure occur in a rectifier element without a simultaneous (or subsequent) failure in the inverter, the standby system would not be switched in. The reliability of the failure monitor, R_{FM}, must, therefore, be degraded by the probability of such an occurrence to provide the actual reliability of the failure monitor function, R_3. The probability of a failure, P_F, in an inverter without a failure in a rectifier is given by

$$P_F = 1 - P_S$$

where P_S, the probability of both failing is

$$P_S = (1-R_2)\ R_1 \quad .$$

Therefore, the reliability of the failure sensing function is

$$R_3 = R_{FM}[1 - (1-R_2)R_1] \quad .$$

The values of the R_i's are then

$$R_1 = R_1' = 0.9814$$

$$R_2 = R_2' = 0.9917$$

$$R_{FM} = 0.9970$$

E757-16

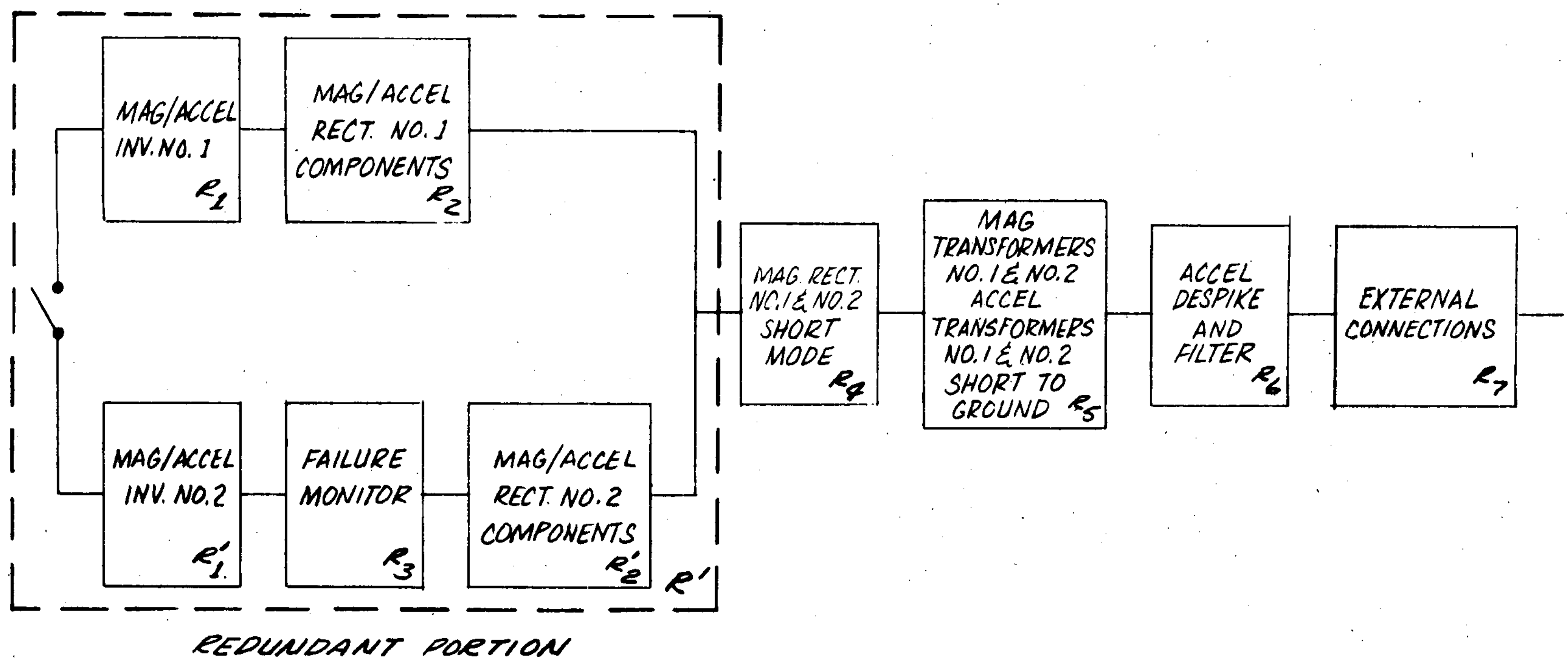

Fig. 14. Accelerator-magnet supply reliability diagram.

$$R_3 = R_{FM}[1 - (1-R_1)R_2] = 0.9919$$

$$R_4 = 0.9958$$

$$R_5 = 0.9986$$

$$R_6 = 0.9987$$

$$R_7 = 0.9999 \quad .$$

The various groupings of the blocks as designated by the R_i's are:

$\underline{R_1, R_2}$ — Series group with reliability R_8

where $$R_8 = R_1 \cdot R_2 = 0.9732$$

yielding an effective failure rate for 10,000 hrs for these elements of

$$\lambda_1 t = 0.00265$$

$\underline{R_1', R_2', R_3}$ — Series group with reliability R_9

where $$R_9 = R_1' \cdot R_2' \cdot R_3 = 0.9653$$

yielding an effective failure rate for 10,000 hrs for these elements of

$$\lambda_2 t = 0.0346$$

$\underline{R_8, R_9}$ — Standby redundant group with failure rates λ_1 and λ_2, respectively. Using Eq. 4 the reliability, R^1, of the standby redundant group is

$$R^1 = \frac{\lambda_2 R_8 - \lambda_1 R_9}{\lambda_2 - \lambda_1} = 0.9993 \quad .$$

Since the remainder of the blocks are in series with R^1, the total reliability of the Accelerator/Magnet is given by

$$R = R^1 \cdot R_4 \cdot R_5 \cdot R_6 \cdot R_7 = 0.9926 .$$

C. LAUNCH CONSIDERATIONS

The analysis to this point has been based on the long 10,000 hour benign environment to be encountered while in space. However, system reliability is degraded by the necessity to survive the rather severe environment of the launch phase. The launch phase is treated mathematically by multiplying the basic component failure rates by an appropriate factor. These factors are listed in Table VI.

Rather than multiply each individual component by its particular factor, the conservative approach of multiplying each component failure rate by the highest factor (100) was taken. It is then only necessary to find an equivalent failure rate for the entire system, multiply this by 100 and then evaluate the reliability degradation for the launch duration (assumed to be 0.2 hour).

$$e^{-\lambda eq \cdot 10^4 hrs} = 0.85$$

$$\lambda eq = 1.6\%/1000 \text{ hrs}$$

$$e^{-\lambda eq \cdot 100 \cdot (0.2 \text{ hrs})} = 0.9997$$

The total system reliability (0.85) must be multiplied by this number to include the launch phase. It can be seen that because of the large difference in time periods, the launch degradation has little effect on over-all reliability.

TABLE VI

Application K-Factors (MIL-HDBK-217A)

Part Type	Specification	Application	K-Factor
Diode-Power	MIL-S-19500	Missile	18
Diode-Silicon	MIL-S-19500	Missile	10
Diode-Zener	MIL-S-19500	Missile	10
Transistor-Power	MIL-S-19500	Missile	75
Transistor-Silicon	MIL-S-19500	Missile	25
Capacitors-Tantalum*	MIL-C-3965	Missile	25
Capacitors-Foil Electrolytic	MIL-C-3965	Missile	40
Capacitors-Aluminum Electrolytic	MIL-C-62	Missile	2.0
Capacitors-Ceramic Temp. Comp.	MIL-C-20	Missile	15
Resistors-Fixed Film	MIL-R-10509	Missile	1.5
Resistors-Accurate Wire Wound	MIL-R-93	Missile	13.0
Resistors-Power Wire Wound	MIL-R-26	Missile	100
Resistors-Fixed Composition	MIL-R-11	Missile	50

Note: : *Tantalum wet slug temperature range 0 - 125°C
: Tantalum glass seal wet slug temperature range 0 - 175°C

References: Hughes Reliability Knowledge on Surveyor Spacecraft.
Hughes Designers Reliability Handbook No. R-67-2, page 8 and MIL-STD-756.
Parts Selection-Control on Satellites "How the Experts Pick Reliable Components" (Copy in Appendix).

SECTION IV

RELIABILITY ANALYSIS/IMPROVED SYSTEM

Based on the reliability analysis on the thermal/vacuum prototype as well as more closely matching the power capability of the supplies to the 15 cm thruster requirements, a modified power conditioning and control system has been designed. As will be shown the reliability of this improved system has been thus increased with no associated weight penalty.

The numerical results that were obtained for the improved system were generated by using the thermal/vacuum prototype system numbers and modifying these to account for any circuit changes. The results of this analysis are summarized in Fig. 15. It may be seen that the total system reliability has been increased to 0.96. A description of the changes along with a summary of the calculations are presented in the following paragraphs.

A. BEAM SUPPLY

The power demand of a 15 cm thruster is such that the Beam Supply can be reduced from the original 7 operating modules with 2 in standby to 4 operating modules with 2 in standby. While this change will not have an appreciable affect on the reliability of the system, it does provide a substantial reduction in the size and weight of the Beam Supply.

Referring to Section III.B.1, the R_i's of the improved Beam Supply are changed as follows

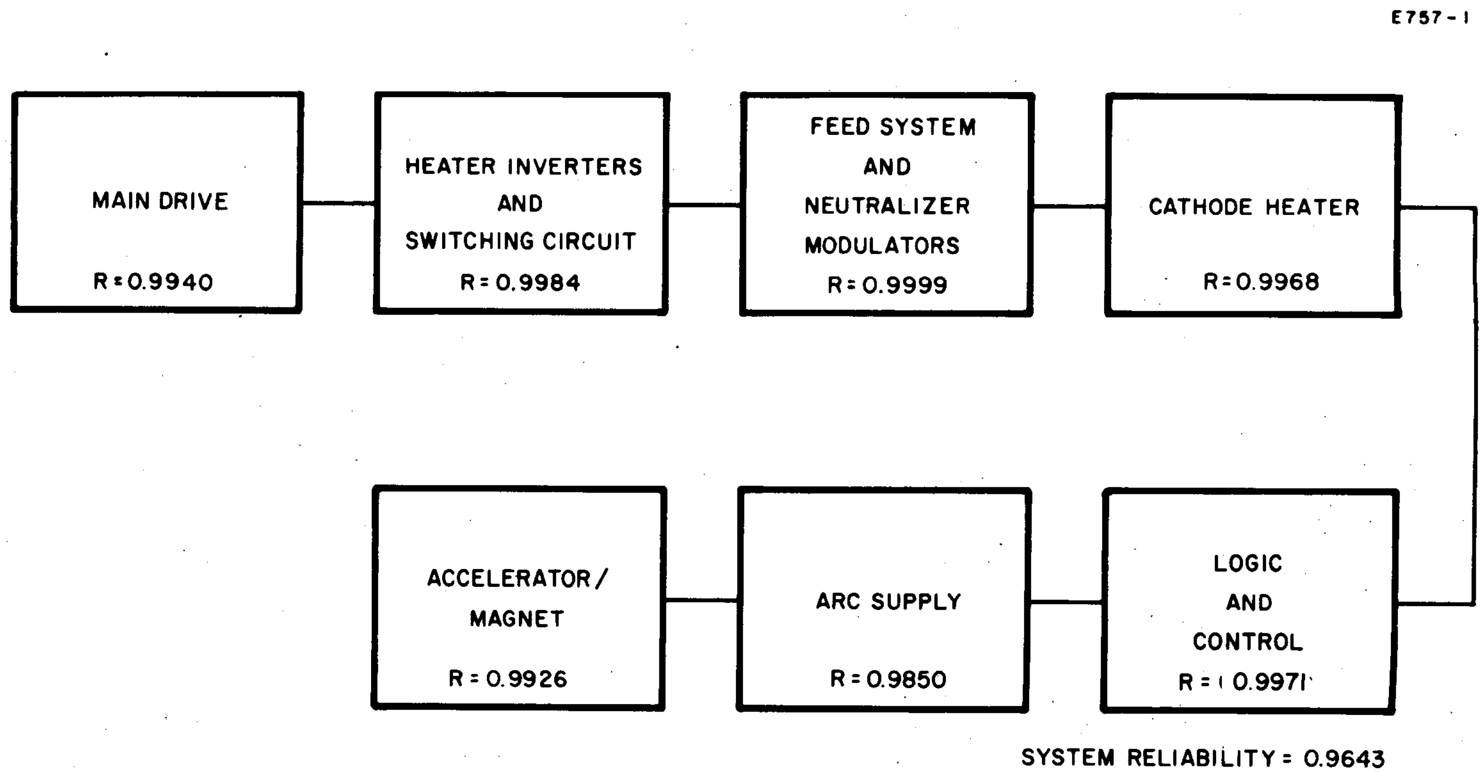

Fig. 15. Reliability summary of improved power conditioning and control system.

$R_1 = e^{-4\lambda t} = 0.9371$ (4 operating modules)

$R_2 = e^{-4\lambda t}\ (4\lambda t) = 0.0609$ (4 operating modules)

$R_3 = e^{-4\lambda t}\ \frac{(4\lambda t)^2}{2} = 0.0020$ (4 operating modules)

$R_4 = R_5 = 0.9980$ (no change)

$R_6 = 0.9974$ (no change)

$R_7 = 0.9982$ (6 transformers)

$R_8 = 0.9988$ (4 operating modules)

$R_9 = 0.9975$ (26 external connections).

The total Beam Supply reliability is $R = (R_1 + R_2R_4 + R_3R_5) \cdot R_6 \cdot R_7 \cdot R_8 \cdot R_9 = 0.9940$.

B. HEATER INVERTERS AND SWITCHING CIRCUIT

No change was made in this subsystem.

C. FEED SYSTEM AND NEUTRALIZER MODULATORS

The existing Modulator subsystem provides regulated power isolated at high voltage to the Vaporizer and Pressurizer. It also provides on/off high voltage isolated power to the Valve and regulated power to the Neutralizer. The current design employs magnetic amplifiers and transformers and is relatively heavy and bulky considering the power level involved. The successful demonstration of isolators for the engine feed systems now allows considerable reduction of the hardware involved in this subsystem.

It is now possible to design a transformerless feed system supply which employs a single transistor switch between the solar array and the load. This switch is operated by threshold detecting the output parameter to be controlled against an analog command level (generated by the control system). The frequency of operation of the switch is determined by the output parameter sensing time constant and may easily be adjusted over a wide range. This design may be mechanized using all semiconductors and microcircuits and thus provides a size and weight advantage over the magnetic system. It also has a lower part count and this simplicity results in higher reliability. A diagram of a typical circuit of this type is shown in Fig. 16.

The reduction in size and weight of these modulator circuits not only improves the basic module reliability, it also allows the addition of a complete redundant system. That is, it is now possible to design a Modulator subsystem which incorporates 100% redundancy and yet is smaller in size and lighter in weight than the original.

For the purpose of analysis, it was assumed that relay switching (one shot operation) would be used to accommodate the redundant system. Although relay switching is not necessarily the optimum method, its assumption does provide a means for assessing the reliability gain through redundancy. Small differences in the switching schemes only affect the calculation in the third or fourth decimal place and thus the relay scheme adequately weights the effect of the switching circuit.

In order to numerically evaluate the effect of this circuit change on subsystem reliability, a new reliability block diagram is necessary. The 100% redundant system is represented by the simple diagram shown in Fig. 17. The failure rate for the new modulator circuit was evaluated by assuming a complete design based on the typical circuit shown in Fig. 16 and tabulating component failure rates on that basis. The total failure rate was found to be 0.1194%/1000 hrs.

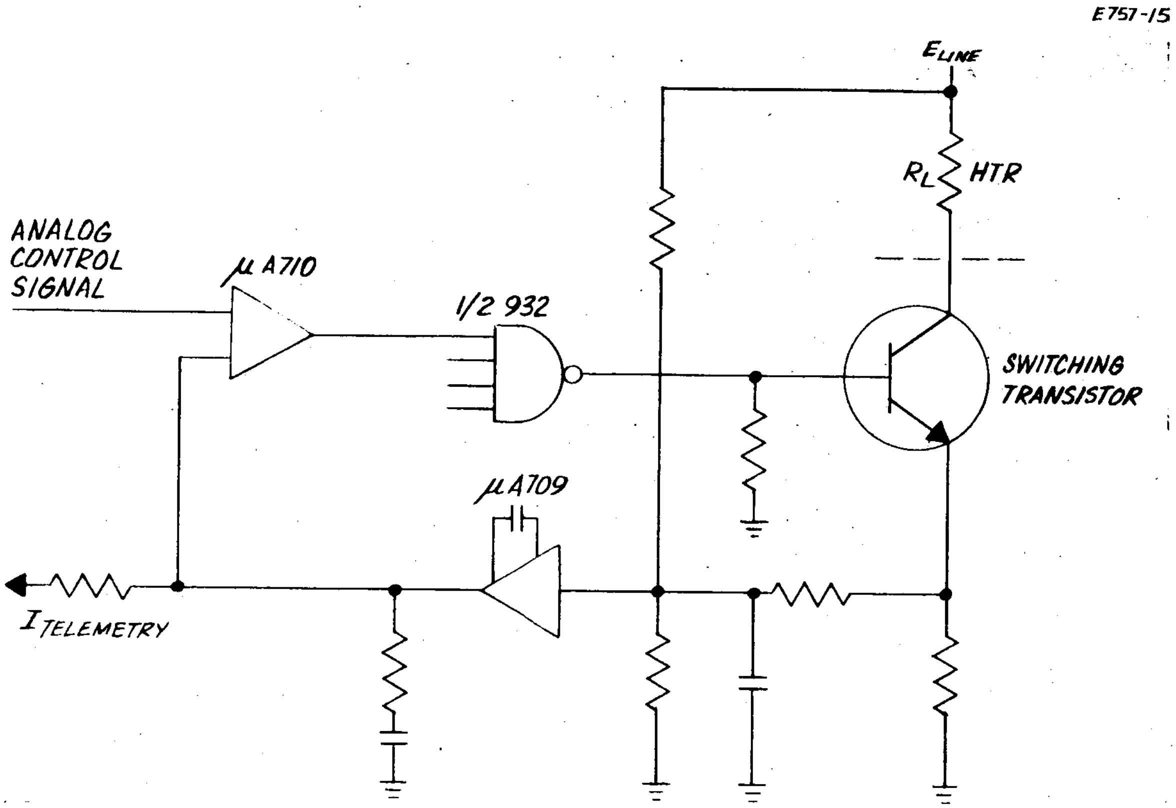

Fig. 16. Transistor switch modulator.

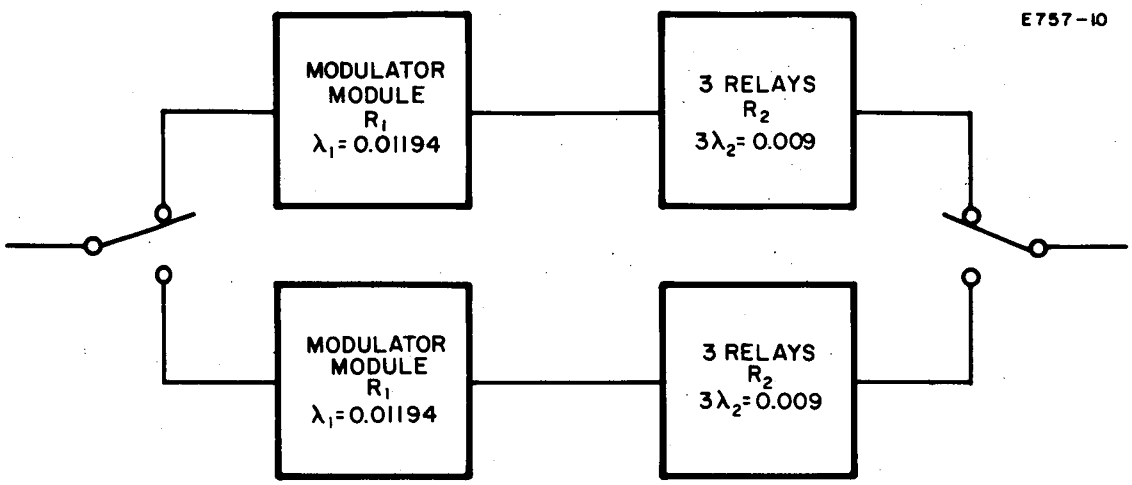

Fig. 17. Improved modulator reliability functional.

It was also determined that six lines would need to be switched to change over to the standby. This switching was to be done with three double pole relays (failure rate for each equals 0.003%/1000 hrs) and hence the failure rates of these relays must be included as series elements. Thus, the total failure rate of the R_1, R_2 series group is $\lambda = 0.1194 + (3 \cdot 0.003) = 0.1284\%/1000$ hrs.

The total reliability of the standby redundant Modulator subsystem is then given by $R' = e^{-\lambda t} (1 + \lambda t) = 0.9999$.

D. CATHODE HEATER SUPPLY

The improvement to the Cathode Heater consists of providing redundant circuits for the regulator and telemetry functions. This redundancy involves only a small number of semiconductor components and thus the change has little effect on size and weight. The effect of redundancy is again evaluated by assuming relay switching. Note that if relay switching were actually employed, small TO-5 size, double pole, relays are available and are fully qualified. Thus, the size and weight considerations were not overlooked when considering this form of switching.

The improvement affects the R_5 block (regulator and transformer) of Fig. 9 with the remainder of the original Cathode Heater diagram being unchanged. The diagram given in Fig. 18 shows the reliability diagram that should be used to replace R_4 in Fig. 9. It may be seen that the original block has been split into two parts. One part remains as nonredundant and the other part forms one half of a redundant pair. It has been determined that 10 lines would be switched and thus 5 relays are required.

The reliability of the redundant portion of Fig. 18 is again $R^1 = e^{-\lambda t} (1 + \lambda t)$ where λ is the sum of the failure rates of the regulator and telemetry and 5 relay switches. From the failure rates previously given $\lambda = 0.1135\%/1000$ hrs and $R' = 0.9999$. The reliability of the modified R_4 block is then $R_4' = R' \cdot R_5 = 0.9971$ where $R_5 = e^{-\lambda_1 t}$.

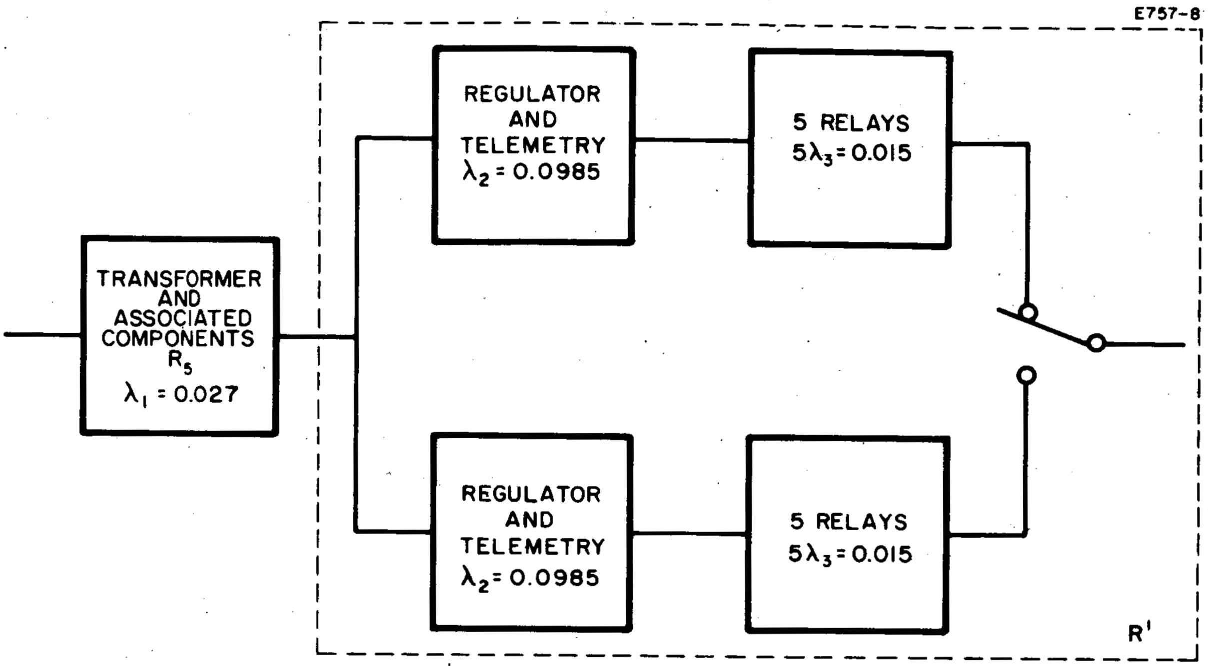

Fig. 18. Modification to R_4 block of cathode heater.

E. LOGIC AND CONTROL

The existing Logic and Control module does not employ redundancy. Because of the small size of the components used in this module, it is possible to add a completely redundant circuit and still keep the package within the confines of a single module. The Logic and Control system is mechanized with integrated microcircuits and thus very dense packaging is possible.

This type of circuitry lends itself to many possible techniques whereby redundancy may be built directly in the configuration. However, again to expedite the analysis, the affect of redundancy is evaluated by assuming relay switching between the operating and standby lines. A block diagram is shown in Fig. 19. It is necessary to switch 30 lines here and thus 15 relays are shown.

The total failure rate of the series elements in the redundant group shown in Fig. 19 is 0.7804%/1000 hrs and the total reliability of this subsystem is given by $R' = e^{-\lambda t}(1 + \lambda t) = 0.9971$.

F. ARC SUPPLY

The improvement to the Arc Supply consists of providing redundant circuits for the regulator and telemetry functions in a manner similar to that of the Cathode Heater improvement. The improvement affects the R_7 block (Rectify, Filter and Regulate) of Fig. 12 with the remainder of the original Arc Supply diagram being unchanged. Figure 20 shows the reliability diagram which replaces R_7 in Fig. 12.

Again the reliability of the redundant portion of Fig. 20 can be found by the expression $R^1 = e^{-\lambda t}(1 + \lambda t)$ where λ is the sum of the failure rates of the regulator and telemetry and the 5 relay switches. From failure rates previously given

$$\lambda = 0.1047\%/1000 \text{ hrs}$$

and

$$R^1 = 0.9958 \ .$$

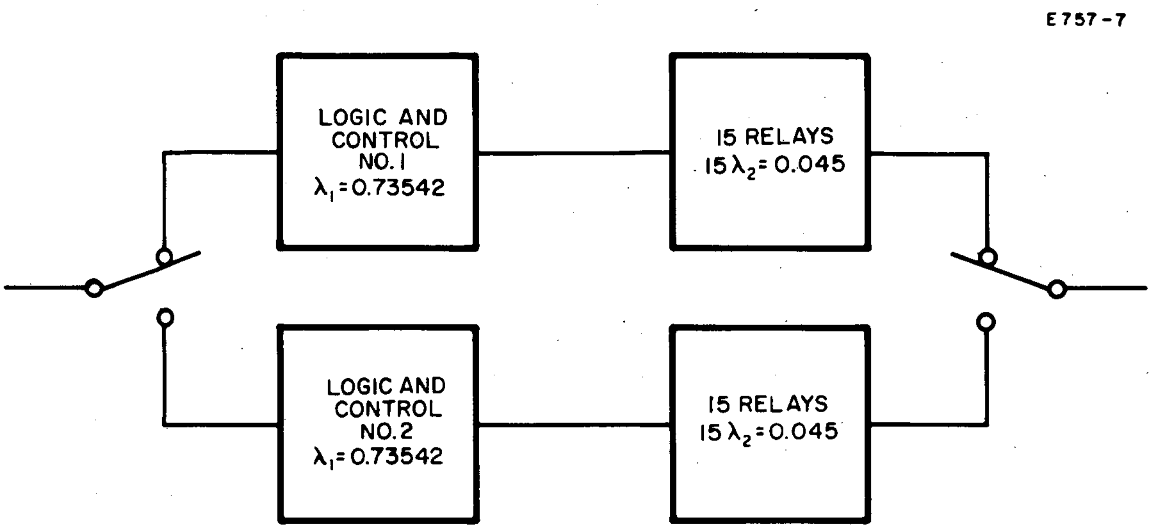

Fig. 19. Improved logic and control reliability functional.

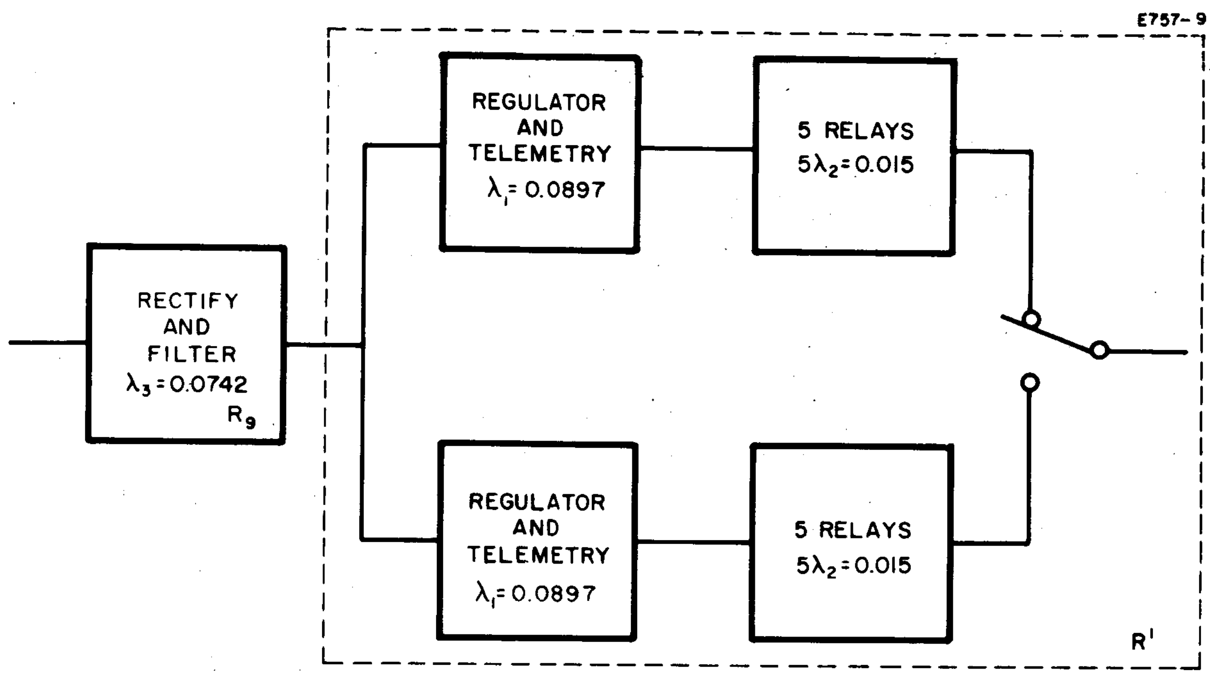

Fig. 20. Modification to R_7 block of arc supply.

The reliability of the modified R_7 block is then $R_7^1 = R^1 \cdot R_9 = 0.9885$ where $R_9 = e^{-\lambda 3t}$.

Thus, the total reliability of the improved Arc Supply is $R = R^1 \cdot R_5 \cdot R_6 \cdot R_7^1 \cdot R_8 = 0.9850$ where R^1, R_5, R_6, and R_8 are obtained from Section III.B.6.

G. ACCELERATOR/MAGNET SUPPLY

An improvement was made to the Accel/Magnet supply which was of rather low order from a reliability standpoint. In fact, there is no noticeable change in the numerical result when this change is incorporated. However, the change involves essentially no hardware and as such, it is a recommended addition.

The Accel/Magnet supply employs a failure monitor circuit which senses whether or not the inverter is functioning properly. However, there are some components "downstream" from the inverter which could fail and yet, not be detected. If this type of failure should occur and the inverter should continue to function properly, the standby system would not be turned on. The numbers involved make the probability of this occurring very small. However, by including the possibility of starting the standby system (in this case, built in logic turns off the main inverter) from a ground command, this mode of failure can be circumvented. Since the interface for accommodating a general command exists, this change is easily accomplished.

APPENDIX A

DERIVATION OF EXACT MATHEMATICAL MODELS

Rigorous derivations of exact mathematical models for the Beam Supply and Cathode Heater subsystems are presented here. Also included in this Appendix are the exact mathematical expressions for the remaining subsystem discussed in this report. These exact mathematical models were derived by considering the sequential failure events possible for those parts of the system utilizing standby redundant elements. (The remaining parts are simple series elements in a reliability sense.) These derivations include the effects of the failure sensing and switching mechanisms on the reliability of redundant configurations. Attention is directed to the possibility of inadvertent switching occurring as well as that of the failure sensing and switching circuits being nonoperable at a time when they are needed.

The derivation of the mathematical model for the Beam Supply was chosen for detailed discussion since it is a key part of the system and is a representative complex case. The derivation for the Cathode Heater configuration was also chosen for detailed discussion. It is typical of the simple form of standby redundancy in which one inverter stands by while the first inverter operates. This basic configuration is used repeatedly in both the present design and in the improved system design.

BEAM SUPPLY

The Beam Supply consists of the modules shown in the functional diagram, Fig. 3 of this report. Figure 4 shows the reliability block diagram. In deriving the mathematical model, Fig. A-1 is helpful in understanding the possible sequences leading to a system failure. The diagram

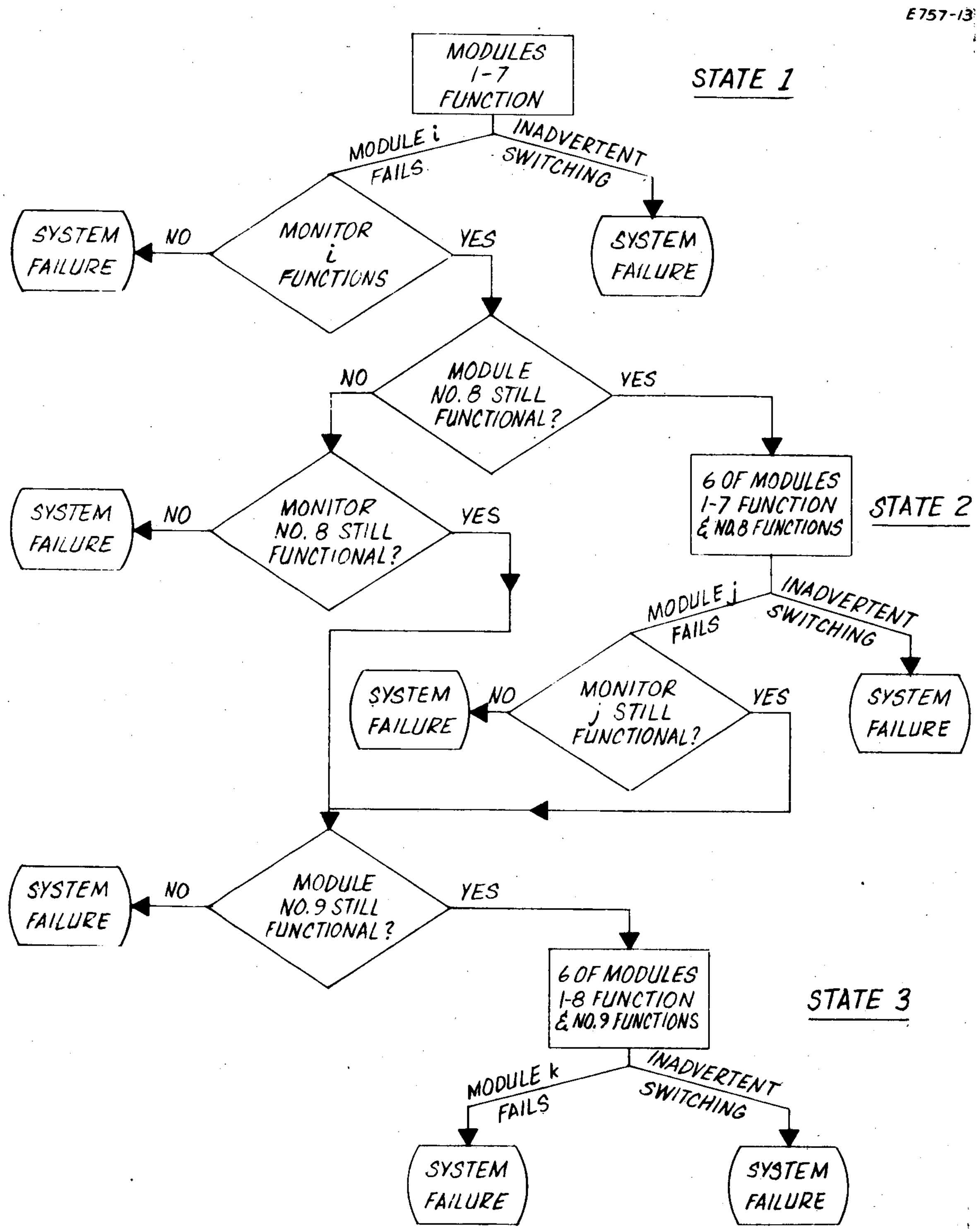

Fig. A-1. Failure modes for Beam Supply inverter modules deals only with the Beam Supply inverter modules. The remainder of the components of the Beam Supply are in series from a reliability viewpoint and their effect is included after consideration of the 9 inverter modules and their failure sensors.

The Beam Supply can be thought of as operating successfully in any one of three states as shown in the rectangular boxes of Fig. A-1. Starting at the top of the figure, the modules will operate in State 1 for the entire mission, providing neither one of the original modules fails nor inadvertent failure sensing and switching occurs for one of the original seven. There is a certain probability of occurrence for each of these failure modes. The subject diagram can be followed through step by step with the branching at each point showing the possible consequences of the subject occurrence. A probability can be assigned to each branching arm at points where alternatives exist.

The probability of successful operation (i.e., reliability) of the beam supply at any time t is simply the probability of operating in either State 1, 2, or 3 at that time.

$$R'(t) = P_1(t) + P_2(t) + P_3(t) \qquad \text{(A-1)}$$

where

$P_n(t)$ = probability of success in state n at time t

$R'(t)$ = reliability of system.

To solve the above equation for system reliability, the solution for each term will be developed. Therefore, let:

λ_1: failure rate for 7 operating modules

λ': failure rate for single module standing by, and

λ_y: failure rate for failure monitor,

then,

$$P_1(t) = e^{-\lambda_1 t} \qquad \text{(A-2)}$$

The term $P_2(t)$ is determined by examining Fig. A-1 to determine the various ways of arriving in State 2 at a time t + h, where h is a small time interval.

One way of arriving in State 2 at time t + h would be to start in State 1 at time t, experience a module failure during the time interval t to t + h, successfully detect the failed module and switch one of the standby modules into operation. A second way to arrive in State 2 at time t + h would be to be in State 2 at time t and experience no failure which would cause a departure from State 2. Assigning probabilities to these two possible ways of being in State 2 at time t + h.

$$P_2(t+h) = P_1(t)\left[\lambda_1 h\, e^{-\lambda_y t}\, e^{-\lambda' t}\right] + P_2(t)\left[1 - \lambda_1 h\right] \qquad \text{(A-3)}$$

since $P_2(t + h)$ is the sum of the two probabilities. The first term corresponds to entering State 2 from State 1 along the single possible successful path. The quantity $\lambda_1 h$ is the probability of failure of a single one of the 7 operating modules during the short time interval h. The quantity $e^{-\lambda_y t}$ is the probability that the failure sensor for the failed module is still operable at time t, and the quantity $e^{-\lambda' t}$ is the probability that the standby module switched in is still operable at time t.

In the second term of eq. A-3, $1 - \lambda_1 h$ is the probability that no failure occurs in the seven operating modules during the time interval t to t + h.

Subtracting $P_2(t)$ from both sides of eq. A-3 and dividing both sides by h yields

$$\frac{P_2(t+h) - P_2(t)}{h} = \lambda_1 e^{-(\lambda_1 + \lambda' + \lambda_y)t} - \lambda_1 P_2(t) \quad . \qquad \text{(A-4)}$$

Note that the previously determined expression for P_1 was inserted. If h is allowed to become increasingly small, eq. A-4 becomes

$$P_2'(t) = \lambda_1 e^{-(\lambda_1 + \lambda' + \lambda_y)t} - \lambda_1 P_2(t) \tag{A-5}$$

But this is a simple first order linear differential equation. Solving the above equation with the boundary condition that $P_2(0) = 0$, yields

$$P_2(t) = e^{-\lambda_1 t}\left(\frac{\lambda_1}{\lambda' + \lambda_y}\right)\left[1 - e^{-(\lambda' + \lambda_y)t}\right]. \tag{A-6}$$

Similarly,

$$\begin{aligned} P_3(t+h) = {} & P_1(t)\left[\lambda_1 h\, e^{-2\lambda_y t}\left(1 - e^{-\lambda' t}\right) e^{-\lambda' t}\right] \\ & + P_2(t)\left[\lambda_1 h\, e^{-\lambda_y t} e^{-\lambda' t}\right] + P_3(t)\left[1 - \lambda_1 h\right] \end{aligned} \tag{A-7}$$

The first term in eq. A-7 is the probability of ending in State 3 at time t + h after being in State 1 at time t. In order for this to happen, one of the original 7 modules must have failed, $(\lambda_1 h)$, the failure sensor for that module must have operated, $(e^{-\lambda_y t})$, the first standby module must have already failed, $(1 - e^{-\lambda' t})$, the failure sensor for the failed standby mdoule must have operated, $(e^{-\lambda_y t})$, and finally, the second standby module must not have failed, $(e^{-\lambda' t})$. The second and third terms are arrived at similarly through the use of Fig. A-1 and the associated probabilities.

Putting eq. A-7 into the form of a differntial equation, and solving the equation with the boundary value $P_3(0) = 0$ yields

$$P_3(t) = \lambda_1 e^{-\lambda_1 t}\left[\frac{1}{\lambda' + 2\lambda_y}\left\{1 - e^{-(\lambda' + 2\lambda_y)t}\right\}\right.$$

$$- \frac{1}{2(\lambda' + \lambda_y)}\left\{1 - e^{-2(\lambda' + \lambda_y)t}\right\} \tag{A-8}$$

$$\left. + \frac{\lambda_1}{2(\lambda' + \lambda_y)^2}\left\{1 + e^{-2(\lambda' + \lambda_y)t}\right\} + \frac{\lambda_1}{(\lambda' + \lambda_y)^2}\, e^{-(\lambda' + \lambda_y)t}\right].$$

Substituting the above equations for $P_1(t)$, $P_2(t)$, and $P_3(t)$ into equation A-1.

$$R'(t) = e^{-\lambda_1 t} + e^{-\lambda_1 t}\left(\frac{\lambda_1}{\lambda' + \lambda_y}\right)\left[1 - e^{-(\lambda' + \lambda_y)t}\right]$$

$$+ \lambda_1 e^{-\lambda_1 t}\left[\frac{1}{\lambda' + 2\lambda_y}\left\{1 - e^{-(\lambda' + \lambda_y)t}\right\}\right.$$

$$- \frac{\lambda_1}{2(\lambda' + \lambda_y)}\left\{1 - e^{-2(\lambda' + \lambda_y)t}\right\} \tag{A-9}$$

$$\left. \frac{\lambda_1}{2(\lambda' + \lambda_y)^2}\left\{1 + e^{-2(\lambda' + \lambda_y)t}\right\} - \frac{\lambda_1}{(\lambda' + \lambda_y)^2}\, e^{-(\lambda' + \lambda_y)t}\right].$$

Referring to the reliability block diagram for the Beam Supply, Fig. 4, the total reliability equation for the Beam Supply is

$$R(t) = R'(t)\, R_6 R_7 R_8 R_9 \tag{A-10}$$

where $R'(t)$ is eq. A-9 above.

HEATER INVERTERS AND SWITCHING CIRCUIT

Referring to Fig. 6, the reliability of the heater inverters and switching circuit is given by

$$R(t) = R_{\substack{\text{Heater}\\ \text{Inverters}}} \cdot R_3 \ . \qquad \text{(A-11)}$$

It can be shown that

$$R_{\substack{\text{Heater}\\ \text{Inverters}}} = R_4 \left\{ e^{-(\lambda + \lambda_s)t} \left[1 + \left(1 + \frac{\lambda_s}{\lambda}\right)(1 - e^{-\lambda t}) \right] \right\} \qquad \text{(A-12)}$$

where

λ : failure rate of operating heater inverter

λ': failure rate of standby heater inverter, assume $\lambda' = \lambda$

λ_s: failure rate of failure sensor and automatic switch.

FEED SYSTEM AND NEUTRALIZER MODULATORS

Since all elements are in series, the reliability of the feed system and neutralizer modulators is given by

$$R(t) = e^{-\Sigma \lambda_i t} \qquad \text{(A-13)}$$

where λ_i: failure rate of the i^{th} component part.

CATHODE HEATER SUPPLY

The derivation of this model follows the pattern of that for the Beam Supply, except in this case (see Fig. A-2) inadvertent switching from Inverter No. 1 does not necessarily cause system failure.

To solve for reliability of the Cathode Heater Subsystem let,

λ_1 : failure rate of a single functioning inverter

λ_2' : failure rate of an inverter in standby operation

λ_z : failure rate, inadvertent switching

λ_y : failure rate, failure sensor and switch, operating when required

λ_y : total failure rate sensor and switch

$\lambda_1 = \lambda_2$: where λ_2 is failure rate of Inverter No. 2 when operating on line.

Then, solving for probability of success in states (1) and (2) of Fig. A-2:

$$P_1(t) = e^{-\lambda_1 t} e^{-\lambda_z t} \tag{A-14}$$

$$\begin{aligned} P_2(t+h) = {} & P_1(t) \left\{ \lambda_1 h \, e^{-\lambda_y t} e^{-\lambda_2' t} \right\} \\ & P_1(t) \left\{ \lambda_z h \, e^{-\lambda_2' t} \right\} \\ & P_2(t) \left\{ 1 - \lambda_2 h - \lambda_z h \right\} \end{aligned} \tag{A-15}$$

$$\begin{aligned} P_2'(t) = {} & P_1(t) \left\{ \lambda_1 \, e^{-(\lambda_y + \lambda_2')t} + \lambda_z \, e^{-\lambda_2' t} \right\} \\ & - P_2(t) \left\{ \lambda_2 + \lambda_z \right\} \end{aligned} \tag{A-16}$$

Solving the above differential equation and substituting $P_1(t)$ and $P_2(t)$ into the expression

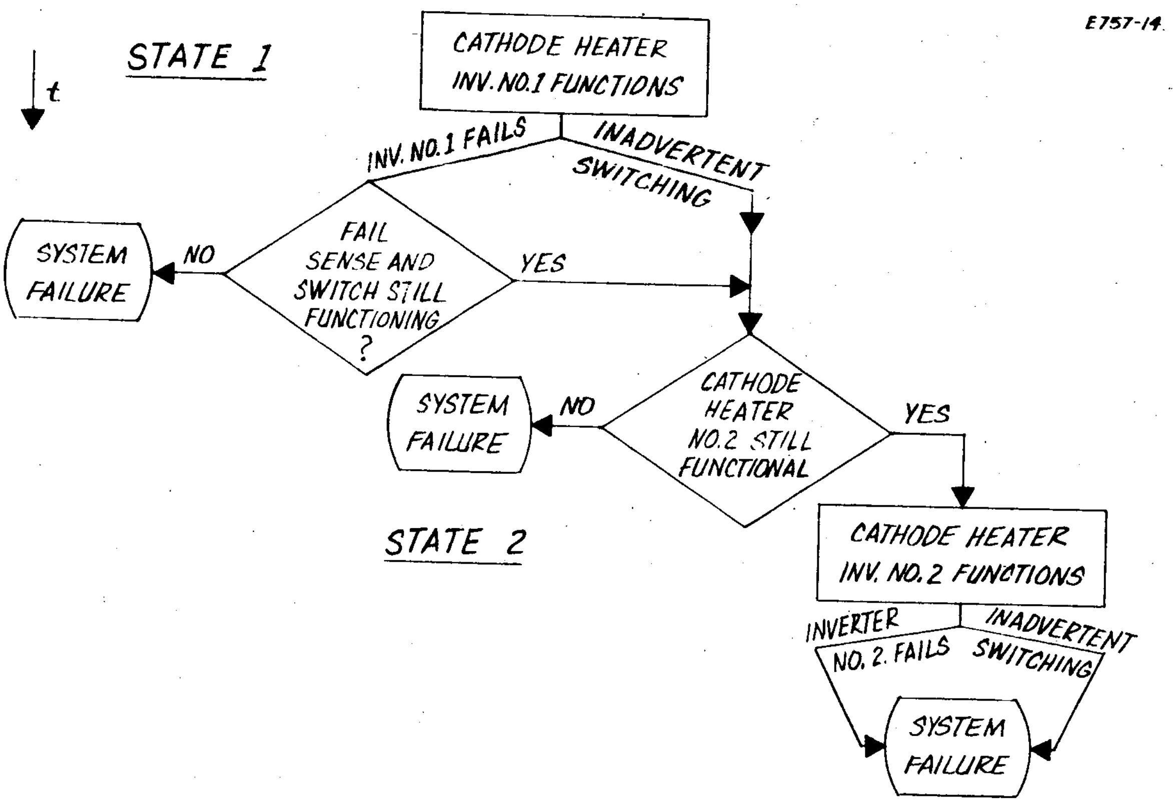

Fig. A-2. Failure modes for Cathode Heater Supply inverter modules

$$R'(t) = P_1(t) \quad P_2(t) \tag{A-17}$$

$$R'(t) = e^{-(\lambda_1 + \lambda_z)t} + e^{-(\lambda_2 + \lambda_z)t}\left[\frac{\lambda_1}{\lambda_1 + \lambda_y + \lambda_2' - \lambda_2}\left(1 - e^{-(\lambda_1 + \lambda_y + \lambda_2' - \lambda_2)t}\right)\right.$$

$$\left.\frac{\lambda_z}{\lambda_1 + \lambda_2' - \lambda_2}\left(1 - e^{-(\lambda_1 + \lambda_2' - \lambda_2)t}\right)\right] \quad . \tag{A-18}$$

Referring to the reliability block diagram for the Cathode Heater (Fig. 9), total reliability is:

$$R(t) = R'(t)\, R_4\, R_5$$

where $R'(t)$ is eq.(A-18) above.

LOGIC AND CONTROL

Since all elements are in series, the reliability of the Logic and Control is given by

$$R(t) = e^{-\sum_1 \lambda_i t} \qquad \text{A-19}$$

where λ_i: failure rate of the i^{th} component part.

ARC SUPPLY

Referring to Fig. 12, the reliability of the Arc Supply is given by

$$R(t) = \left[R_{\text{Inverters}}\right] R_5 R_6 R_7 R_8 \quad . \qquad \text{A-20}$$

It can be shown that

$$R_{\text{Inverters}} = e^{-(\lambda_1 + \lambda_{s_1})t}$$

$$+ e^{-(\lambda + \lambda_{s_2})t} \left[\frac{\lambda_1}{\lambda_1 + 2\lambda_{s_1} - \lambda_{s_2}} \left(1 - e^{-(\lambda_1 + 2\lambda_{s_1} - \lambda_{s_2})t} \right) \right.$$

$$\left. + \frac{\lambda_{s_1}}{\lambda_1 + \lambda_{s_1} - \lambda_{s_2}} \left(1 - e^{-(\lambda_1 + \lambda_{s_1} - \lambda_{s_2})t} \right) \right]$$

where λ : failure rate of a single operating inverter

λ_1 : failure rate of two operating inverters

λ' : failure rate of single inverter operating in standby

λ_{s_1} : total failure rate, 2 monitors and 2 relays

λ_{s_2} : total failure rate, 1 monitor and 2 relays.

As a worst case assumption, let $\lambda' = \lambda$.

ACCELERATOR/MAGNET SUPPLY

Referring to Fig. 14, the reliability of the Accelerator/Magnet Supply is given by

$$R(t) = \left[R_{\substack{\text{Inverters} \\ \text{and Rect's.}}} \right] R_4 R_5 R_6 R_7 \quad .$$

It can be shown that

$$R_{\substack{\text{Inverters}\\ \text{and Rect's.}}} = e^{-(\lambda_3 + \lambda_s)t}\left[\frac{\lambda_1}{\lambda_s + \lambda_3}\left(1 - e^{-(\lambda_s + \lambda_3)t}\right) + \frac{\lambda_s}{\lambda_3}\left(1 - 3^{-\lambda_3 t}\right)\right] \tag{A-23}$$

where λ_1: failure rate of inverter No. 1

λ_2: failure rate of Inverter No. 2

λ_3: $\lambda_1 + \lambda_2$

λ_z: failure rate of inadvertent operation of failure monitor

λ_y: failure rate of nonoperation of failure monitor when required

λ_s: total failure rate of failure monitor.

APPENDIX B

COMPONENT FAILURE RATES AND STRESS SHEETS

In order to provide a numerical evaluation of the reliability of the power conditioning and control system, the failure rates of the components employed must be established. Furthermore, these failure rates which must be based on accepted documentation must consider the stress (i.e. temperature, current, voltage, etc.) under which these components will operate.

This Appendix presents, along with a listing of established failure rates, component stress and failure rate tabulation sheets. These stress sheets form the basis on which the numerical solution of the reliability equations are obtained. Each component in the system has been listed with its electrical and thermal stress. Based on the indicated stress, the failure-rate document referenced has been used to determine the failure-rate at the operating stress.

The documents used for failure-rates were those considered to be the most accurate reflection of recent experience with space electronic components. The HAC data, for example, reflects substantial long-term data collected from Syncom and Early-Bird, whereas the data in 217-A reflects the most recent derating technique for semiconductors, based on junction temperatures rather than ambient air temperature.

SUMMARY OF FAILURE RATES

The basic failure rates used in this analysis are listed in Table B-I. Wherever a component departs from the 10% stress value, these failure rates are degraded (increased) relative to the base failure rate in the manner specified in MIL Handbook 217.

There is no single source that can be consulted to obtain failure rates for all of the components. The basic standards, MIL Handbooks 217 and 217A contain failure rates based on the history of components

Notes on Table B-I

A. Mil-Hdbk-217A Capacitor and Resistor failure rates were utilized directly. Where Hi Rel (Level IV) parts (were available the equivalent part failure rates were used. The levels chosen from Mil-Hdbk-217A for these four parts were:

Level R - Paper (or paper plastic) Capac. and Solid Tant Capac.

Level O - Metal Film Resistors

B. The environment postulated for the mission these parts will encounter has been set conservatively equivalent to lab controlled conditions, therefore, an application factor of 1 was assigned.

C. Semiconductor failure rates were taken from Mil-Hdbk-217 initially and then adjusted to be consistent with Hughes experience on Space programs such as Syncom 2 and 3, Earlybird, and Surveyor. The part failure rates utilized in the preceding analysis are based on Hughes experience and judgement for the postulated parts mission environment.

D. Failure rates for magnetics are derived from Mil-HDBK-217 modified by Hughes extensive experience with Syncom and Early Bird Satellites.

which are operated primarily in a military environment and which have not been procured under the stringent controls placed on components for a space program. The military environment contains such factors as wide temperature and humidity variations, continued mechanical stresses throughout equipment life, handling by personnel, and many others which are not found in the benign environment of a space mission. (A very dramatic comparison between "ground" and space environments was observed during Syncom 2 testing. During one year of ground operation, 17 component failures were experienced whereas the spacecraft operated in orbit for over two years without a single component failure.) However these MIL handbooks contain the most extensive compilation of component failure histories and as such, they still must be relied upon heavily.

In addition to the military data, there has been some history accumulated on space missions. Hughes has compiled data on the Syncom 2, Syncom 3, Earlybird, and Surveyor programs. The data gathered from the satellite programs is very representative of the mission environment being dealt with here, since both long time duration and free fall operation are involved. The process of determining the failure rates to be used then becomes one of starting with the MIL handbook as a base and either using these directly or altering them according to recent data obtained from space missions. The procedure used here emphasized the conservative approach in that a safety factor which caused the failure rates to be higher than estimated was employed in most cases. This procedure was followed in order to add some contingency for the fact that the exact mission has some unknowns which cannot be evaluated. Finally it was assumed that all measures to insure high reliability parts screening during procurement would be taken.

By evaluating each component class according to the above considerations, the data presented in Table B-I was developed. The particular failure rate source used in each case is given in the table. The failure rates used for this analysis have been carefully and conservatively

TABLE B-1

Basic Failure Rates

Base conditions for this table are: Chassis Temp. of 70° and less than 0.10 stress on each part.

PART TYPE	PART CATEGORY	F. R. in %/10^3 hrs.	F. R. Source*
Resistor	Carbon Composition	.00035	1
	Metal Film (Hi Rel)	.0025	1 (Level 0)
	Wirewound Pwr.	.0009	1
Capacitor	Ceramic	.00020	1
	Solid Tantalum (Hi Rel)	.00012	1 (Level R)
	Dipped Mica	.00003	1
	Glass	.0055	1
	Paper	.00024	1 (Level R)
Diodes, Silicon	Power	.008	3
	Regulator (Zener Power)	.005	3
	General Purpose-low pwr.	.002	3
	Bridge Rectifier (4)	.008	3
	SCR	.0085	3
Transistors Silicon	Power	.020	3
	General Purpose	.004	3
	Switching	.002	3
Integrated Ckts.	Monolithic, Standard	.007	4
Magnetics	Inductors coils & chokes, Power	.003	2
	Transformer, Power	.020	2

PART TYPE	PART CATEGORY	F. R. in $\%/10^3$ hrs.	F. R. Source*
	Transformer,		
	Input Current	.014	2
	Magnetic Ampl.	.020	3
	Magnetic Ampl.	.014	
Miscell-aneous	Thermistor	.005	2
	Relay (one operation only) Balanced arm Babcock lg. Crystal Can		
	Fuse	.005	2
Connections	Pressure Contact,		
	Pin	.0005	4
	Solder Joint	.0001	1

*Failure Rate Sources:

1. MIL-HDBK-217A
2. Multiple Source - Average to assumed environmental conditions, taking note of parts programs and manufacturing control programs.
3. MIL-HDBK-217 - curves, using modified base rate
4. HAC Experience: Syncom, Earlybird, Surveyor

chosen to represent parts which were representative of the earlier Hughes space parts programs on which complete data is known and available. Indications from feedback data on the current space programs are that a large improvement in reliability of parts and systems has been experienced.

Integrated circuits are a class of components which because of their newness do not have extensive failure rate histories. Thus, assigning a failure rate here is not quite so straightforward as with other parts. However, industry data is being made available as rapidly as possible and estimates and predictions can be made based on existing information. Industry data does indicate that the achievable range of failure rate in 1965 was in the range of 0.005 to 0.2%/1000 hours. Reliability growth rate of integrated circuits is reflected in the Texas Instruments, Inc., data shown in Fig. B-1 and the compiled data shown in Tables B-2 and B-3. Table B-2 gives MIL grade part failure rates for benign environmental operation. Table B-3 gives modified Minuteman grade part failure rates for benign environmental operation. The modification includes the elimination of certain long duration tests, recording of data and individual part serialization. The parts controls selected for the proposed equipment are between these two grades of parts. A failure rate of 0.005%/1000 hours has been selected as a realistic reliability requirement for the standard monolithic integrated circuits during the time period under consideration. A number of suppliers are working with Hughes to supply integrated circuits to this failure rate requirement. The failure rate used in this analysis was 0.007%/1000 hours.

COMPONENT SELECTION PROCEDURES

In order to achieve the maximum reliability, it is very important to start with the most reliable parts that can be obtained. First, components must be selected which have inherently high reliability and, second, sufficient constraints must be placed on the procurement of these parts such that the best of the lot are selected.

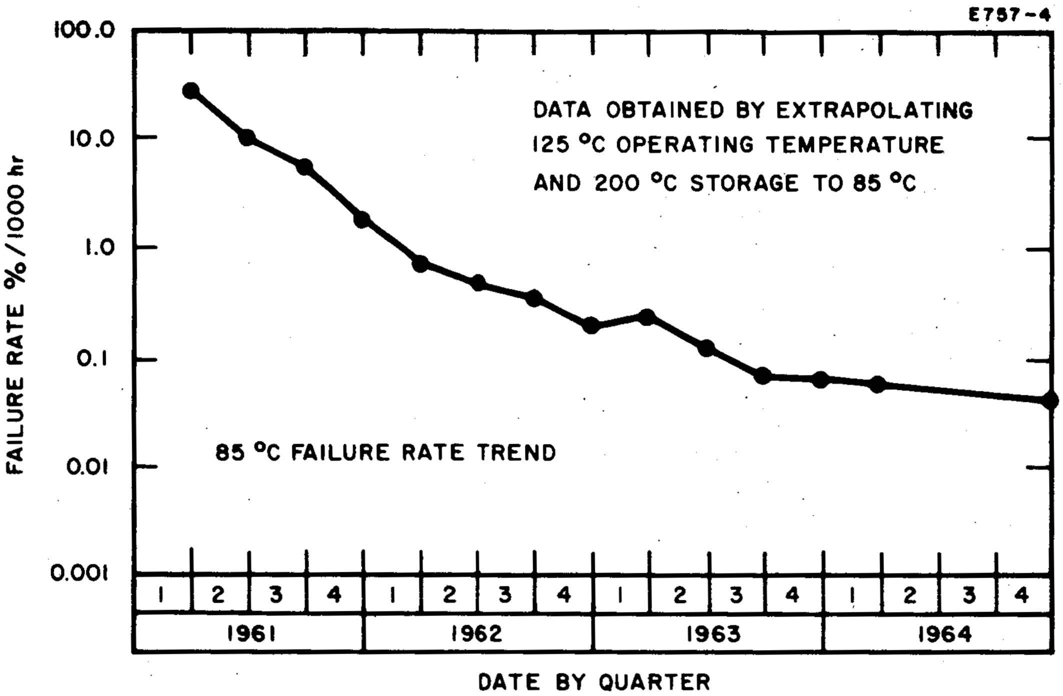

Fig. B-1. Reliability trend chart for integrated circuits.

TABLE B-2

Grade 2 Predicted Failure Rates — Benign Environmental Operation*

Component Generic Category	Failure Rate %/1000 hr			Basis
	1965	1967	1969	
Resistors	0.002	0.001	0.0005	Polaris Achieved
Capacitors	0.010	0.002	0.0010	Polaris Achieved
Diodes	0.010	0.002	0.0010	Polaris Achieved
Transistors	0.010	0.003	0.0015	Polaris Achieved
Transformers	0.020	0.009	0.0030	Polaris Achieved
Chokes and Inductors	0.010	0.009	0.0030	
Integrated Circuits	0.015	0.005	0.0020	Supplier Data
Resolvers and Synchros	0.100	0.100	0.0700	Polaris Achieved

TABLE B-3

Grade 2A Predicted Failure Rates — Benign Environmental Operation*

Component Generic Category	Failure Rate %/1000 hr			Basis
	1965	1967	1969	
Resistors	0.001	C.0005	0.0002	Minuteman Achieved
Capacitors	0.002	0.0010	0.0005	Minuteman Achieved
Diodes	0.002	0.0010	0.0005	Minuteman Achieved
Transistors	0.003	0.0015	0.0008	Minuteman Achieved
Transformers	0.009	0.0030	0.0020	Minuteman Achieved
Chokes and Inductors	0.009	0.0030	0.0020	
Integrated Circuits	0.005	0.0020	0.0010	Supplier Data
Resolvers and Synchros	0.100	0.0700	0.0100	Polaris Achieved

*Reproduced from "Quantitative Reliability Prediction," by Owens and Dolcimascolo, Proc. of 1966 Annual Sym. on Rel.

Components which are recognized as having inherently high reliability are most readily selected from lists of space qualified parts. The Hughes documents in the 988000 category are recognized by NASA as defining space qualified parts. The JPL lists are also recognized as being valid compilations of qualified parts. Thus, for the most part, selecting high reliability components is a matter of locating a part type from existing documents. However, there are cases where (state-of-the-art components are used to meet performance requirements and yet because of their newness, they have not been qualified. In these cases, a qualification procedure must be initiated in order to bring the part up to the proper level. Ultimately, every component in the system should have an accompanying high reliability document which fully defines its characteristics for the mission to be performed.

In order to insure that the very best control and final part selection is obtained, it is necessary to place constraints on procurement. A typical example of testing to be performed by the supplier is given below.

1. Pre-screening tests which consist of Temperature Cycling, Centrifuge, Macroscopic and Microscopic Inspection prior to sealing,

2. 240 hour intermittent life (15 min.-On, 5 min.-off) at rated power,

3. 1260 hours of power aging at half-rated power.

Readings on the parts are taken at 0, 240, 250, and 1500 hours. Up to three times as many parts are purchased as required. The data on each device is plotted (by computer) and only those devices which remain stable and within specification are selected for flight use. Resident Quality Control Engineers are assigned at each supplier to assure that the proper data is recorded, all tests are accomplished and that no "short cuts" that would affect quality are made. Since all parts received 100 percent inspection at the suppliers, only sample incoming inspection is performed. This inspection is primarily for reading correlation.

Only a very brief description of the parts control program necessary for a space program has been presented. It should be recognized that the controls imposed in this area have a definite affect on component failure rate and as such they have been reviewed here. Detailed description of a full parts program is provided in Appendix C.

STRESS SHEETS

Stress sheets have been developed for each subsystem discussed in Section III of this report. Each component employed has been listed along with its expected electrical and thermal stress. Finally the failure rates of each component at operating stress is presented. These stress sheets follow.

DESIGN REVIEW

INVENTORY -- SECTION IV

DR FILE NO. ____________

PAGE NO. ____________

RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Transformer - Power		HAC					.020	1	.020	
		Transformer - Signal		HAC	--		85		.014	1	.014	
		Inductor		HAC	--		85		.003	1	.003	
		Transistor, Power		HAC	.03		80		.020	2	.040	
		Transistor, Gen Purp		HAC	.01		80		.004	2	.008	
		Diode - Switching		HAC	.05		75		.001	11	.011	
		Diode - Gen Purp		HAC	.05		75		.002	4	.008	
		Bridge Rect. 1 Watt		HAC	.25		90		.010	1	.010	
		Capacitor, Glass		217A	.10		70		.0026	1	.0026	
		Capacitor, Solid Tant		217A	<.10		70		.0002	2	.0004	
		Capacitor, Solid Tant		217A	<.40		70 ~~11~~		.0004	3	.0012	
		Capacitor, Paper		217A	.03		70		.00008	1	0.00008	
		Resistor, Carbon		217A	<.10		75		.0003	6	.0018	
		Resistor, W. W.		217A	<.25		100		.0012	2	.0024	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR.

Beam Module

DESIGN REVIEW

INVENTORY -- SECTION IV

DR FILE NO. ____________

PAGE NO. ____________

RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
	DTul 945, 930, 936	DT Micrologic		HAC	5V		75		.007	3	.021	
		Connections - Solder		HAC	--		--		.0001	100	.01	
		Connector - (8, Active Pins)		HAC	--		--		.004		.004	
	GFA7	Fuse (7 Amp)		HAC	--		--		.005	1	.005	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR. 0.16248

Beam Module (Cont'd)

6660 CC-EN REV. 3-61

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INVENTORY -- SECTION IV

DR FILE NO. ____________

PAGE NO. ____________

RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Capacitor, Glass		217A	.35		70		.0052	2	.0104	
		Capacitor, Ceramic		217A	.50		70		.0022	1	.0022	
		Capacitor, Solid Tant		217A Level R (0.1 f/ 10^3 hrs)	.50		70		.0007	1	.0007	
		Resistor, Carbon		217A	<.20		70		.0005	12	.0063	
		Resistor, W. W.		217A	.42		70		.0015	1	.0015	
		Choke, Arc Lim.		HAC	--		85		.003	1	.003	
		Connector (4 Pins Active)							.002		.002	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR. 0.0258

Beam High Volt Filter

DR FILE NO. ____________

PAGE NO. ____________

RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Diode, Switching		HAC	.05		75		.001	3	.003	
		Resistor, Carbon		217A	.05		75		.0003	1	.0003	
		Capacitor, Solid Tant		217A (Level R)	.03		70		.0002	1	.0002	
		DT Micrologic		HAC	5V		75		.007	2	.014	
		Transformer, Output		HAC	--		85		.002	1	.002	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE – %/1000 HR. 0.0195

Main Drive Fail Sensing

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

DR FILE NO. ______

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, wirewound 1.5K 3W		217A	0.3		100		.002	1	0.0020	
		Resistor, wirewound 3-Ω 3W			0.1		80		.00097	1	0.00097	
		Resistor, carbon comp.			<0.1		70		.0003	5	0.0015	
		Resistor, carbon comp.			0.4				.0014	1	0.0014	
		Capacitor, paper, fixed			0.2				.0008	1	0.00008	
		Capacitor, paper, fixed			<0.1				.00024	2	0.00048	
		Capacitor, solid tantalum			0.4				.00039	4	0.00156	
		Capacitor, solid tantalum			0.35				.00032	2	0.00064	
		Capacitor, solid tantalum			<0.1				.0001	1	0.0001	
		Diode, general purpose		HAC	<0.1				.002	5	0.0100	
		Diode, general purpose			0.2				.003	2	0.0060	
	A→	Transistor, power			<0.1		75		.020	2	0.0400	
		Transistor, switching			<0.1		70		.002	2	0.0040	
		Micrologic, IC			—				.007	3	0.0210	

MTBF: CALCULATED ______ GOAL ______

TOTAL FAILURE RATE - %/1000 HR. ______

Htr. Inv. Module

DESIGN REVIEW

INVENTORY -- SECTION IV

DR FILE NO. ______

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Transformer, power		HAC	—		85		.020	1	0.0200	
		Transformer, feedback			—		70		.014	1	0.0140	
		7 Amp Fuse			—		70		.005	1	0.0050	
		Connections, solder			—		70		.0001	96	0.0096	
	A	Diode, switching			<0.1		70		.001	13	0.0130	
		Connector (8 active pins)			—		70		.004	.1	0.0040	

MTBF: CALCULATED ______ GOAL ______

TOTAL FAILURE RATE - %/1000 HR. 0.15533

Htr. Inv. Module

6660 CC-EN REV. 3-61

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	0.4		70		.0014	2	0.0028	
		Resistor, carbon comp.			0.3				.0009	1	0.0009	
		Resistor, carbon comp.			0.2				.0006	1	0.0006	
		Resistor, Carbon comp.			<0.1				.0003	17	0.0051	
		Resistor, power wirewound			0.25				.0015	1	0.0015	
		Resistor, power wirewound			0.15				.0011	2	0.0022	
		Thermistor		HAC	0.1				.005	1	0.0050	
		Capacitor, solid tantalum		217A	0.45				.00056	1	0.00056	
		Capacitor, solid tantalum			0.4				.00039	1	0.00039	
		Capacitor, solid tantalum			0.35				.00032	1	0.00032	
		Capacitor, solid tantalum			0.3				.00025	1	0.00025	
		Capacitor, solid tantalum			0.25				.00021	1	0.00021	
		Capacitor, solid tantalum			0.2				.00017	1	0.00017	
		Capacitor, solid tantalum			<0.1				.0001	2	0.0002	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR.

Failure Sensing & Auto Sense (2 Req'd) ____________ Htr. Inv.

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Diode, switching		HAC	<0.1		70		.001	16	0.0160	
	A	Silicon controlled rectifier			<0.1				.0085	2	0.0170	
		Transistor, switching			<0.4				.012	2	0.0240	
		Relay			0.45				.003	1	0.0030	
		Connections, solder			—				.0001	110	0.0110	
	A	Diode, general purpose			<0.1				.002	1	0.0020	
		Connector (6 active pins)			—				.003	1	0.0030	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE - %/1000 HR. 0.09620

Failure Sensing & Auto Sense (2 Req'd)__________Htr. Inv.

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

DR FILE NO. ____________

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	0.4		70		.0014	1	0.0014	
		Resistor, carbon comp.		217A	<0.1				.0003	1	0.0003	
		Diode, switching		HAC	<0.1				.001	2	0.0020	
		Transistor, swtiching			0.35				.004	1	0.0040	
		Relay			0.45				.003	1	0.0030	
		Capacitor, paper		217A	<0.1				.00008	1	0.00008	
		Connections, solder		HAC	—				.0001	7	0.0007	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE – %/1000 HR. 0.011480

Relay & Ckty__________Htr. Inv.

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DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
Command Start #2 (2 Req'd)												
		Resistor, carbon comp.		217A	<0.1		70		.0003	1	0.0003	
		Resistor, power wirewound			0.15				.0011	1	0.0011	
		Capacitor, solid tantalum			0.45				.00057	1	0.00057	
		Diode, switching		HAC	<0.1				.001	1	0.0010	
											0.00297	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE – %/1000 HR.

Command Start No. 2 ________ Htr. Inv. + Sw. Ckts.

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DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
Command	Start	# 1 (1 Req'd)										
		Resistor, carbon comp.		217A	<0.1		70		.0003	1	0.0003	
		Resistor, power wirewound			0.15				.0011	1	0.0011	
		Capacitor solid tantalum			0.4				.00039	1	0.00039	
		Diode, switching		HAC	<0.1				.001	1	0.0010	
											0.00279	

MTBF: CALCULATED ______ GOAL ______

TOTAL FAILURE RATE - %/1000 HR.

Command Start No. 1______Htr. Inv. + Sw. Ckts.

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DESIGN REVIEW

INVENTORY -- SECTION IV

Use 1/2 λ for fail short mode only

DR FILE NO. ____

PAGE NO. ____

RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Diode, general purpose		HAC	0.10		70		002	4	0.0040	
		Diode, switching		HAC	<0.1				001	2	0.0010	
		Capacitor, solid tantalum		217A	0.4				00039	1	0.00039	
		Capacitor, solid tantalum		217A	0.35				00032	2	0.00064	
		Connections, solder		HAC	—				0001	18	0.0018	

MTBF: CALCULATED ____ GOAL ____

TOTAL FAILURE RATE – %/1000 HR. See note (1) 0.00783

0.01566

Multiply by 2 since ckts used in both inv's.

Low Voltage Filter ____ Htr. Inv.

6660 CC-EN REV. 3-61

DR FILE NO. ____________

PAGE NO. ____________

RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	0.4		70		0015	3	0.0045	
		Resistor, carbon comp.		217A	0.3		70		0009	4	0.0036	
		Resistor, carbon comp.		217A	0.25		70		00075	2	0.00150	
		Resistor, carbon comp.		217A	0.15		70		00047	5	0.00235	
		Resistor, carbon comp.		217A	0.1		70		00035	24	0.0084	
		Resistor, power wire wound		217A	0.15		70		0011	3	0.0033	
		Capacitor, solid tantalum		217A	0.4		70		00039	3	0.00117	
		Capacitor, solid tantalum		217A	0.15		70		00015	5	0.00075	
		Capacitor, solid tantalum		217A	<0.1		70		0001	2	0.00020	
		Diode, Bridge rectifier		HAC	<0.1		70		008	8	0.0640	
		Diode, general purpose		HAC	0.3		70		004	6	0.0240	
		Diode, switching		HAC	<0.1		70		001	12	0.0120	
		Diode, zener		HAC	<0.1		70		005	2	0.0100	
		Transistor, general purpose		HAC	<0.2		70		006	1	0.0060	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR.

Modulator - Feed System and Neutralizer

6660 CC-EN REV. 3-61

DR FILE NO. ____________

PAGE NO. ____________

RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Transistor, general purpose		HAC	<0.1		70		.002	3	0.0060	
		Mag Amp, power		HAC	---		85		.020	3	0.0600	
		Transformer, power		HAC	---		85		.020	3	0.0600	
		Transformer, signal					70		.014	3	0.0420	
		Inductor			---		85		.003	5	0.0150	
		Relay			<0.4		70		.003	1	0.0030	
		Connections, solder			---		70		.0001	200	0.0200	
		Connector (12 active pins)							.006	1	0.0060	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR. 0.35377

Modulator - Feed System and Neutralizer

DESIGN REVIEW

INVENTORY -- SECTION IV

DR FILE NO. ____________

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	<0.1		70		.0003	4	0.0012	
		Resistor, carbon comp.		217A	<0.2		70		.0005	2	0.0010	
		Resistor, power wirewound		217A	0.3		70		.0016	2	0.0032	
		Capacitor, solid tantlum		217A	0.1		70		.00012	2	0.00024	
		Diode, general purpose		HAC	0.2		70		.003	2	0.0060	
		Diode, general purpose		HAC	<0.1		70		.002	2	0.0040	
		Diode, zener		HAC	0.2		70		.0075	2	0.0150	
		Diode, Switching		HAC	<0.1		70		.001	2	0.0020	
		Transistor, general purpose		HAC	<0.1		70		.004	2	0.0080	
		Transistor, power		HAC	<0.1		70		.020	2	0.0400	
		Mag Amp		HAC			85		.010	1	0.0100	
		Transformer, input		HAC			85		.014	1	0.0140	
		Fuse		HAC	---		70		.005	2	0.0100	
		Connections, solder		HAC	---		70		.0001	26	0.0026	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE – %/1000 HR. ____________

Cathode Htr. Inv. Mod.

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

DR FILE NO. ____________

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Connector (8 pin active)							.004	1	0.0040	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE - %/1000 HR. 0.12124

Cathode Htr. Inv. Mod.

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	0.37		70		0012	1	0.0012	
		Resistor, carbon com.		217A	0.2		70		0006	2	0.0012	
		Resistor, carbon comp.		217A	0.1		70		0003	6	0.0018	
		Capacitor, solid tantalum		217A	0.25		70		00021	5	0.00105	
		Diode, switching		HAC	0.1		70		001	3	0.0030	
		Transistor, switching		HAC	0.2		70		003	1	0.0030	
		Transistor, switching		HAC	0.3		70		004	1	0.0040	
		Relay		HAC	0.4		70		003	1	0.0030	
		Connections, solder		HAC	---		70		0001	40	0.0040	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE - %/1000 HR. 0.02225

Fail Sense and Switch Cathode Htr. Controller

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	0.4		70		.0014	2	0.0028	
		Resistor, carbon com.		217A	0.2		70		.0006	3	0.0018	
		Resistor, carbon comp.		217A	<0.1		70		.0003	9	0.0027	
		Resistor, film, fixed		217A	<0.1		70		.0025	1	0.0025	
		Resistor, power, wirewound		217A	0.3		70		.0016	1	0.0016	
		Capacitor, solid tantalum		217A	0.3		70		.00025	1	0.00025	
		Capacitor, solid tantalum		217A	0.2		70		.0018	1	0.0018	
		Diode, Bridge rectifier		HAC	<0.1		70		.008	2	0.0160	
		Diode, switching		HAC	0.4		70		.0025	1	0.0025	
		Diode, switching		HAC	<0.1		70		.001	4	0.0040	
		Diode, zener		HAC	0.2		70		.0075	1	0.0075	
		Transistor, switching		HAC	0.1		70		.002	3	0.0060	
		Inductor		HAC	0.2		85		.003	2	0.0060	
		Transformer, poler		HAC	--		85		.020	3	0.0600	

MTBF: CALCULATED ______ GOAL ______

TOTAL FAILURE RATE - %/1000 HR. ______

Regulator and Transformer Cath. Htr. Controller

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Relay		HAC	0.4		70		.003	1	0.0030	
		Connections, solder		HAC	---		70		.0001	70	0.0070	

MTBF: CALCULATED ______ GOAL ______

TOTAL FAILURE RATE - %/1000 HR. 0.12545

Regulator and Transformer - Cath. Htr. Controller

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY –– SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R–67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R–67, C & M, ETC.)	(6) ELECT–MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	0.5		70		0018	1	0.0018	
		Resistor, Carbon comp		217A	0.4		70		0013	2	0.0026	
		Resistor, Carbon comp.		217A	0.2		70		0005	7	0.0035	
		Resistor, Carbon comp.		217A	0.1		70		0003	25	0.0075	
		Resistor, power wirewound		217A	0.2		70		001	1	0.0010	
		Capacitor, solid tantalum		217A	0.4		70		00039	1	0.00039	
		Capacitor, solid tantalum		217A	0.35		70		00032	2	0.00064	
		Capacitor, solid tantalum		217A	0.3		70		00025	3	0.00075	
		Capacitor, ceramic		217A	0.3		70		001	3	0.0030	
		Capacitor, ceramic		217A	0.1		70		0002	3	0.0006	
		Diode, switching		HAC	0.2		70		0015	4	0.0060	
		Diode, switching		HAC	0.1		70		001	2	0.0020	
		Diode, zener		HAC	0.4		70		0125	3	0.0375	
		Diode, zener		HAC	0.2		70		0075	4	0.0300	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE – %/1000 HR.

LOGIC (DIGITAL) P/O System Timing and Control Function - LOGIC AND CONTROL

6660 CC–EN REV. 3–61

DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Diode, zener		HAC	<0.1		70		.005	1	0.0050	
		SCR		HAC	<0.2		70		.01275	1	0.01275	
		SCR		HAC	<0.1		70		.0085	2	0.0170	
		Transistor, signal		HAC	<0.3		70		.004	1	0.0040	
		Transistor, signal		HAC	<0.1		70		.002	1	0.0020	
		Transistor, general purpose		HAC	<0.4		70		.010	1	0.0100	
		Transistor, general purpose		HAC	<0.2		70		.006	2	0.0120	
		Transistor, general purpose		HAC	<0.1		70		.004	10	0.0400	
		Micrologic, IC		HAC	---		70		.007	5	0.0350	
		Connections, solder		HAC	---		70		.0001	170	0.0170	
		Connector (8 active pins)		HAC	---		70		.004	1	0.0040	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE – %/1000 HR. 0.25603

LOGIC (DIGITAL) P/O System Timing and Control Function - LOGIC AND CONTROL

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	<0.1		70		.0003	6	0.0003	
		Diode, switching		HAC	<0.2		70		.0015	2	0.0030	
		Diode, zener		HAC	<0.2		70		.0075	2	0.0150	
		Transistor, signal		HAC	<0.1		70		.002	2	0.0040	
		Micrologic, IC		HAC	---		70		.007	24	0.1680	
		Connector (8 active pins)		HAC	---		70		.004	1	0.0040	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR. 0.1943

Logic (Digital) P. O. High Power Control Logic - Logic and Control

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CIRCUIT SYMBOL	PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	SURFACE TEMP. °C	SOURCE (R-67, C & M, ETC.)	ELECT-MECH STRESS	M, E OR C	TEMP. STRESS °C	M, E OR C	UNIT FAIL RATE	NUMBER USED	TOTAL FAILURE RATE	NON-PREFER.
		Resistor, carbon comp		217A	<0.3		70		.0008	2	0.0016	
		Resistor, carbon comp.		217A	<0.2		70		.0005	5	0.0025	
		Resistor, carbon comp.		217A	<0.1		70		.0003	38	0.0114	
		Resistor, power wirewound		217A	<0.3		70		.0014	2	0.0028	
		Resistor, film, fixed		217A	<0.1		70		.0025	38	0.0950	
		Resistor, film, fixed		217A	<0.3		70		.0028	1	0.0028	
		Capacitor, solid tantalum		217A	<0.45		70		.0005	4	0.0020	
		Capacitor, solid tantalum		217A	<0.3		70		.00023	2	0.00046	
		Capacitor, dipped mica		217A	<0.1		70		.00003	29	0.00087	
		Capacitor, paper, fixed		217A	0.15		70		.00008	2	0.00016	
		Diode, switching		HAC	<0.1		70		.001	9	0.0090	
		Diode, zener		HAC	<0.2		70		.0075	3	0.0225	
		Transistor, signal		HAC	0.3		70		.004	2	0.0080	
		Transistor, signal		HAC	<0.1		70		.002	4	0.0080	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE – %/1000 HR. ____________

Analog Control System - Logic and Control

6660 CC-EN REV. 3-61

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INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Amplifier, IC		HAC	<0.2		70		.007	12	0.0840	
		Connections, solder		HAC	---		70		.0001	300	0.0300	
		Connector (8 active pins)			---		70		.004	1	0.0040	

MTBF: CALCULATED ______ GOAL ______

TOTAL FAILURE RATE - %/1000 HR. 0.28509

Analog Control System - Logic and Control

6660 CC-EN REV. 3-61

DESIGN REVIEW

INVENTORY -- SECTION IV

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	<0.4		70		.0013	2	0.0026	
		Resistor, carbon comp.		217A	<0.3		70		.0008	2	0.0016	
		Resistor, carbon comp.		217A	<0.2		70		.0005	2	0.0010	
		Resistor, carbon comp.		217A	<0.1		70		.0003	8	0.0024	
		Resistor, power wirewound		217A	<0.3		70		.0015	2	0.0030	
		Resistor, power wirewound		217A	<0.2		70		.001	1	0.0010	
		Capacitor, solid tantalum		217A	<0.4		70		.00035	2	0.0007	
		Capacitor, solid tantalum		217A	<0.2		70		.00015	2	0.0003	
		Capacitor, solid tantalum		217A	<0.1		70		.0001	2	0.0002	
		Capacitor, paper, fixed		217A	0.2		70		.00008	1	0.00008	
		Diode, switching		HAC	<0.3		70		.002	2	0.0040	
		Diode, switching		HAC	<0.2		70		.0015	4	0.0060	
		Diode, switching		HAC	<0.1		70		.001	7	0.0070	
		Diode, Zener		HAC	<0.2		70		.0075	2	0.0150	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR.

Arc. Inv. Mod.

6660 CC-EN REV. 3-61

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CIRCUIT SYMBOL	PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	SURFACE TEMP. °C	SOURCE (R-67, C & M, ETC.)	ELECT-MECH STRESS	M, E OR C	TEMP. STRESS °C	M, E OR C	UNIT FAIL RATE	NUMBER USED	TOTAL FAILURE RATE	NON-PREFER.
		SCR		HAC	0.3		70		.0017	2	0.0034	
		Transistor, general purpose		HAC	0.2		70		.006	3	0.0180	
		Relay		HAC	---		70		.003	1	0.0030	
		Transformer, power		HAC	---		85		.020	1	0.0200	
		Transformer, signal		HAC	---		70		.014	1	0.0140	
		Mag Amp, signal		HAC	---		70		.014	1	0.0140	
		Connections, solder		HAC	---		70		.0001	96	0.0096	
		Connector (8 active pins)			---		70		.004	1	0.0040	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE - %/1000 HR. 0.13088

Arc. Inv. Mod.

6660 CC-EN REV. 3-61

DESIGN REVIEW

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	<0.4				.0013	1	0.0013	
		Resistor, carbon comp.		217A	<0.2		70		.0005	1	0.0005	
		Resistor, power wirewound		217A	<0.2		70		.001	1	0.0010	
		Capacitor, solid tantalum		217A	0.5		70		.00072	1	0.00072	
		Diode, switching		HAC	<0.1		70		.001	2	0.0020	
		Transformer, power		HAC	---		85		.020	1	0.0040	
		Transformer, signal		HAC	---		85		.014	1	0.0028	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR. 0.01232

Monitor Arc Inv.

6660 CC-EN REV. 3-61

DESIGN REVIEW

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RELIABILITY CALCULATION

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☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	0.5		70		.002	1	0.0020	
		Resistor, carbon comp.		217A	0.4		70		.0014	2	0.0028	
		Resistor, carbon comp.		217A	0.15		70		.0005	2	0.0010	
		Resistor, carbon comp.		217A	0.1		70		.00035	5	0.00175	
		Capacitor, solid tantalum		217A	0.5		70		.00072	2	0.00144	
		Capacitor, solid tantalum		217A	0.2		70		.00017	2	0.00034	
		Diode, Bridge rectifier		HAC	<.01		70		.008	3	0.0240	
		Diode, power rectifier		HAC	0.2		70		.012	4	0.0480	
		Diode, switching		HAC	<0.1		70		.001	1	0.0010	
		Diode, zener		HAC	0.1		70		.05	3	0.0150	
		Transistor, signal		HAC	<0.1		70		.002	1	0.0020	
		Choke		HAC	--		70		.003	4	0.0120	
		Transformer, signal		HAC	---		70		.014	3	0.0420	
		Connections, solder		HAC			70		.0001	66	0.0066	
		Connector (8 active pins)							.004	1	0.0040	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE - %/1000 HR. 0.16393

Rectifier - Filter and Regulator - Arc Inv.

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RELIABILITY CALCULATION

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☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor, carbon comp.		217A	<0.4		70		.0013	1	0.0013	
		Resistor, carbon comp.		217A	<0.1		70		.0003	1	0.0003	
		Diode, switching		HAC	<0.1				.001	1	0.00075	
		Diode, switching		HAC	<0.1				.001	2	0.00025	
		Transistor, signal		HAC	<0.2				.003	1	0.00075	
		Relay		HAC	---				.003	1	0.0030	

MTBF: CALCULATED ______ GOAL ______

TOTAL FAILURE RATE - %/1000 HR. 0.00635

Relay Closed Mode - Arc Inv.

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RELIABILITY CALCULATION

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☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Resistor W.W.		217A	<.40		70		.002	2	.004	
		Resistor, carbon			<.10				.0003	3	.0009	
		Resistor, carbon			<.20				.0005	2	.0010	
		Resistor, carbon			<.40				.0015	2	.0030	
		Capacitor - Ceramic			<.10				.0002	1	.0002	
		Capacitor - Paper			<.40				.00008	3	.00024	
		Capacitor - Solid Tant			<.40				.00039	3	.00117	
		Diode - Switching		HAC	<.10				.001	9	.009	
		Diode - Gen. Purp.			<.30				.004	3	.012	
		Diode - Gen. Purp.			<.40				.005	3	.015	
		Diode - Gen. Purp.			<.45				.006	2	.018	
		Transistor, - Power			<.20				.020	2	.040	
		Transistor, Gen. Purp.			<.30				.004	3	.012	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR.

Accel/Mag Inv. Mod.

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		Transformer - Signal		HAC	-		70		.014	1	.014	
		Inductor		↓	-		85		.003	1	.003	
		Micrologic DTL Ckt		↓	-		70		.007	3	.021	
		Transformer - Power		↓	-		85		.020	1	.020	
		Connector (8 active pins)		↓	-		70		.004	1	.004	
		Connections, solder		↓	-		70		.0001	88	.0088	

MTBF: CALCULATED ________ GOAL ________

TOTAL FAILURE RATE - %/1000 HR. 0.18731

Accel/Mag Inv. Mod.

6660 CC-EN REV. 3-61

DESIGN REVIEW

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RELIABILITY CALCULATION

SEE HAC HANDBOOK R-67 FOR GENERAL INSTRUCTIONS. COL. (4), MEASURED VALUES ONLY. COLS. (7) AND (9), INDICATE WHETHER INSTRESSES ARE MEASURED M, CALCULATED C, OR ESTIMATED E. COL. (11) IS FOR USE WHEN COMPONENTS ARE GROUPED FOR EARLY INVENTORIES. COL. (13), INDICATE BY X. APPLICABLE TO ALL INVENTORIES.

☐ BLOCK NO. ________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		DIODE - POWER		HAC	.21		70		.012	1	.012	
		DIODE - SWITCHING		↓	<.10		↓		.001	2	.002	
		RESISTOR - CARB.		217A	<.20				.0005	1	.0005	
		CAPACITOR - PAPER		217A	<.20				.00008	1	.00008	
		MICROLOGIC DTL CKT.		HAC	<.20				.007	2	.014	
		TRANSFORMER - POWER(1/7λ)		HAC	—		↓		.002	1	.003	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR. 0.03158

Accel/Mag - Failure Monitor

6660 CC-EN REV. 3-61

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RELIABILITY CALCULATION

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☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CIRCUIT SYMBOL	PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	SURFACE TEMP. °C	SOURCE (R-67, C & M, ETC.)	ELECT-MECH STRESS	M, E OR C	TEMP. STRESS °C	M, E OR C	UNIT FAIL RATE	NUMBER USED	TOTAL FAILURE RATE	NON-PREFER.
		Transformer, Power		HAC			70		.020	1	.020	
		Transformer, current		HAC					.014	1	.014	
		Resistor, carb.		217A	< .10				.0003	4	.0012	
		Capacitor, - Solid Tant.		217A	.10				.00012	1	.00012	
		Diode - Gen. Purp.			< .10				.002	2	.004	
		Diode - Gen. Purp. (Failure open mode only)			.15				.0025	2	.005	
		Diode - Power (1/4[illegible])			.21				.003	2	.006	
		Gen. Purp. Transistor-Low Pow.			<.10				.004	1	.004	
		H.V. Bridge Rect. <1 W			<.10				.008	1	.008	
		673 - 5 Bridge Rect.			<.10				.008	1	.008	
		Fuse 2 Amp			<.10				.005	1	.005	
		Connector (8 active pins)							.004	1	.004	
		Connections, solder							.0001	36	0.0036	

MTBF: CALCULATED ______ GOAL ______

TOTAL FAILURE RATE - %/1000 HR. 0.08292

Accel/Mag______RECT No. 1
RECT No. 2

DR FILE NO. ____________

PAGE NO. ____________

RELIABILITY CALCULATION

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☐ BLOCK NO. ______

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
MAG. RECT. No. 1		PWR SILICON RECT.		HAC	.10		70		.006	1	.006	
& No. 2 - Sht.		Short Mode Only)										
Mode. 3/4 ⋏		Short Mode Only)			.21		70		.009	4	.036	
											0.42	
MAG. TRANSF. NO 1 & NO 2 - ACCEL.		MAG. POWER TRANSF. Sht. to Grd Only 1/7 ⋏			85				.003	2	.006	
TRANSF. NO 1 & NO 2 SHT to GRD.		ACCEL. POWER TRANSF. SHT. to GRD ONLY 1/5 ⋏			85				.004	2	.008	
											.014	
		CHOKE		HAC	--				.003	2	.006	
		DIODE - GEN. PURP.		HAC	.10				.002	1	.002	
ACCEL. DESPIKE		RESISTOR - W.W		217A	.10				.0009	1	.0009	
& FILTER		RESISTOR - CARBON			.10				.0003	4	.0012	
		RESISTOR - CARBON			.20				.0006	1	.0006	
		CAPACITOR - SOLID TANT.			.15				.00014	1	.00014	
		CAPACITOR - SOLID TANT			.40				.00039	1	.00039	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR.

Accel/Mag - Series Elements

DR FILE NO. ____________

PAGE NO. ____________

RELIABILITY CALCULATION

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☐ BLOCK NO. ____________

☐ ENTIRE ITEM

(1) CIRCUIT SYMBOL	(2) PART NUMBER (900,000, MIL, TUBE TYPE, ETC.)	(3) COMPONENT FAMILY NAME (AS CLASSIFIED ON FAILURE RATE CHARTS)	(4) SURFACE TEMP. °C	(5) SOURCE (R-67, C & M, ETC.)	(6) ELECT-MECH STRESS	(7) M, E OR C	(8) TEMP. STRESS °C	(9) M, E OR C	(10) UNIT FAIL RATE	(11) NUMBER USED	(12) TOTAL FAILURE RATE	(13) NON-PREFER.
		CAPACITOR - CERAMIC			.33				.0012	1	.0012	
		CAPACITOR - CERAMIC			.10				.0002	1	.0002	

MTBF: CALCULATED ____________ GOAL ____________

TOTAL FAILURE RATE - %/1000 HR. 0.01263

Accel/Mag - Series Elements

6660 CC-EN REV. 3-61

APPENDIX C

RELIABILITY DOCUMENTS

1. Hughes Parts Program
2. Hughes Satellite Operational Data Analysis
3. How the Experts Pick Reliable Components

These documents are reproduced here to describe HAC techniques of part screening and the resultant statistical data accumulated on failure rates of parts so screened, on applications such as Syncom and Early-Bird. Since these failure rates have been used in this report for many components, the reference documents will substantiate the choice of these latest HAC rates rather than those of earlier documents such as MIL Hdbk 217.

HUGHES PARTS PROGRAM

At the inception of the Syncom Program, Hughes recognized the necessity for a more stringent and comprehensive parts program, and took steps to improve the quality of parts used in satellites. The basic philosophy of this program was that the satellite system could not be any better than the parts used in it. As a result of this each part used in the satellites was treated as a separate entity e.g., given specific individual attention.

The parts used were procured to the requirements of individual parts specification which required the suppliers to conduct "burn-in" tests on each part and supply test data on a lot basis. Upon receipt of the parts at Hughes each part was 100% inspected to the requirements of the Procurement Specification and then placed in bonded storage. The highly successful results of the Syncom Satellite in orbit (cumulative time of 53 months with one part failure, non catastrophic) attests to the parts program.

The parts program has been considerably improved since the Syncom Program. The procurement specifications for the Intelsat I, Intelsat 2 and ATS (Applications Technology Satellite) Programs were changed to include the following additions by the parts supplier:

1. Parts are subjected to a 100% pre-screening test consisting of the following as a minimum.

    a) Visual Inspection prior to encapsulation
    b) Centrifuge (acceleration)
    c) Temperature Cycling
    d) Seal tests
    e) X-Ray
    f) Serialization
    g) Electrical parameter tests

2. After the "burn-in" test (240 hours intermittent life test) each part is subjected to Power Aging up to a total of 1260 hours. This has recently been reduced to 510 hours as a result of data analysis, e. g. the parts become stable after a cumulative test time of 750 hours. It should be mentioned that these requirements apply to semiconductors. Similar requirements are invoked for passive parts.

3. Parameter readings are taken at 0, 240 and 750 hours and identified to each part serial number.

HUGHES PARTS PROGRAM Continued -

4. Up to 3 times as many parts as required are procured.

5. Parts are selected for flight usage by computer program explained later.

6. Hughes Quality Engineers monitor each supplier during the manufacture and test of the parts.

   The parts upon receipt at Hughes are subjected to sample receiving inspection since they had previously been inspected by Hughes Quality Personnel at the suppliers facility.

PARTS QUALIFICATION

The majority of the parts for the Proposed Enperiment have been previously qualified during the Syncom, Intelsat 1 and 2 and ATS Programs by the Hughes Components Department.

Those parts that have not previously been qualified by Hughes will be subjected to qualification tests that will demonstrate confidence in the adequacy of the parts.

Hughes Aircraft Company's obligation is to utilize components parts that are appropriately qualified for the end product. In this context, the term "qualified" denotes engineering satisfaction that the design of the component is adequate for its intended use and the samples tested satisfactorily met specified requirements. Qualification testing is not intended for evaluating a vendor's production capability nor to determine the adequacy of a vendor's quality assurance program. (This facet is covered by the Quality Control Requirements imposed contractually on the suppliers).

That testing necessary to support past experience and engineering judgment with respect to the application and the component and manufacturer being considered for approval is performed.

Testing other than, or in addition to, full qualification tests should be considered when it will provide necessary and more meaningful information. Special evaluations and reliability tests are considered and may be used as the basis or part of the basis for approval.

The same rules and effort involved with the qualification and approval of an initial source is applied to all subsequent sources. Varying degrees of evaluation may be applied to different sources for the same item where engineering knowledge of the vendors and their components indicates different levels of competency, quality or design and the risk factor associated with the individual approvals is assessed as being different.

PARTS QUALIFICATION Continued -

Under certain circumstances, additional testing may be desirable after initial approval has been granted. In general, post approval tests w ll be conducted only when a problem has developed in the later usage of a component, when a vendor makes changes to an item or when the risk of its use increases in new or more severe applications. Such tests may also be conducted to verify the correctness of an initial approval or to supplement approval.

PARTS SCREENING PROGRAM

General - Hughes Aircraft Company recognizes the need to obtain the best parts available for Communications Satellite Programs. The basic philosophy of the parts program is to subject the parts to relatively severe prescreening tests to cull the weaker parts. These tests do not however exceed the manufacturer's ratings. The parts are then subjected to a 10-day (240 hours) "burn-in" or intermittent life test. During this test, the devices are operated at rated power at a specified on-off cycle (depending on the specific device and application). Upon successful completion of the burn-in test the parts are subjected to power aging for an additional 510 hours. The power aging test is designed to simulate as closely as practical the stresses the parts will see in actual operation.

Up to three times as many parts as required are subjected to the above testing. Parts parameters are recorded at 0, 240 and 750 hours. Those parts that exhibit minimum drift are selected for use.

The guide lines for procurement of electronic parts and the methods used to screen reliable parts are published by the Product Effectiveness Department. The Component Department implements the reliability and quality objectives through two basic programs. Procurement Control and Supplier Parts Screening. Eleven tasks are involved in these two basic programs. These are summarized as follows:

1) Procurement specification preparation
2) Procurement source control
3) Qualification of component parts.
4) Lot acceptance provisions for components parts.
5) Part application review
6) Failed part analysis
7) Supplier part screening
8) Parts qualification status list

The Quality Control organization provides two additional programs to ensure that the quality and high reliability criteria have been accomplished. These are:

9) Vendor source inspection and test verification program.
10) 7094 Computer parts data analysis program.

A detailed description of each of these tasks and programs follows.

PROCUREMENT CONTROL

Procurement Specification

Preparation of Procurement Specifications - A normal function of the Components Department is the preparation of parts procurement specifications. When conventional Military Specifications are not adequate for space environment applications, new specifications are prepared for each part. These specifications contain (in detail) the special requirements or provide supplements to existing specifications which assure the procurement of the most appropriate and reliable parts. Hughes past experience will be used to the fullest extent in determining which characteristics of the various component parts should be emphasized. Component tests, such as 100 percent burn-in, extreme value screening, and other special tests required of the vendor will be required to assure obtaining highly reliable, drift stabilized component parts. Those tests that are specified in the specification or its addendum, require the vendor to submit certified data as to test results with each production shipment.

Revision of Procurement Specifications - In addition to the preparation of the procurement specification, the Components Department is responsible for the review and approval of any changes to the specification. Any requests for changes from the vendor, manufacturing, purchasing, engineering, or any other organization must be processed and approved by the Components Department.

These requests will be thoroughly reviewed and will be approved only if the change will not affect the suitability or reliability of the parts.

Procurement Source Control - The Components Department has primary responsibility in the selection of vendors for component parts.. These vendors are limited to those listed on the procurement specification and are selected on the basis of the Company's past experience with the vendor, the results of qualification tests of the vendor's products, and evaluation of the vendor's capabilities as determined by survey inspection of his facilities, quality control and manufacturing procedures.

Lot Acceptance for Component Parts - The Components Part Procurement Specification includes requirements for lot acceptance testing to be performed by the part manufacturer. Lot acceptance tests will be performed in accordance with Hughes 988,000 part specifications for semiconductors. Generally, the tests are MIL-STD, and consist of temperature cycle, thermal shock, vibration fatigue, shock, and lead fatigue. The results of acceptance testing provides assurance that the lot of parts being supplied are substantially of the same quality and reliability as the lot of parts originally qualified.

Failure of a lot to meet the acceptance criteria of the specification is sufficient evidence for lot rejection. Review of the acceptance test data, on the failed lot, aids in establishing the necessary corrective action to be taken by the vendor to prevent further manufacturing discrepancies.

Further use of the acceptance test data is made as follows:

1) To determine lot to lot variability of control and parameters
2) To provide correlation between in-house and supplier test data
3) To provide a quick partial qualification of new lots
4) To provide evidence for disqualification of an unsatisfactory supplier.
5) To establish necessary or desirable changes of rating or parameter limits.

Component Parts Application Review - The Components Department has a group of senior component engineers who will be assigned to the various design groups to provide on-the-spot assistance to the designers to assure the use of standard reliable parts.

A minimum of one senior component engineer will participate in each of the Communication Satellite Design Reviews. He will review the application of each part in the unit to determine suitability and proper application. He is to recommend any appropriate changes to the design review chairman and follow-up to see that the drawings are not released until his recommendations or a suitable substitute have been followed. Where indicated by questionable or unknown application, special tests will be performed to determine the suitability and reliability of the application.

Failed Part Analysis - The analysis of failed parts is initiated by a Trouble and Failure Report (TFR). The failed part accompanied by a copy of the TFR is sent to the Components Department for complete analysis. A case record is established by the failure analysis coordinator, and a planned series of analysis and investigations is undertaken including:

1) Mode of failure review
2) Mechanism of failure analysis
3) Physics of failure studies
4) Causative materials analysis
5) Correlation studies
6) Part and type information record
7) Part application liaison

As a result of the above analysis, the Components Department will initiate the appropriate corrective action and supplier liaison on all part failures. Written replies are required from the supplier as to the corrective action taken, and these reports are filed as part of the failure history.

PROCUREMENT CONTROL Continued -

Supplier Part Screening

Screening tests as required by the part specification and the "nature" of the part, will be performed on electronic parts to develop any latent defects. Each part will receive some combination of the tests described below, with duration and level adapted to provide a nondestructive but mildly accelerated environment.

1) For Semiconductors

a) All parts are to be serialized
b) Temperature cycle
c) Seal
d) Centrifuge
e) Visual examination (before final assembly)
f) Electrical parameter test
g) High and low temperature
h) X-ray (after assembly)
i) Intermittent life (240 hour burn-in) *
j) End points
k) Physical dimensions
l) Vibration
m) Thermal shcok
n) Power a ging **

2) For Passive Devices

a) Serial number
b) X-ray
c) Temperature cycle
d) Seal
e) Electrical acceptance test (T-1) recorded

Burn-in ***
Electrical acceptance test (T-2) recorded ****

* - Burn-in may be performed at ambient or elevated temperature, continuous or 15 minutes on, 5 minutes off, 50 to 100 percent of rated power (junction temperature).

** - Extended power aging is performed at ambient or elevated temperature, continuous at 25 to 50 percent of rated power for up to 510 hours.

*** - Burn-in may be performed at ambient or elevated temperature, continuous, at 100 to 200 percent of rating. Test duration 240 hours.

****- Parameter drift limits are applied for T-1 minus T-2 recordings.

Parts Qualification Status List

The Components Department will creat a list of parts qualified for use on the program. Each listing will provide specific identification of the parts and their qualification status. The list will contain those parts which are in the process of being qualified and the expected date of completion. These lists will be submitted to the customer or a monthly basis.

Vendor Source Inspection and Test Verification Program

The Quality Control Organization will provide qualified personnel to conduct source inspection at the part supplier's facility to assure that the specification screening tests are being conducted. The Hughes Source Inspector performs a visual inspection during the manufacturer's fabrication and witnesses the series of acceptance tests including the power aging and recording of test data. His responsibilities also include the reporting of progress during the manufacturing phases, schedule information, problems areas, and general status accountability.

Parts Data Computer Program

General - All component parts procured for Communications Satellite Programs will be subjected to extensive testing by the vendor and by Hughes Aircraft Company prior to their use in the satellites. The parts will be given a complete analysis involving up to three repeated measurements on each of several critical parameters measured at various intervals during a power aging test lasting up to 750 hours. Although most of these tests will be performed by the vendors, the data measurements taken at the test intervals will be submitted to Hughes part selection computer program for the selection of the best parts within the lots. Also, samples of incoming parts will be tested to obtain confirmation of the vendor's results. The following sections describe the various types of analysis performed by the 7094 Computer in making its selection of prototype and flight parts.

Components Test Data - For the parts procurement program, Hughes will instruct each of the component manufacturer to submit component parts test data for each device supplied. The manufacturer will subject the parts to a series of burn-in and power aging tests and will periodically measure a set of one to four critical parameters of the device. Each device then may have as many as 12 parameters readings, as shown in Table 1.

TABLE 1 PARAMETER READINGS

	PARAMETER			
Test Interval	A	B	C	D
T-1	XA1	XB1	XC1	XD1
T-2	XA2	XB2	XC2	XD2
T-3	XA3	XB3	XC3	XD3

All of the data on line T-1 will be on one IBM Card. Data of line T-2 will be on a second card, etc. Readings of 1 2, 3. and 4 critical parameters will be taken at three different times during the burn-in and power aging test. (See Table 2)

TABLE 2 PARAMETER READING TIMES

Intermittent burn-in 250 hours, 100 percent rated power at 25°C, 15 minutes on, 5 minutes off		Continuous power aging, 510 hours, 50-percent rated power 25°C
0 hour T-1	240 hours T-2	750 hours T-3

The critical parameter readings taken at T-1, T-2, and T-3 will be punched on IBM Cards. The critical parameters readings will be those parameters previously chosen by the Components Department, as the parameters which are most significant to device screening. The resulting test data will be transmitted to Hughes Quality Control within 72 hours after the readings have been taken at each test time.

Computer Data Reduction - The computer program, which will be utilized for the Communications Satellite Programs to select the prototype and flight parts, is statistical in nature. As the data cards (T-1, T-2 and T-3) are submitted by a vendor for a purchase order, the IBM Cards are verified for their correctness and content. The data (T-1 and T-2) is logged and stored, by part and purchase order number, until T-3 data is received, etc., and after verification all of the data is ready to be joined with the computer program deck.

The computer program is the same for all parts. A control card is made for each type of part. The Components Department provides the part specification limits for all parameters measured by the vendor during testing. In addition to the specification limits, other limits are put in the computer, such as drift delta change from consecutive test intervals, etc. The control cards are made up by Quality Control and are joined with data and program deck for the computer run. Figure 1 shows the part and paper control flow for all electronic parts.

The computer is programmed to print the part number, purchase order number, date, and all general information about that part type. Next, it prints all the data by test interval and by parameter. The following page carries by part serial number any part which may have missing data on the card, or out-of-specification data. When parts fall into this category, they are deleted from the computer analysis. These parts will not appear on the release order which goes to project stores and defines the selected parts, and are handled as discrepant material by the Material Review Board.

Once this is accomplished, the computer proceeds to perform its computations. In the case of a four-parameter part type, the first page of the analysis will list all the general information such as the vendor, purchase order number, item number, and Hughes part number. The upper and lower specification limits for each parameter, the Mean and Standard Deviation for each parameter, the Mean of Delta X for each parameter, and the standard deviation X of Delta X for each parameter, plus the added controls, such as lot distribution sigma limits for the part type.

To obtain the analysis results for each part type by its serial number, the computer stores all the data on the cards. It is programmed to calculate the mean and standard deviation of the total lot by each parameter for every test interval. This represents four parameters at three test intervals, for a total 12 numerical distribution plots. In addition, the computer calculates the mean and the standard deviation of the delta change of the total lot by each parameter for the test intervals (T-1 - T-2), (T-2 - T-3) and (T-1 - T3). This represents another 12 numerical distribution plots. The program utilizes the parameter's upper and lower specification limits, plus sigma limits and

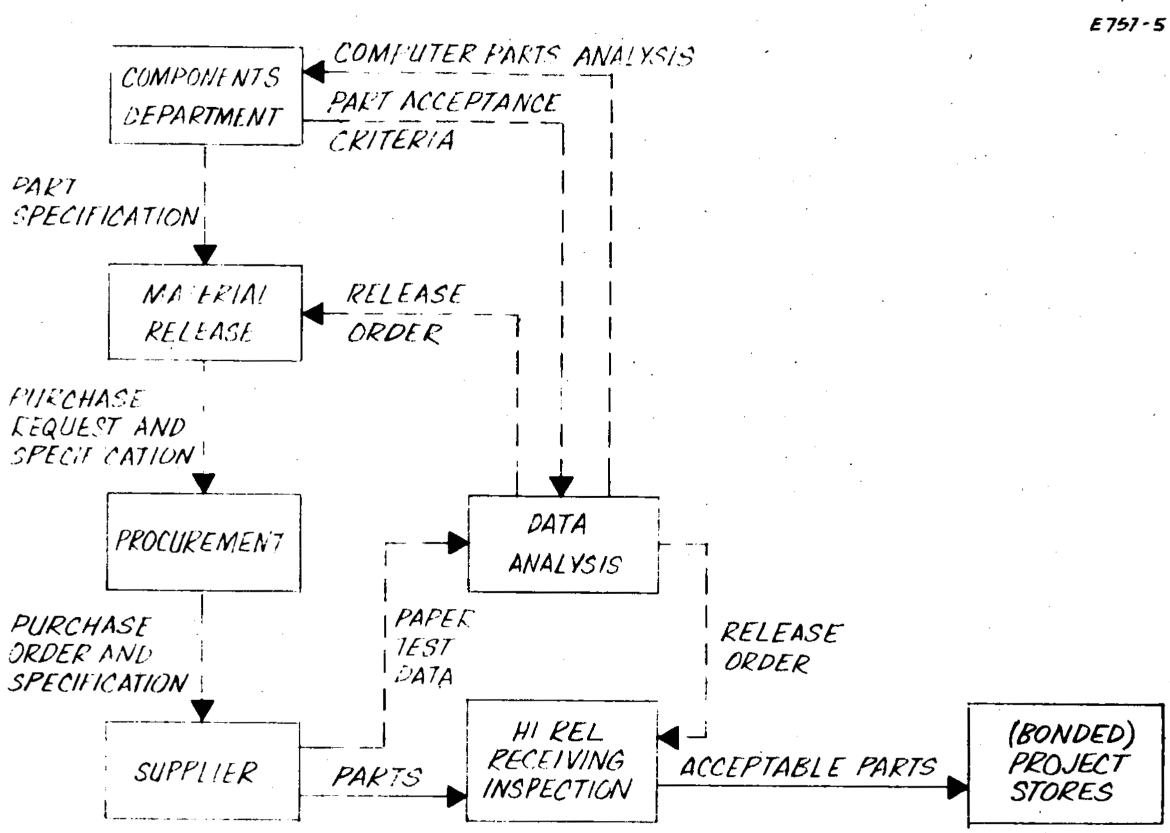

Fig. 1. Parts and paper flow.

delta, change sigma limits (2σ), to frame all the test readings. In its calculations, the computer overlays the above 12 numerical distribution plots, calculated for the parameters X test interval (T-1, T-2, T-3) with the 12 numerical distribution plots calculated for the delta change ($\Delta 12$, $\Delta 23$, $\Delta 13$) X test intervals (T-1, T-2) to select the parts by serial number that exhibit the most stable characteristics. In order for the computer to determine and to weigh its calculations, a key parameter is designated by the Components Department. The other parameters are designated in descending order as determined from the part type and design applications. In this manner, the computer can rank its selection. The printout is not in a rank order file but rather by part serial number sequence and is used as a release order.

HUGHES AIRCRAFT COMPANY

INTERDEPARTMENTAL CORRESPONDENCE

TO:	R. M. Bentley	CC:	E. J. Althaus	DATE:	13 April 1966
ORG:	22-86		R. F. Ohlemacher	REF.	2207.1/53
			Distribution		
SUBJECT:	Hughes Satellite Operational Data Analysis			FROM:	R. J. Schulhof
				ORG.	22-07-00
				BLDG.	366 MAIL STA. C1181
				EXT.	8-3646

INTRODUCTION

This is the fourth in a continuous series of progress reports on the Space Systems Division Reliability and Maintainability Staff's operational satellite monitoring effort. The satellites currently monitored are Syncom II, Syncom III and Early Bird. The purpose of the project is to modify current ground environment part failure rates to reflect the space environment. An important advantage in using parts data from actual Hughes built systems rather than part life tests is that it is no longer necessary to assume perfect design utilization, fabrication, derating or environment.

RESULTS

As of 31 March 1966, exactly one part failure has occurred in the electronics of the aforementioned satellites - a 2N2185 PNP analog transistor located in a telemetry encoder of Syncom II. The failure is known to have occurred in the interval 8 August to 22 October 1964. Two temporary losses of capability have occurred, neither of which could be termed a part failure as such. Failures have occurred in the H_2O_2 control systems, e.g. sticking valves, and these shall be treated in the Appendix.

Given the current SSD ground environment* failure rates, the probability of only one part failure to date is .04. That is to say, the hypothesis that the ground environment failure rates are not too high for synchronous satellite application may be rejected with a .04 probability of error of the first kind.

A K factor which may be applied to a HAC built satellite having roughly the same parts mixture has been calculated. This K factor is a function of the number of failures observed and the total part operating hours and, thus, is a random variable.

The current unbiased and maximum likelihood estimate** of K is .20 while an 80% confidence interval is [.045, .717].

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* See Table 1

** See "Hughes Satellite Operational Data Analysis, 31 March 1965

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R. J. Schulhof to R. M. Bentley
13 April 1966
Page 2

This means that if a parts count failure rate prediction on the electronics on a Hughes synchronous spinning satellite using current SSD ground environment failure rates (see Table 1) gave a mean life of θ years, the best estimate of the true mean life in the space environment would be $\theta/.2=5\theta$ years.

Although K will converge to the "true" K factor for large samples, our sample to date is relatively small and large variations in K may be observed from report to report.

Since no part type has accumulated enough operating hours to represent its ground environment mean-time-to-failure, there is not enough evidence to indicate which parts are responsible for the increased life. Therefore, if the failure rate of any specific part in the space environment is required, it would be incorrect to merely assume .2 times the ground environment failure rate unless the part were to be used along with all the others and in roughly the same proportions as in Syncom and Early Bird. Therefore, individual best estimates of each part type based only upon its operating hours have been provided in Table 1 for the case in which individual part failure rates are needed.

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TABLE 1

Part Type	Operating Time 10^5 Part Hours	SSD Ground Environment Failure Rate 10^{-5} Fail/Hr.	Best Estimate 10^{-5} Fail/Hr.	80% Confidence Interval 10^{-5} Fail/Hr.	α Error to Reject Ground Failure Rate
Capacitors					
Ceramic	154.143	.002	.0016	.000,.012	.735
Glass	72.009	.001	.0009	.000,.025	.931
Paper	3.737	.002	.0020	.000,.486	.993
Tantalum	20,239	.010	.0086	.000,.090	.817
Connectors					
CoAx	33.773	.004	.0036	.000,.054	.873
Others	.948	.010	.0099	.000,1.919	.991
Crystals	1.119	.020	.0196	.000,1.625	.977
Diodes					
eneral Purpose	21,493	.005	.0046	.000,.085	.898
Mixer	.466	.040	.0394	.000,3.907	.982
Switching	56.914	.002	.0018	.000,.032	.892
Varactor	8,378	.100	.0590	.000,.217	.433
Zener	14.116	.010	.0090	.000,.129	.868
High Voltage	.631	.030	.0295	.000,2.881	.981
Ferrite Devices	1.413	.100	.0895	.000,1.287	.868
Coils, Chokes					
Inductors	82.398	.007	.0047	.000,.022	.562
Transformers	17.073	.014	.0117	.000,.107	.787
Resistors					
Carbon	184.000	.001	.0009	.000,.009	.831
Film	29,265	.005	.0045	.000,.062	.864
Wire Wound	2.320	.010	.0098	.000,.784	.977
Transistors					
Analog	31.698	.010	.0145	.007,.109	.959
Digital	40.356	.005	.0043	.000,.045	.817
Tuneable Cavities	2.585	.010	.0098	.000,.704	.974
S 'er or Weld					
onnections	2,134.464	.0004	.00023	.000,.0009	.426
TWT	.375	.640	.5338	.000,4.85	.786
Filters	1.632	N.A.	N.A.	.000,1.114	N.A.
Sensitors	.079	.010	.0100	.000,23.052	.999

Further Calculations Using Data in Table 1

Expected number of part failures if the SSD ground failure rates are correct: 4.944

Observed failures: 1

$$\text{K factor} = \frac{\text{observed failures}}{\text{expected failures}} = \frac{1}{4.944} = .202$$

80% confidence interval for K factor $.045 \leq K \leq .717$

Probability of one failure or less using SSD ground environment failure rates (rejection error): .043

Explanation of entries in Table 1

1) Operating time - actual total part operating hours for part type in Hughes satellites to 31 March 1966.

2) SSD ground environment failure rate. Current ground environment failure rate used for parts count failure rate predictions by SSD Reliability and Maintainability Staff.

3) 80% confidence interval. An interval based on the operating hours in (1) which contains the true synchronous, spinning satellite space environment failure rate with probability at least .80.

4) Best Estimate. Best estimate for synchronous, spinning satellite space environment failure rate based on SSD ground environment failure rate individual operating hours in space, and number of failures occurring suitable for use separate from other parts.

5) Rejection Error. Probability of error of the first kind if the SSD ground environment failure rate for the specific part is rejected at this time.

The method of analysis for the above may be found in "Hughes Satellite Operational Data Analysis" for 31 March 1965.

Prepared by: ____________________
R. J. Schulhof

Approved by: ____________________
E. J. Althaus

RJS:mjw

APPENDIX

ANALYSIS OF OPERATIONAL DATA HYDROGEN PEROXIDE SUBSYSTEMS

The analysis of data for the hydrogen peroxide subsystems is complicated by the fact that two different types of failures must be considered.

1) failure due to actual operation - i.e., dependent upon cycles of operation,

2) time dependent failures - such as those caused by corrosion.

Assuming that the forces contributing to time dependent failures are independent of those due to cycles of operation, we may assume the failure distribution to be approximately Poisson, i.e., if we have n identical devices, the i(th) one having been in orbit for t_i hours and having been used in c_i cycles of operation, the number of part failures would approximately have the distribution

$$f(N) = \frac{\left(\left(\lambda_t \sum_{i=1}^{n} t_i\right) + \lambda_c \sum_{i=1}^{n} c_i\right)^N}{N!} e^{-\left(\lambda_t \sum_{i=1}^{n} t_i + \lambda_c \sum_{i=1}^{n} c_i\right)}$$

where λ_t is the total time dependent failure rate for a unit and λ_c is the total cycle dependent failure rate for a unit.

If failures can be identified as time dependent or cycle dependent, we may estimate the parameters λ_t and λ_c independently by

$$\hat{\lambda}_t = \frac{\text{total time dependent failures}}{\sum_{i=1}^{n} t_i}, \quad \lambda_c = \frac{\text{total cycle dependent failures}}{\sum_{i=1}^{n} t_i}$$

To date no cycle dependent failures have occurred, but two time dependent failures have occurred:*

1) The lateral solenoid valve in Syncom 2 failed to open.

2) A pressure relief valve in System I of Syncom 3 failed to open.

The "calendar" time on each system is defined as: Time at last successful operation - time of lift off.

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* See Hughes Communication Satellites Operational Summary.

The calendar time may be calculated from the table below:

SYSTEM		DATE OF LAST OPERATION	LIFT OFF DATE	HOURS
Syncom 2		7-3-64	7-26-63	8,200
Syncom 3	System I	10-29-65	7-19-64	9,000
	System II	7-16-65	7-19-64	8,700
HS-303	System I	4-14-65	4-6-65	200
	System II	12-2-65	4-6-65	5,700
			Total	31,800

Note: Hours are rounded to the nearest hundred.

The number of cycles is as follows:

SYSTEM		CYCLES
Syncom II		2820
Syncom III,	System I	1835
	System II	255
HS-303	System I	1704
	System II	1495
	Total	8109

A system consists of one radial jet, one axial jet, propellant tanks, fill vent and relief valve, pressure reducer, and manifolding.

90% confidence intervals on λ_t and λ_c, assuming the number of each type of failure has a Poisson distribution, may be calculated as

$$[0 \leq \lambda_c \leq 30 \times 10^{-5}] \text{ failures/cycle}$$

$$[1.6 \times 10^{-5} \leq \lambda_c \leq 18.8 \times 10^{-5}] \text{ failures/hour.}$$

The preliminary estimate of the total time dependent failure rate used in reliability predictions on Syncom and Early Bird was 2.3×10^{-5} failure/hour. The expected number of failures using this failure rate is .731.

The data indicates that the space environment is at least as bad as had been predicted for existing H_2O_2 subsystems although, at this time, the difference is not highly significant.

How the Experts Pick Reliable Components

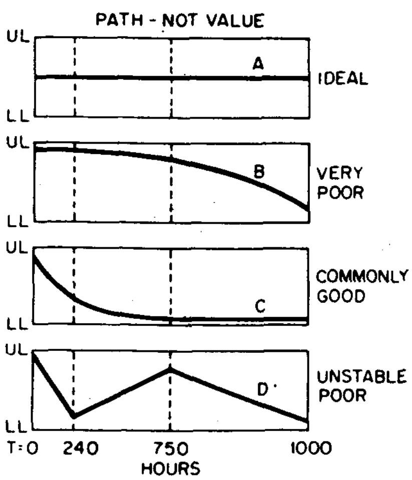
MAXIMIZING THE PROCUREMENT FUNCTION

Approaches used by a number of companies were detailed at 1966 Annual Symposium On Reliability Hughes, GE, Bellock & NASA Experiences Detailed

A PRO IN RELIABILITY since its earliest days, C. M. Ryerson, now at Hughes Aircraft, reported how degradation screening of highest quality component parts was accomplished for Syncom, Early Bird, ATS satellite and the Surveyor Moon Lander.

On Early Bird 19,000 parts (100%) were screened using power-on aging test. Degradations of one to four parameters were measured at four time intervals for each serialized part and then analyzed by data processing. Each part was then earmarked for flight or ground use. As many as 30 per-

Degradation Path Is Due to Part Reliability



Detailed Screening Results of Hughes Study

Part Type	Major Screening Parameter	Quantity parts received	Quantity graded flight	Quantity graded non-flight	Quantity graded reject
CAPACITOR					
Tantalum	C	1348	877	317	154
Paper-Mylar	C	148	102	40	6
Glass	C	2860	2110	460	290
Ceramic	C	347	203	57	87
Mica Button	C	187	148	32	7
Ceramic standoff	C	260	226	29	5
TC Ceramic	C	141	92	22	27
		(100%)	(71.0%)	(18.1%)	(10.9%)
RESISTORS					
Carbon Film	R	2471	1421	511	539
Carbon Film	R	126	97	56	3
Carbon Film	R	626	430	147	49
Metal Film	R	1465	916	347	202
Sensistor	R	50	45	0	5
Thermistor	R	12	12	0	0
W.W.	R	79	26	23	30
W.W.	R	27	17	10	0
		(100%)	(61.0%)	(21.9%)	(17.1%)
DIODE					
1N3070	I_R	185	138	47	0
1N702A (Zener)	V_Z & I_R	142	114	17	11
1N1313 (Zener)	V_Z & I_R	115	91	19	5
1N3595	I_R	3087	2522	489	76
1N1184	I_R	56	34	22	0
1N3062	I_R	261	229	31	1
1N3070 series-1	I_R	168	0	148	20
-2	I_R	904	658	204	42
RD500, RD600	I_R	68	51	16	1
1N2970B (Zener)	V_Z	46	35	10	1
		(100%)	(76.9%)	(19.9%)	(3.2%)
TRANSISTOR					
2N1709	h_{FE}	21	14	0	7
Family 2N1724	h_{FE_1}	56	41	15	0
Family 2N2150	h_{FE_2}	106	68	37	1
2N918	I_{EBO}	45	35	7	3
	V_{CE_1}	445	358	84	3
2N1506A	Power Gain	40	27	13	0
2N2997, 2N1405	h_{FE_2}	580	473	78	29
2N1141	I_{CBO}	99	66	27	6
2N871	h_{FE_1}	104	80	24	0
2N1717	h_{FE_1}	196	156	32	8
2N1936	h_{FE}	19	15	0	4
	h_{FE_2}	88	37	38	13
2N2920	h_{FE_1}/h_{FE_2}	42	27	12	3
2N2906, 2N2907	h_{FE_3}	872	549	247	78
2N2484	h_{FE_1}	1010	907	84	19
	h_{FE_1}	27	19	5	3
2N2608, 2N3882, 2N708	I_{DSS}	20	14	6	0
Zener Special	V_Z	36	23	13	0
		(100%)	(76.5%)	(18.8%)	(4.7%)
VARACTOR & Misc.					
	C&I_R	218	80	70	68
	C&I_R	96	52	30	14
	C&I_R	234	120	64	50
Diode					
	NF_o	96	60	14	22
		(100%)	(49.3%)	(28.1%)	(22.6%)
TOTAL		19629	13813	3924	1892
		(100%)	(70.4%)	(20.0%)	(9.6%)

cent of the highest quality parts which passed the screening tests were considered not suitable for flight use — even though operational parameters were still within spec limits.

Ryerson assumed different lots of supposedly identical lots could have significant reliability differences depending on how well the supplier had the process under control and how good his qualification techniques were. Ryerson says four categories of supplier reliability are: crude lot (no specific reliability), mixed lot (several definable levels of reliability), quality lot (mostly high reliable parts), and screened lot (contains no obviously unreliable parts). For this reason, the Hughes expert said it was futile to test any lot for reliability without first determining lot failure characteristics.

"Mean lot reliability has its maximum significance only when derived from lots screened for potential rejects," he said.

Degradation the Key

Hughes finds each part has certain "tell-tale" parameters that usually indicate potential or incipient unreliability. Tests to spot parameter shifts were usually from 1000 to 1500 hours long. All parts of a lot were tested and cycled on a power-on-off schedule patterned after normal use schedules. Load and temperature conditions were usually maximum (the degradation test itself indicated if the maximum conditions were too severe).

The exact parameter values at the start and finish of the test were considered less important than the *degradation path* in relation to limits set.

Ryerson warned that the usual approach of rejecting values in tails outside set distribution limits (at the end of power-aging tests) could be wrong. He demonstrated that even if the part showed very little degradation (indicating reliability), it might fall in the tail area if it were near the limit in the first place and be automatically rejected. Other parts which started in the middle of the distribution could exhibit two or three sigma instability and still be accepted. The clue, therefore, is the actual plot of each part. (See curves.)

A total of 15 million part hours were chalked up in screening the 19,000 parts (510 line items in 143 part types) for the Early Bird.

All tests were run by the supplier and the test results were keypunched on IBM cards either by the supplier or Hughes.

Analysis was made on an IBM 7094 computer. The analysis involved sorting, computing figures of merit, ranking of parameters and figures of merit, distribution analysis and print out in various presentations.

Best parts were rated flight grade. Less than best but not rejects were used for non-flight service. As mentioned, 30 percent of the parts tested were rejected.

Ryerson points out that the value of the degradation testing lies in the fact that all of the parts including the 30 percent rejected were well within normal quality acceptance standards. Degradation testing, as Ryerson sees it, is not a substitute for tight quality control, but should be used in addition to quality control.

Detailed screening results as well as typical indicator parameters are shown.

Combination Testing at GE

Acceleration testing of components is the goal of every reliability engineer and H. W. Endicott and T. M. Walsh of GE Spacecraft Dept. think they have the answer. Writing in the Symposium Proceedings, these two gentlemen describe how they combine step-stress testing and constant-stress testing to quickly evaluate the life of components.

In a test of resistors, for example, they found that the degradation mechanism was such that step stress data could have been used to predict with accuracy the results of long-time constant stress results.

Endicott and Walsh conclude that two step-stress tests and three constant-stress tests are the best procedure for a complete component evaluation.

The report, "The two step-stress tests indicate the stress limitations of the part (in conjunction with failure analyses of the failed parts) and provide information for selecting the stress levels for the constant-stress tests. Proper analysis shows the stress levels and failure mechanism relationship with time. Results of the combined tests provide information on the failure distribution and data points for constructing a life versus stress curve."

Step stressing alone is useful for lot acceptance, quality control, requalification and evaluation of screening techniques once the relation between step stressing and constant stressing is known.

Step stressing is fast, and useful results are obtained even though large variations in lot quality exist, the authors say. Constant testing

(Continued on next page)

Typical Indicator Parameters Used by Hughes

Tantalum capacitors
- Leakage current at 25°C
- Capacitance at 25°C
- Dissipation factor at 25°C
- Leakage current at 65°C

Paper mylar capacitors
- Insulation Resistance at 25°C
- Capacitance at 25°C
- Dissipation factor at 25°C
- Insulation Resistance at 85°C

Glass Capacitors
- Capacitance at 25°C
- Dissipation factor at 25°C
- Insulation resistance at 25°C

Ceramic capacitors
- Insulation resistance at 25°C
- Capacitance at 25°C
- Power factor at 25°C
- Insulation resistance at 85°C

Mica button capacitors
- Insulation resistance at 25°C
- Capacitance at 25°C
- "Q" at 25°C
- Insulation resistance at 85°C

Film resistors
- Resistance at 25°C
- Noise at 25°C

Diodes
- I_R reverse leakage
- V_F forward voltage drop
- TCBV thermal coefficient
- V_Z zener voltage
- Z_Z zener impedance

Transistors
- h_{FE} beta
- I_{CBO} leakage current
- P_g power gain
- V_{CE} (sat) saturation voltage
- h_{FE7}/h_{FE2} beta ratio
- I_{DSS} leakage current (drain to source)
- I_{GSS} leakage current (gate to source)
- BV_{CEO} breakdown voltage (collector to emitter)
- V_P gate to source pinch-off voltage, at reverse-biased drain

may fail all parts if level is too high, or none if too low.

Constant stress alone is okay when the approximate quality of parts is known. A the proper high level of stress failure, degradation is provided in a short time. Use of three stress levels makes it possible to relate failure to stress and time. This information can be extrapolated for failure at various derated levels.

Details on the complete plan are covered in the Proceedings.

Replacement Rates Lower

After studying the replacement rate of components in four military systems, T. L. Taner of Bell Telephone Labs has come up with some new data. He finds that the replacement rate for most components are one order of magnitude lower than those shown in MIL

Taner's Estimated Replacement Rates When Applied to Solid State Computer Systems.

Component	Replacement Rate/ 10^9 Component Hrs.
Resistors	
Fixed	
Carbon Composition	1
Carbon Film	1
Metal Film	1
Power Wirewound	4
Variable	
Carbon	10
Wirewound	40
Magnetic	
Coil, RF	10
Reactor, Power	10
Transformers	
Power	20
Audio	20
RF	20
Pulse	20
Relay, Armature	
Low Level, Sealed	100
Capacitors	
Fixed	
Ceramic	20
Glass	0.1
Mica	0.3
Paper	10
Plastic	5
Electrolytic	
Aluminum	40
Solid Tantalum	5
Wet Tantalum	20
Semiconductors	
Diodes	
Low Power-Ge	20
Low Power-Si	5
Med. Power-Si	8
Zener-Si	10
Transistors	
Low Power-Ge	20
Low Power-Si	10
Med. Power-Si	20
High Power-Si	200

Handbook 217 except for some resistors and glass capacitors which are two magnitudes lower. (See table.)

The improvements are due to general advances in the state of the art, according to Taner. He implied these new figures can be used for system reliability prediction purposes.

Taner reported that no wear-out phenomena were present for devices in low-signal level applications.

Basic causes of failures (which were mostly catastrophic) can be traced to imperfection in component, workmanship errors in assembling and testing, and human error in assembling.

Bell Telephone experience in designing and manufacturing submarine cable repeaters leads Taner to believe more reliability in military systems can be achieved if greater precautions are taken to eliminate human errors throughout manufacturing and installation processes. He said greater emphasis should be placed on training and education of all who affect reliability.

NASA Experience Similar

The experience of NASA (National Aeronautical and Space Administration) leads W. M. Redler of NASA's Office of Reliability and Quality Assurance to conclusions similar to Taner's. "The greatest problem is that of getting sufficient quality control and care in the production, handling, storing, testing, fastening and application of parts and associated materials," Redler states.

A breakdown of Saturn failures (including the Pegasus spacecraft) indicates the problem. Vehicle and ground support equipment are covered.

Saturn Number	Design Problems	Quality Problems	Operational Problems
SA-1	2	38	109
SA-2	14	12	114
SA-3	13	32	138
SA-4	1	39	95
SA-5	41	248	293
SA-6	54	194	275
SA-7	71	119	268
SA-8	118	290	286
SA-9	75	274	252
SA-10	29	206	201

Many quality and some operational problems are due to human errors such as improper processing, handling errors, etc. Said Redler, "The fact that many defects have been found to be the results of human errors points to the need for more careful design reviews and increased quality control and quality assurance. The parts, components and subsystems of complex space systems receive much handling and exposure to damage and contamination. Adequate training and surveillance of personnel in fabrication test and inspection procedures is a must . . ."

Redler feels physics of failure and physics of aging programs have gradually improved electronic components in general. He calls for the development of standard screening and burn-in tests for space parts based on such physics of failure and aging programs. Expanded tests in integrated circuits are needed.

Failure rates of highest reliable parts that can be used for estimating reliability of electronic space systems were supplied by Redler (See table.)

Mechanical and electromechanical parts are apt to be the limiting components unless more effort is applied to their analysis and mathematical modeling for failure and wearout characteristics, Redler said. **EP**

High Reliability Parts Failure Rates That Can Be Used in Estimating Reliability of Electronic Space Systems.

% 1000 hours, 60% Confidence Level

Part Type	Lowest Estimated	Lowest Indicated
Battery, Ni-Cad	.04	.022
Capacitors		
Fixed Ceramic	.0001	.0006
Fixed Glass	.00015	
Fixed Mica	.00015	.012
Fixed Mylar	.0006	.037
Fixed Ta, Solid	.001	.010
Var. Glass	.0035	.017
Connectors		
Multipin (per pin)	.000007	.008
Coaxial	.00001	.044
Diodes	.0004	.00052
Inductors	.00095	.013
Integrated Ckts	.004	.01
Memory Cores		.00005
Relays, 10 amp 0.3%/10,000 ops, 90% CL		
Relays, Latching	.1 (MIL-HDBK 217 value)	.037
Resistors		
Fixed Film	.0002	.00024
Fixed Comp.	.0002	.00024
Fixed WW	.001	
Solar Cells	.0001	.00014
Transistors	.0005	.00097