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23	G					63	H	58.2	G		
24	G					64	J	60.1	G		
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27	G					67	J	67.1	H		
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29	H					69	G				
30	H	30.1				70	G				
31	H	31.1				71	G				
32	G	31.2				72	G				
33	H					73	E				
34	J	34.1				74	C				
35	F					75	G				
36	G					76	K	76.1	K		
37	H					77	G				
38	G					78	K	78.1	K		
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ABSTRACT AND LIST OF KEY WORDS

D2-100255 "Reliability Analysis and Supporting Data - Lunar Orbiter"

ABSTRACT: This document provides a prediction of the inherent reliability of the Lunar Orbiter Subsystem. The inherent reliability prediction model, failure rate data sources, environmental factors, and duty cycle factors used in this analysis are included in this document.

KEY WORDS:

Reliability
Reliability Prediction
Reliability Assessment
Lunar Orbiter
Failure Rate
Duty Cycle
Functional Block Diagram

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1.0 SCOPE

1.1 CONTRACTUAL COMPLIANCE

This document is prepared in compliance with Paragraph 1.6.1 of Appendix D to the Lunar Orbiter Statement of Work, dated March 18, 1964, and fulfills the initial requirements of Paragraphs 3.3 and 4.4 of NPC 250-1 as amended by Appendix A which state:

"3.3 Reliability Prediction and Estimation (Not Req'd For AGE)

Early in the conceptual design stage, the contractor shall commence development of reliability prediction models for the system. These models shall be revised as required by evaluation of the system design, design changes and as data from specific reliability engineering analyses and various test results become available. These models shall be used as:

a. A timely means of emphasizing potential reliability problem areas and guiding design trade-offs.

b. A basis for test program planning and a basis for reliability assessment in the reliability evaluation program.

c. A guide for additional failure mode, effect, and criticality analyses.

d. A basis for redundancy studies.

The reliability prediction reports shall be provided in sufficient detail, so that the results can be verified. These reports shall include reliability functional block diagrams, mathematical models, complete piece-part count, detailed time and environmental elements, appropriate failure rates, sources of data, and assumptions made. The models shall be utilized to apportion design reliability goals at the component functional assembly level. The contractor shall also develop an operational mathematical model of the spacecraft subsystem to include reliability functional block diagrams and descriptions, logic diagrams, sequence time bar graphs, profiles for environments and associated parameters and general arrangement drawing. Functional block diagrams for the operational mathematical model shall be carried to the lowest component level ("black box"). Updating for the final design configurations shall be continued for use for the assessment model of paragraph 4.4."

"4.4 Reliability Assessment (Not Req'd For AGE)

At specified milestones in the Reliability Evaluation Phase, the contractor shall perform assessments of system reliability by revising failure mode and criticality analyses (see Paragraph 3.4) and by updating his reliability models (see Paragraph 3.5) as necessary to incorporate newly available test results and to reflect design changes and refinements.

The reliability assessment model is an evaluation of the operational mathematical model generated under Paragraph 3.5 and is not an overlapping task. An assessment shall be made at the completion of the component qualification tests and at subsequent dates to be determined, as spacecraft subsystem test data become available."

1.2 NASA REVIEW REQUIRED

NASA review of this document is required in accordance with Line Item 5 of Table II of Appendix D to the Lunar Orbiter Statement of Work.

The initial release of this document shall be submitted to NASA no later than 90 calender days after contract go-ahead and shall be revised monthly thereafter.

The Contractor is proceeding with the analysis subject to NASA concurrence or redirection.

2.0 INTRODUCTION AND BACKGROUND

This document provides a continuing inherent reliability analysis for the Lunar Orbiter System based on data available up to fifteen days prior to the document release date. In support of this analysis the prediction model, factors used, and failure rate data sources are included in this document. The model, predictions (analyses) based on this model and supporting data are revised and updated as required on a monthly basis. G

The information used in constructing the model was obtained from the functional block diagrams, parts counts, and determinations of duty cycles according to the best estimates of the subsystem designers. The 720 hour E-1 photographic mission is used for this analysis. See Section 4.6 for a summary of the mission. G K

The models and predictions of mission success are used as the basis for analytically comparing the current reliability status with the goals and for trade studies between the various design parameters, such as weight and power requirements.

It must be noted that the reliability predictions in this document are the inherent reliabilities of the designs. That is, it is assumed that the reliability of the equipment is not significantly degraded through improper manufacture, test, handling, transportation or use.

3.0 SUMMARY AND RECOMMENDATIONS

This document is intended to present only a specific area of the total reliability effort. It presents the predicted inherent reliability of the Lunar Orbiter Spacecraft based on the state of the design at the time of each prediction. D2-100259, "Failure Mode, Effect and Criticality Analysis - Lunar Orbiter" presents the subsystem level failure mode and effect analysis. Component and necessary part level failure mode, effect and criticality analysis are included in the data packages prepared for Preliminary and Critical Design Reviews. Analyses and trade studies, including discussion of reliability problem areas are included in the regular technical progress report.

The Lunar Orbiter reliability predictions are summarized in a series of graphs and tables as described in Section 3.1. Section 4 outlines the general ground rules and assumptions used to make these predictions.

A short summary of the mission objectives and a simplified time - environmental profile are also included. Detailed reliability predictions for each subsystem of the Spacecraft are contained in Section 6.

See Document D2-100110 "Spacecraft Subsystem Design Criteria Specification - Lunar Orbiter" for a more detailed description of mission objectives and Spacecraft functional configuration and performance requirements. For a more detailed description of the Spacecraft environments see D2-100101-1, "Spacecraft Subsystem Environmental Criteria Specification - Lunar Orbiter".

3.1 Reliability Summary

Figure 3.1, "Lunar Orbiter Predicted Inherent Reliability", summarizes the reliability predictions for the 30-day E-1 photographic mission and for a shorter 20-day mission in which a portion of the photographic data are transmitted back to earth. This shorter 20-day mission consists of the first four phases of the E-1 mission as defined in Section 4.6.

Figure 3.2, "Lunar Orbiter Spacecraft Reliability Predictions", shows the changes in the Lunar Orbiter predicted inherent reliability since the start of the program. The reliability goal of .70 for the spacecraft is taken from D2-100177, "Lunar Orbiter Reliability Goals Allocation".

Figure 3.3 shows the probability of attaining at least one successful mission versus the number of mission attempted. Figure 3.4 shows the probability of attaining at least "3" successes out of five missions attempted. In both Figure 3.3 and 3.4, the probability of success for a single mission is

3.1 Reliability Summary (continued)

the Lunar Orbiter predicted inherent reliability as shown in Figure 3.1.

Table #1, "Lunar Orbiter System Reliability Summary", lists the reliability values for the various subsystems during the different mission phases and for specific mission objectives. For example, from this table one can read the probability of the spacecraft surviving the launch and boost phase, the probability of obtaining all of the photographic data as defined in the E-1 missions, and other similar probability statements. It is also possible to determine the reliabilities of the various subsystems for the different mission phases.

LUNAR ORBITER PREDICTED INHERENT RELIABILITY
April 1965

Subsystem	Reliability for E-1 Photographic Mission (30 Day Mission)	Reliability for 20 Day Photographic Mission (a portion of the E-1 Photo Data Transmitted to Earth)
SPACECRAFT		
Power	.991	.994
Structures & Mechanisms	.993	.993
Photographic	.909	.928
Communication	.947	.965
Velocity Control	.995	.995
Attitude Control (includes Programmer)	.831	.881
Unassigned	.970	.978
Spacecraft Total	.680	.760
LAUNCH VEHICLE		
Atlas	.900	.900
Agena D	.950	.950
TOTAL	.581	.649

Figure 3.1

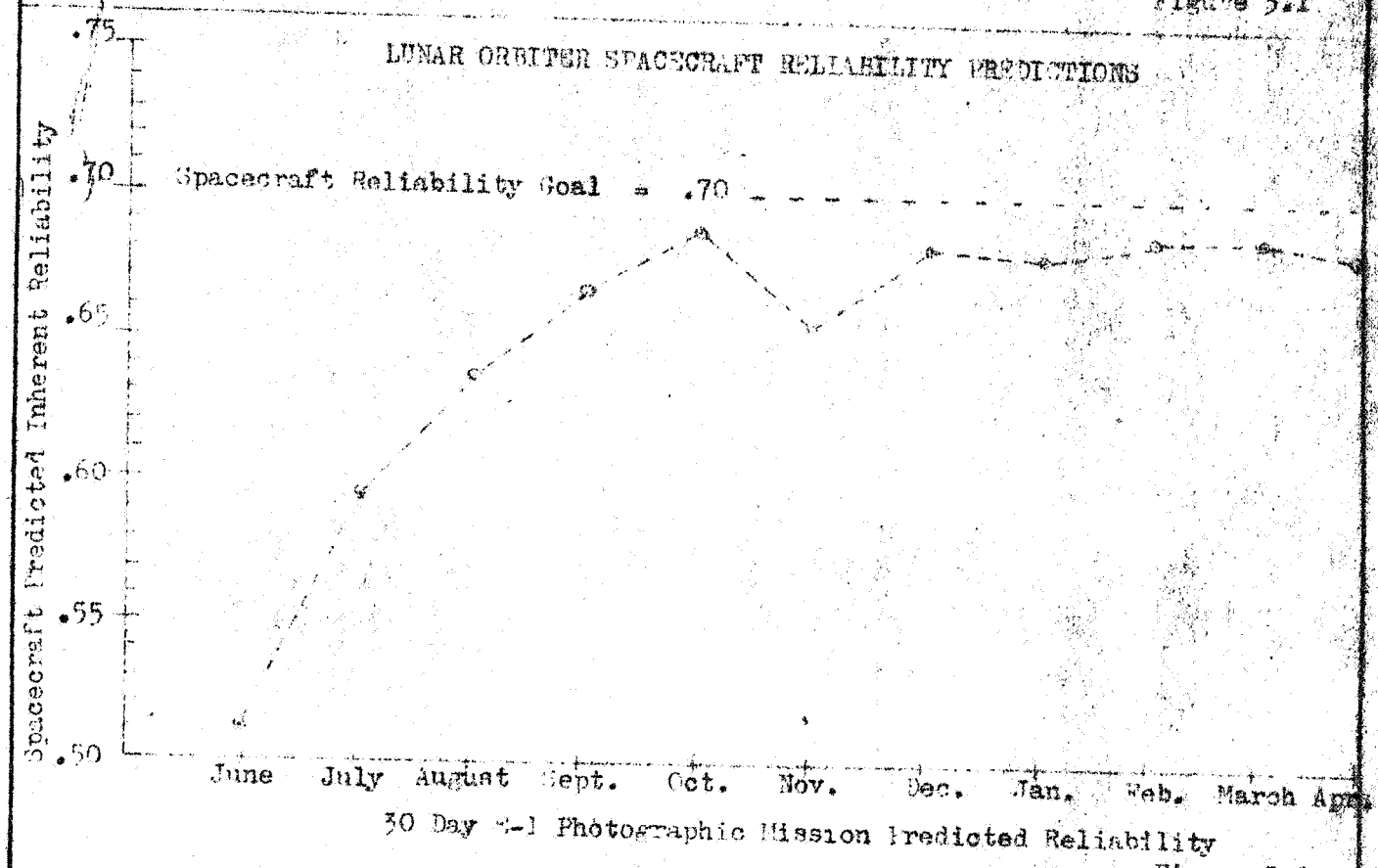
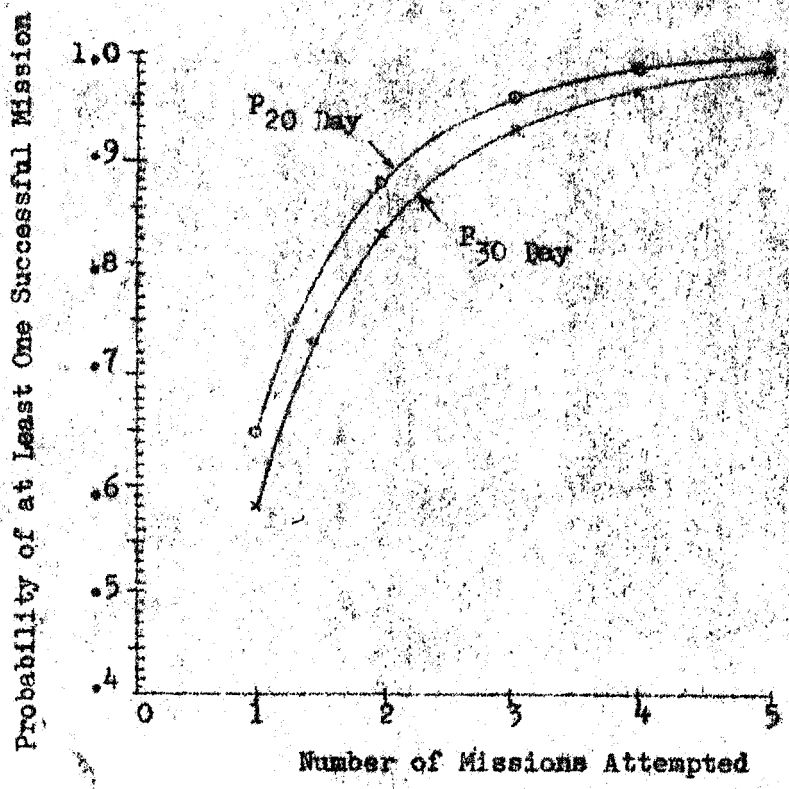


Figure 3.2

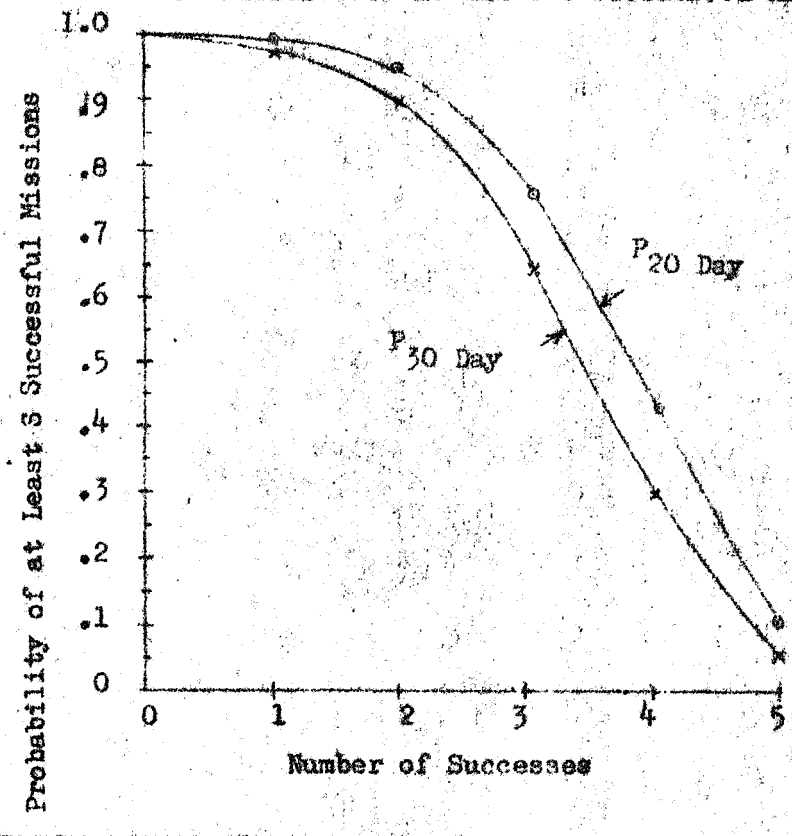
PROBABILITY OF AT LEAST ONE SUCCESSFUL MISSION OUT OF N ATTEMPTS



N	$P_{30\ Day}$	$P_{20\ Day}$
1	.581	.649
2	.824	.877
3	.926	.957
4	.969	.985
5	.987	.995

Figure 3.3

PROBABILITY OF AT LEAST S SUCCESSFUL MISSIONS OUT OF 5 ATTEMPTS



S	$P_{30\ Day}$	$P_{20\ Day}$
0	1.0	1.0
1	.987	.995
2	.898	.946
3	.649	.764
4	.305	.426
5	.066	.115

Figure 3.4

SUBSYSTEM	MISSION PHASES (E-1 MISSION)					30 DAY PHOTOGRAPHIC MISSION TOTAL
	LAUNCH & BOOST	TRANS-LUNAR	INITIAL LUNAR ORBIT	FINAL ORBIT (1st PART)	FINAL ORBIT (2nd PART)	
SPACECRAFT						
Power	.9997	.9990	.9975	.9981	.9973	.991
Structures & Mechanisms	.9966	.9980	.9994	.9996	.9996	.993
Photographic	.9862	.9903	.9748	.9728	.9787	.909
Communication	.9978	.9939	.9850	.9875	.9825	.947
Velocity Control	.9989	.9935	.9983	.9995	-	.995
Attitude Control (includes Programmer	.9929	.9774	.9459	.9592	.9435	.831
Unassigned	.9989	.9964	.9913	.9931	.9934	.970
Spacecraft Column Total	.9712	.9542	.8969	.9134	.8957	
Spacecraft Cumulative Total	.9712	.9266	.8312	.7591	.6799	.680
LAUNCH VEHICLE						
Atlas	.900	-	-	-	-	.900
Agena D	.950	-	-	-	-	.950
System Column Total	.8304	.9542	.8969	.9134	.8957	
System Cumulative Total	.830	.792	.711	.649	.581	.581

3.2 Comments

The predicted reliability of the spacecraft did not change significantly from the previous prediction. At the time of this revision, the Spacecraft Critical Design Review has been held. Several action items are still outstanding, both on the spacecraft and on several subsystems.

The Boeing Company Reliability Data Central has recently compiled failure rate data on parts and equipment used on Minuteman ground equipment. Some of these data are included in Section 9.0 of this document. These failure rates have been used to update the predictions on several Lunar Orbiter equipment.

It is planned that this revision (Revision K, April 1965) will be the last issue of this document. All future changes in the Lunar Orbiter predicted reliability will be presented in D2-100255-1, "Operational Mission Model - Lunar Orbiter" and D2-100255-2, "Reliability Evaluation Model - Lunar Orbiter". The latter document will also use test data to update the reliability predictions. This documentation plan was transmitted to the NASA in Boeing Letter 2-1551-20-032 dated March 9, 1965.

7.3 Recommendations

Based on Boeings experience with small, gear reduced, DC motors, used on Minuteman ground equipment, it is recommended that suppliers and users of this type motor emphasize the failure mode, effect and criticality analysis and quality control requirements on these items. For a summary of the problems experienced on these items see the Boeing Company Experience Retention Files.

Letter 2-1551-20-[illegible] (dated April 6, 1965) to NASA requested reliability data on all Government Furnished Equipment. Some failure rate data based on supplier predictions have been received on all spacecraft equipment except the micrometeoroid detectors. The failure mode, effect, and criticality analysis data have not. It was requested that NASA submit the data as soon as possible. In addition, actual use data on spacecraft equipment would also be useful.

4.0 Elements of the Reliability Prediction

This section states the basic ground rules, procedures and assumptions used in constructing the system model and predicting the inherent reliability of the Lunar Orbiter.

4.1 Basic Procedure

It is assumed, unless otherwise stated, that all parts have a constant failure rate within a particular environmental envelope, and that all parts operate independently insofar as their failure rates are concerned. These two assumptions lead to the standard prediction procedure now accepted for use on new space and military systems, and which has been used on the Lunar Orbiter.

This prediction procedure consists essentially of breaking down the system into its functional elements, performing a probability analysis on each of these elements to determine their inherent reliabilities, and combining the reliability of each of these elements to determine the system reliability. The probability analysis performed on each functional element consists of determining the basic failure rate of the element by a parts count analysis, modifying the failure rates with a K factor to reflect the severity of the environment in which the equipment operates and with a duty cycle factor to reflect that portion of the time in which the functional element operates. It is assumed that the element follows the exponential failure distribution. The predicted inherent reliability of the element is then calculated according to the following formula,

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

where

R = Reliability

λ = Failure rate in failure per hour

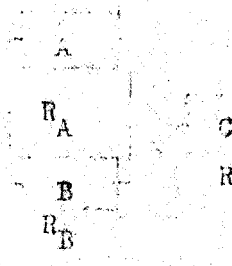
K = Environmental weighting factor

D = Duty cycle

t = time in hours.

The bases for assigning K factors and duty cycle factors to the various equipments during each of the mission phases are given in Sections 4.3 and 4.4 respectively.

This procedure is modified as necessary whenever redundancy is used. For example, if two parts, A and B, are in parallel redundancy, the reliability of the network, R_N, is equal to the quantity one minus the product of the unreliabilities of the two parts times the reliability of the switching device used to sense a failure in either A or B and switch the failed part out of the network,



$$R_N = \left[1 - (Q_A\ Q_B)\right] R_C.$$

The following mathematical formulae are used to combine the various system elements, depending on their functional relationships.

The reliability of two or more items operating in series is the product of their reliabilities,

$$R_a = R_{a_1}\ R_{a_2} \ldots R_{a_n} = \prod_{i=1}^{n} R_{a_i}.$$

The reliability of two or more items operating in parallel is one minus the product of their unreliabilities,

$$R_B = 1 - (1-R_{b_1})\ (1-R_{b_2}) \ldots (1-R_{b_n})$$

$$= 1 - \prod_{i=1}^{n} (1 - R_{b_i}).$$

For two units in standby, that is, one unit is operating and the second is operated as a substitute only after the first fails, the reliability is equal to the probability the first will survive until time t plus the probability that if the first unit fails at some time t_1 before time t, the second unit will assume the function and operate successfully until time t.

Sophisticated mathematical and statistical techniques are available to assist in analyzing any systems or networks which cannot be handled by these simple procedures.

The basic methodology used in constructing the system model and making the reliability predictions is similar to that given in Boeing Document BP-3246, "Reliability Methods Manual". These methods are compatible with those in other documents which outline reliability prediction techniques such as MIL-STD-441, "Reliability of Military Electronic Equipment"; MIL-STD-756, "Procedures for Prediction and Reporting Prediction of Reliability of Weapons Systems"; MIL-HDBK-217, "Reliability Stress Analysis for Electronic Equipment"; the RCA "Reliability Notebook"; the ARINC "Reliability Theory and Practice", the IBM-SSC "Reliability Training Text" and other similar documents.

The reliability of equipment as determined from historical use data is compared with the predicted inherent reliability of the equipment whenever use data on similar missions is available. If there are discrepancies between these two reliabilities, an investigation will be performed to determine the source of the differences. Based on this investigation, the prediction procedure or the design, manufacture, handling, test and use of the equipment will be revised to ensure the maximum actual equipment reliability possible.

4.2 Sources of Data

The following list states the order of preference for failure rate data to be used in predicting the inherent reliability of the Lunar Orbiter:

1. Historical data from similar equipment used in space missions, for example Mariner, Tiros, Ranger, Telstar and others if the data has been made available.

2. Historical data from other space or weapon systems, for example Minuteman, Atlas, Century Series Aircraft, B-52, etc.

3. Historical data from ground equipment or commercial equipment, for example, Minuteman ground equipment, commercial computer equipment, etc.

4. Vendors or users certified reliability test data.

5. MIL-HDBK-217, MIL-R-381xx series, MIL-specifications, AVCO data, or equivalent generic type data. Whenever they are available, "failure-rate-by-mode-of-failure" data, as given in D2-22963, will be utilized.

The Boeing Company, Aero-Space Division, Reliability Data Central contains much data of the type given in 2 and 3 above. Type 1 data are now on order or being processed for inclusion in the records system to supplement those which are now available. Examples of Type 5 data can be seen in Boeing Document D2-22571, "Manufacturers Reliability Data".

4.3 "K" Factors

Use-environment weighting factors ("K" factors) are used to weight the failure rate according to the severity of the environment in which the equipment will operate. For example, if the failure rate for a component came from its previous use in ground support equipment, it is necessary to multiply this failure rate by an appropriate K factor to reflect its present use in a space vehicle.

For the Lunar Orbiter, the boost and launch environment has been assigned a K factor of 140. A K factor of 1 will be used to translate data from ground equipment to space and orbit.

4.3.1 Boost and Launch

Considering the lunar orbiting environment as the base 1 for the K factors, the launch and boost environment has been assigned a K factor of 140. This factor of 140 is based on a recent study performed by The Boeing Company Reliability Research Organization. In this study, boost and launch environment profiles for other space boosters were compared to that of the Lunar Orbiter. This study is briefly summarized below.

Based on past experience, it was assumed that vibration induced stresses (including acoustical) during launch and boost will greatly exceed the combined stresses of all other environmental factors. It was also assumed that the K factor is directly proportional to the vibration induced stress level; at least in the range of vibration levels of interest here. These assumptions lead to the ratio

$$\frac{\text{LOS launch-boost environmental K factor}}{\text{LOS launch boost vibration level}} = \frac{\text{previously established environmental K factor}}{\text{vibration level corresponding to previously established K factor}}.$$

The 17 g-rms design specified vibration level in D2-100101-1 was taken to be the LOS launch boost vibration level. The figure of 9.3 g-rms, listed in MIL-STD-810, was used as the vibration level for previously established K factors. The average of K factors in MIL-STD-756A, AVCO Reliability Data Series, and other published K factor determinations was K = 75.

Based on the assumptions and data, the Lunar Orbiter launch and boost environmental K factor is calculated to be,

$$\frac{K}{17} = \frac{75}{9.3}, \quad K = 140.$$

4.4 Duty Cycle

Whenever equipment is placed in a non-operating configuration while in space, a failure rate of 20 percent of its operating failure rate will be assigned to that equipment. That is, if an item has a failure rate of .0006/hr. while operating in space, it will be assigned a failure rate of (.0006) (.20) = .00012/hr. while in a non-operating or standby mode. Therefore, if an item operates 60 percent of the time for purposes of predicting its reliability, it will be assigned an adjusted duty cycle (D) of 68 percent, where .68 = .60 + 0.2(100 - 60).

4.5 Derating

When making predictions based on parts counts and generic type failure rate data, the failure rate is altered by the amount of derating used by the designer. For example, if a designer derates a metal film resistor by a factor of 75 percent (i.e., operates at only 25 percent of rated wattage) then the failure rate will be reduced by a certain amount. This amount varies according to the part and part type used.

Whenever derating is used in the Lunar Orbiter equipment, the information will be included as part of the analysis with that particular equipment. The term "Stress Ratio", defined as

$$\text{Stress Ratio} = \frac{\text{Operating Stress Level}}{\text{Rated Stress Level}},$$

will be used synonymously with the concept of derating. In this context stress is meant to be the most significant operating parameter for the part insofar as its failure rate is concerned.

According to D2-[illegible] "Thermal Control Subsystem Design Specification Lunar Orbiter", equipment inside the spacecraft thermal barrier has a maximum design temperature of 85°F (30°C). Therefore, all part derating will use 30°C as the equipment ambient. If engineering analysis indicates higher localized temperatures for a particular part or equipment, the higher temperature will be used.

4.6 Time-Environmental Profile (continued)

For a more detailed breakdown of the mission profile, see memorandum 2-1552-10-259. A discussion of differences in the mission due to variations in the mission geometry and time of year of the mission is contained in D2-100110.

For a detailed description of the environmental profile for each mission phase see Document D2-100101-1, "Spacecraft Subsystem Environmental Criteria Specification - Lunar Orbiter".

The effects of the launch and boost environment on spacecraft reliability was treated in Section 4.5. Other environmental factors which significantly affect the reliability of any equipment will be noted with the detailed reliability prediction of that equipment.

5.0 Follow-On Work

The Lunar Orbiter system reliability model as given in this document will be used to generate other analysis and trade study data. For example, redundancy versus weight trade off studies will be based on these predicted inherent reliabilities. The reliability goals apportionment will be updated in consideration of these results. The reliability predictions based on this model will also be used in assigning the criticality ranking in the failure mode and effect, and criticality analyses.

For the operational mathematical model, the system reliability is combined with measures of the system performance to produce a measure of the total system effectiveness. For example, the probability that the system will not be degraded by meteorites and/or micrometeorites must be calculated. The probability that the radiation from a solar flare will not degrade system operation beyond acceptable limits will also be calculated. These, and other similar kinds of probabilities when combined will provide the measure of mission effectiveness.

Test data on the system components and parts will also be used to update the system mode. For example, all reliability demonstration test data and qualification test data will be used to increase the accuracy of the failure rates used in the prediction of the system reliability. In this manner the reliability prediction model evolves into an operational mathematical model and into a reliability assessment mode. This evolution is depicted in Figure 5.1, "Lunar Orbiter Model Development Plan," abstracted from D2-100151, "Reliability Program Plan - Lunar Orbiter." Section 3 of D2-100151 assigns responsibilities for all of the tasks involved in the follow-on work.

4.6 Time-Environmental Profile

The E-1 mission profile used for this analysis is summarized below. The class E-1 mission objective as defined in Document D2-100110, "Spacecraft Subsystem Design Criteria Specification - Lunar Orbiter" consists of class A-1, A-2a, C and D mission objectives.

"Class A: Photos of areas within the particular lunar region bounded by ± 100° latitude and ± 60° longitude (cartographic).

1. Site examination of a single target such as the area surrounding a landed Surveyor, or a selected landing site for a Surveyor or Apollo."

2.a. Site search of a single target such as a potential landing site for Surveyor or Apollo (low altitude).

Class C: Selenodetic Data

1. Lunar gravitational potential
2. Lunar size and shape

Class D: Lunar Environmental Data

1. Micrometeroid flux
2. Energetic particle flux."

NOTE: The reliability predictions consider only the probability of acquisition of the photographic data. Equipment which is used only in getting class "C" and "D" data is not included in calculating the spacecraft predicted inherent reliability.

The various mission phases are taken from the typical mission profile in memorandum 2-1552-10-259, December 23, 1964. It must be noted that the mission phases used in the reliability predictions do not conform exactly to the typical mission profile referenced above. One change is to group portions of the mission which have similar environmental or functional characteristics for convenience in making the reliability calculations. For example, the half hour coast period between Agena firings is switched from the "Launch and Boost" phase to the "TransLunar" phase.

Another change is to use nominal time periods for those portions of the mission which may vary according to the launch date and specific area of the moon to be photographed. For example, the June 23, 1966 launch which is used in the time line analysis in memorandum 2-1552-10-259 requires only a 44 hour wait period in the "Initial Lunar Orbit". Depending on the launch date and mission geometry, the wait time can vary between two and twelve days. The mission profile for the reliability predictions uses a 9 day wait period before orbit transfer.

4.6 Time-Environmental Profile (continued)

The typical mission profile used in this analysis is not a "worst case", but a nominal mission adequately considering all portions of the mission.

MISSION PHASES

1. Launch and Boost

This mission phase starts with the end of pre-launch countdown and ends with the separation of the Agena D. Time = .20 hr. (12 min.) in this phase. The coast period between Agena firings has been assigned to the Translunar phase.

2. Translunar

This mission phase starts with the separation of the Agena D and ends with injection into initial Lunar Orbit. Time = 89.8 hours this phase; 90 hours total time.

3. Initial Lunar Orbit

This mission phase starts with injection into Initial Lunar Orbit and ends with transfer into Final Lunar Orbit. Fourteen frames taken (20 meter and 160 meter resolution). Four frames of Initial Lunar Orbit photos are transmitted back to earth. Time = 218 hours this phase; 308 hours total time.

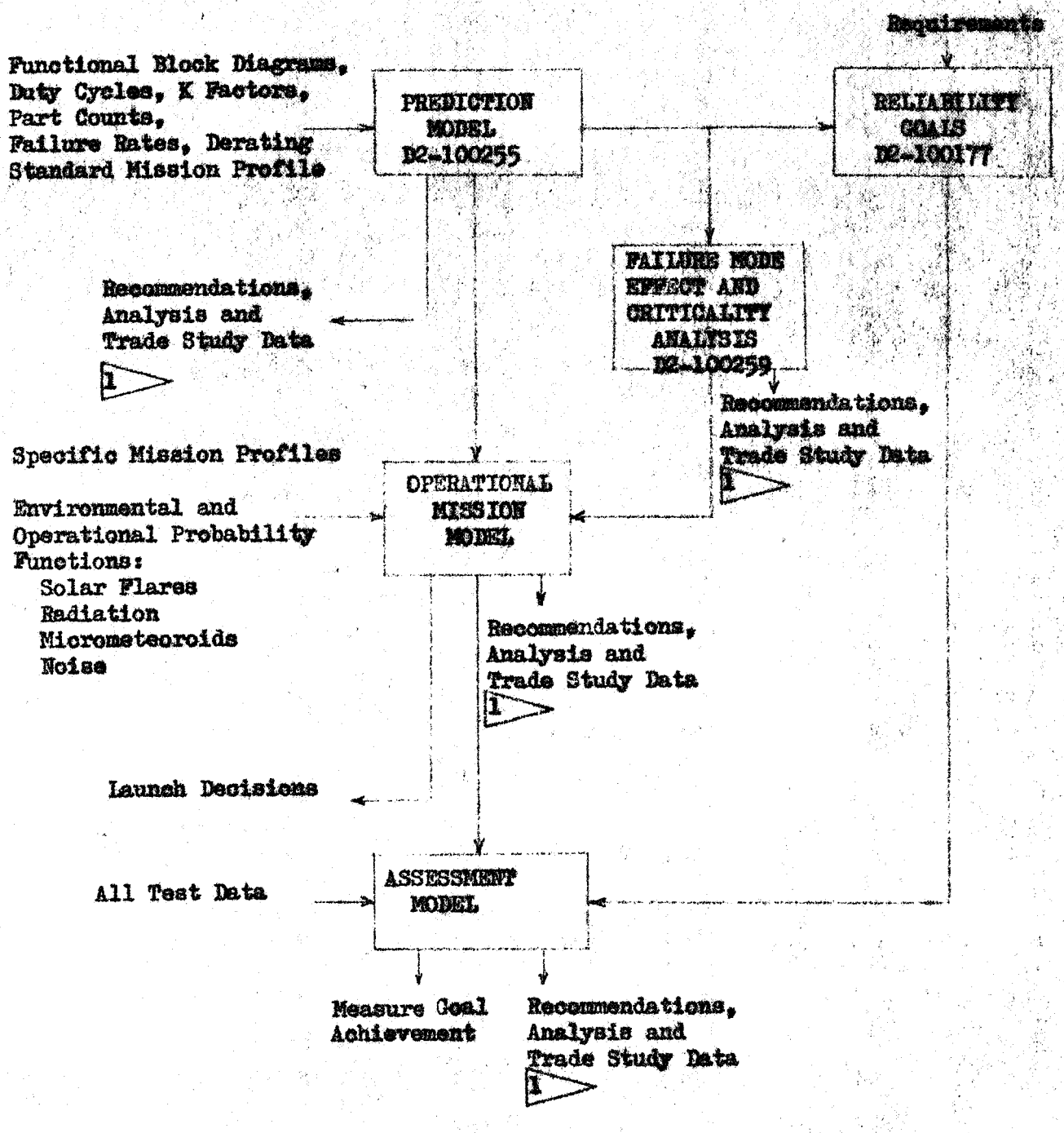
4. Final Lunar Orbit, 1st Part

This mission phase starts with transfer into Final Lunar Orbit and ends 172 hours later. During this phase all of the high resolution photos are taken and processed. Approximately thirty-five percent of photo data are transmitted back to earth. Time = 172 hours this phase; 480 hours total time.

5. Final Lunar Orbit, 2nd Part

This phase consists of the last 10 days of the 30-day standard mission. During this time all the remaining photo data are transmitted back to earth. Time = 240 hours this phase; 720 hours total time.

LUNAR ORBITER MODEL DEVELOPMENT



1 Reported in the regular technical progress report

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6.0 Subsystem Breakdowns

The reliability information on each subsystem in the Lunar Orbiter Spacecraft is presented as follows. First is a functional block diagram, a reliability block diagram and a mathematical model. Then the reliability predictions and calculations are summarized in tabular form in the "System Reliability Charts". The "Sequence Time Bar Graphs" then present a simplified time line analysis of the equipment operation. Finally, the derivation of the failure rate for each equipment is presented.

Except for the "Subsystem Reliability Summary" charts, all of the information is self-explanatory. These charts summarize the predictions for each of the spacecraft's subsystems. The symbols used on these charts are defined below.

λ	Failure rate (in failures per hour or failures per cycle, as applicable)
K	Environmental weighting factor (see Section 4.3)
D	Adjusted duty cycle (see Section 4.4)
t	time
f	$f = \lambda KDT$. That is, f is the product of failure rate, K factor, duty cycle and time of the mission phase in hours
$\sum f$	The sum of the f's for that particular piece of equipment
R	Reliability

The product of the adjusted failure rate times the time of the mission phase for each equipment during each mission phase is indicated in block labeled "f". The column sum represents the sum of these products for the subsystem during each particular mission phase or objective. The cumulative sum represents the total sum of these products through that particular mission phase. The column and cumulative reliabilities are merely the reliabilities associated with their respective sums.

Insofar as possible, the following data has been made available for each of the subsystems included in the Lunar Orbiter Spacecraft:

a. Functional block diagrams

b. Parts counts analysis for each equipment

c. Sequence time bar graphs

d. Duty cycles for each mission phase for each equipment

6.0 Subsystem Breakdowns (continued)

e. Failure rates

f. Derating information

g. Reliability Summary Charts

This basic information was used in conjunction with the E-1 mission profile to make the reliability predictions.

The following information will be incorporated into the system model and used to periodically update the reliability predictions as the information becomes available:

a. Detailed time and environmental profiles

b. General arrangement drawings

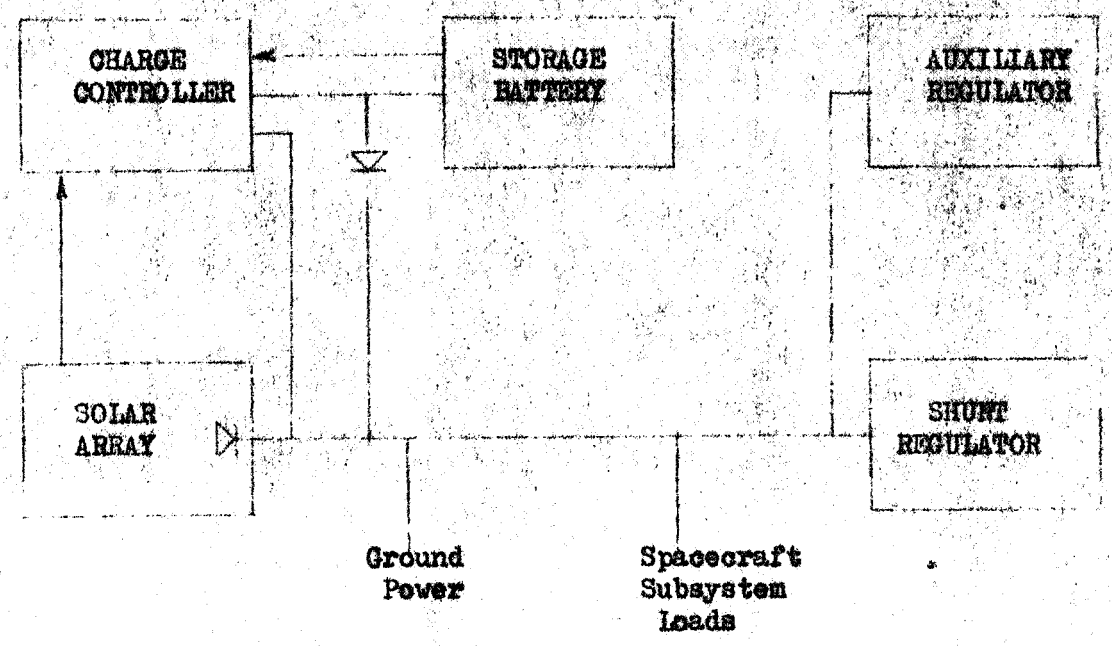
c. Logic diagrams

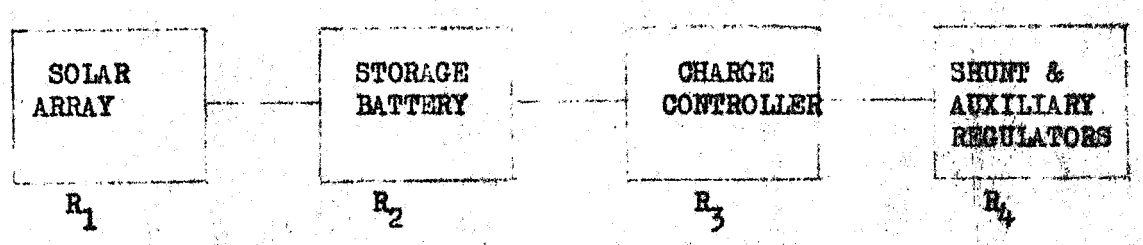
d. Power distribution block diagrams

Any other information which would serve to increase the accuracy of the reliability predictions will be considered and utilized as it becomes available.

For a general functional description of each of these subsystems, see Document D2-100110. That document also contains a general description of most of the equipment contained in each subsystem. Detailed descriptions of the function, design criteria, size, weight, test specifications and other information must be obtained from the specific design data.

POWER SUBSYSTEM - FUNCTIONAL BLOCK DIAGRAM





$$R_{Total} = R_1 R_2 R_3 R_4$$

POWER SUBSYSTEM - RELIABILITY BLOCK DIAGRAM

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Solar Array [1]	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
$\lambda = 5.35 \times 10^{-6}$ f=	.000160	.000480	.001160	.000920	.001280	Σf = .004000 R = .9960
Battery [2]	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
$\lambda = .265 \times 10^{-6}$ f=	.000008	.000024	.000058	.000046	.000064	Σf = .000200 R = .9998
Charge Controller	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
$\lambda = 3.3 \times 10^{-6}$ f=	.000092	.000297	.000719	.000568	.000792	Σf = .002468 R = .9976
Shunt Regulator	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
$\lambda = 2.6 \times 10^{-6}$ f=	.000072	.000234	.000567	.000447	.000624	Σf = .001944 R = .9981
	K= D=	K= D=	K= D=	K= D=	K= D=	
$\lambda =$ f=						Σf = R =
	K= D=	K= D=	K= D=	K= D=	K= D=	
$\lambda =$ f=						Σf = R =
Column Sum	.000332	.001035	.002504	.001981	.002760	
Column Reliability	.9997	.9990	.9975	.9981	.9973	
Cumulative Sum	.000332	.001367	.003871	.005852	.008612	.008612
Cumulative Reliability	.9947	.9987	.9962	.9942	.9914	R = .9914

[1] See Page 31
[2] See Page 32

POWER SUBSYSTEM - RELIABILITY SUMMARY (SHEET 1 OF 1)

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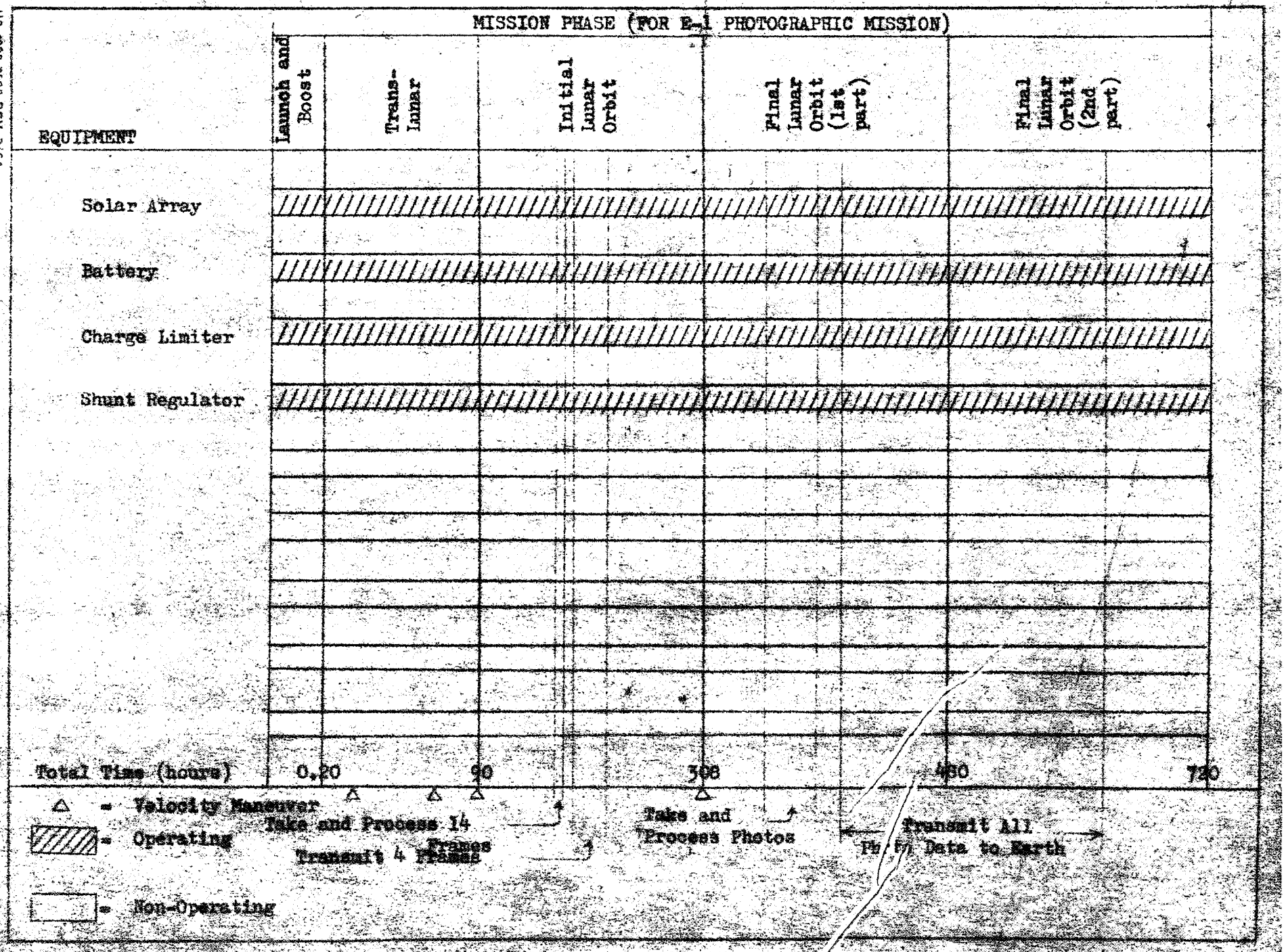
MISSION PHASE (FOR E-1 PHOTOGRAPHIC MISSION)
EQUIPMENT
Launch and Boost
Trans-Lunar
Initial Lunar Orbit
Final Lunar Orbit (1st part)
Final Lunar Orbit (2nd part)
Solar Array
Battery
Charge Limiter
Shunt Regulator
Total Time (hours)
0.20
90
308
480
720
Take and Process 14 Frames
Transmit 4 Frames
Take and Process Photos
Transmit All Perf Data to Earth
= Velocity Maneuver
= Operating
= Non-Operating

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Power Subsystem - D2-100115

Shunt Regulator, RCA Drawing #1/26469

Function: Dissipating excess current from the solar array to prevent the unregulated bus voltage from exceeding a predetermined limit.

Predicted $\lambda = 2.6 \times 10^{-6}$/hr.

Part Type	n	$\lambda/10^{-6}$ [1]	$n\lambda$
Transistor			
Signal	10	.038	$.38 \times 10^{-6}$
Power	8	.10	.80
Resistor			
WW	16	.019	.30
WW Power	37	.017	.63
Metal Film	32	.006	.19
Diode			
General Purpose	10	.005	.05
Zener	2	.047	.09
Capacitor	14	.007	.10
Connector Pins	41	.001/pin	.04
Solder Joint	325	.00004	.01
		TOTAL	2.59×10^{-6}

[1] - Failure rates taken from Minuteman ground equipment field use data - see Section 9.0.

Power Subsystem - D2-100116

Battery Charge Controller RCA Drawing #1755659

Function: Limit the charge current to the battery for protection of the battery.

Predicted $\lambda = 3.25 \times 10^{-6}$

Part Type	n	$\lambda / 10^{-6}$ hr	n λ
Transistor			
General Purpose	19	.038	$.07 \times 10^{-6}$
Resistor			
Wirewound	11	.017	.19
Metal Film	24	.006	.14
Carbon Comp.	9	.014	.13
Var. Wirewound	3	.400	1.20
Diode			
General Purpose	37	.005	.18
Zener	2	.047	.09
Capacitor			
Solid Ta	12	.007	.08
Ta Foil	1	.005	.01
Mica	1	.004	.01
Inductor	6	.10	.60
Transformer	6	.056	.34
Connector Pins	197	.001/pin	.20
Solder Joints	340	.00004	.01
			TOTAL 3.4×10^{-6}

The charge controller also uses the Auxiliary Solar Array. This array consists of 4 panels in parallel, each having 10 solar cells and one diode in series. The array will operate successfully if at least two of the four panels are operating.

With power diode $\lambda = .04 \times 10^{-6}$ and λ solar cell $= 0.1 \times 10^{-6}$,
$R_{panel} = e^{-\lambda t} = e^{-[10(.1) + .04]\ 10^{-6}\ (755\ \text{hours})} = .999215$.

Power Subsystem - D2-100176

Battery Charge Controller RCA Drawing 2175669 (continued)

Assuming that the panels do not fail short to ground (see Page 31)
the reliability of the Array = P { 2 out of 4 panels operate } ≥ .9999.

1 - Failure rates taken from Minuteman ground equipment field use data - see Section 9.0.

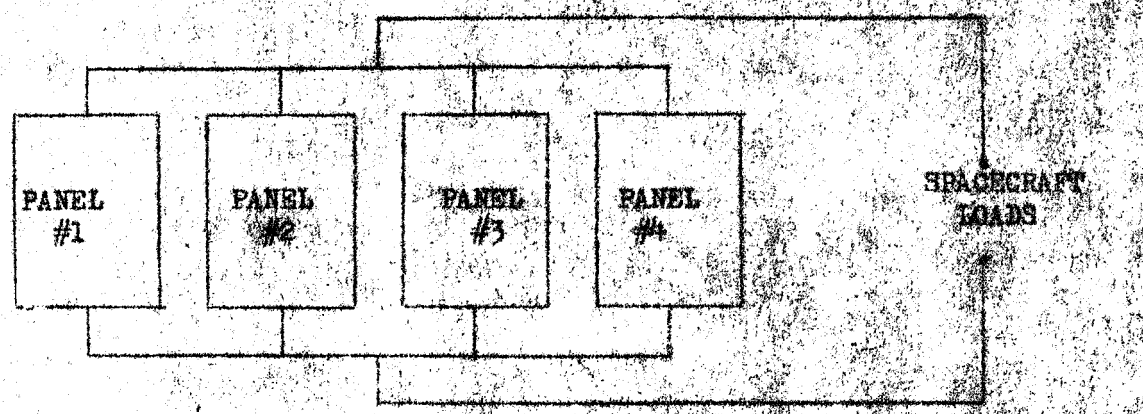
Lunar Orbiter Power Subsystem

Solar Array - RCA Drawing #1756846

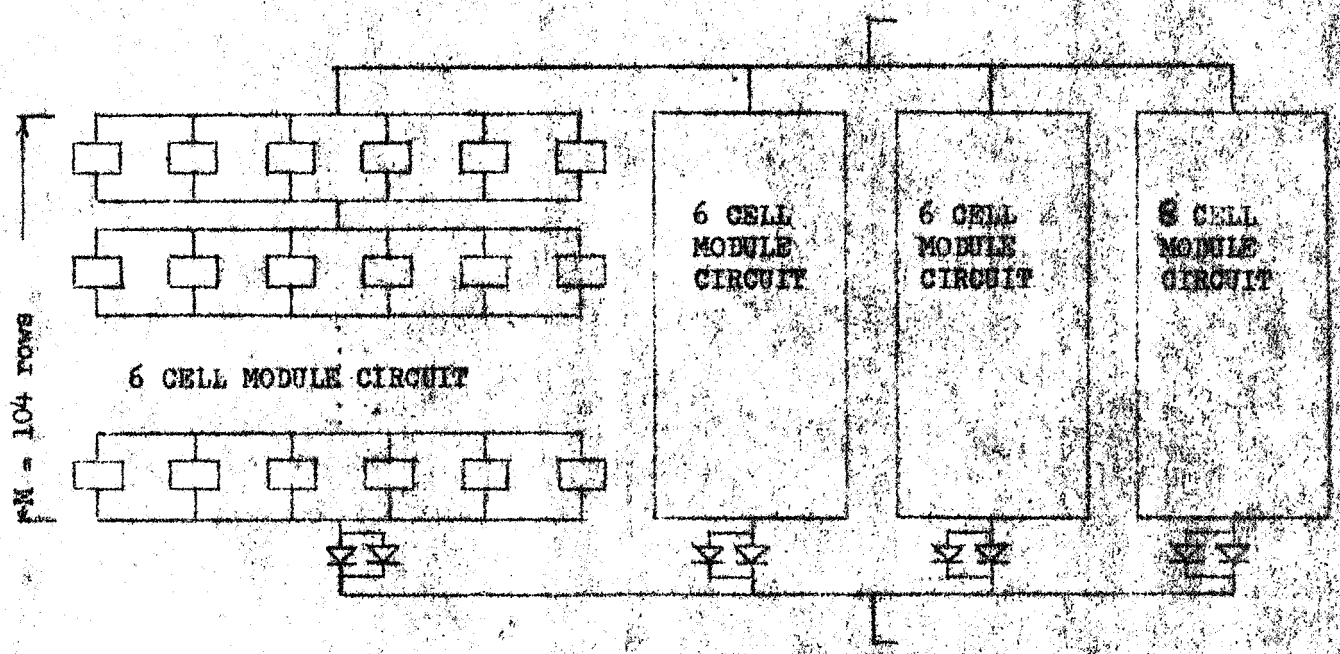
Function: Provide power for the Spacecraft and recharging the battery while the solar array is in sunlight.

Predicted Reliability $R \geq .996$ [1]

The Solar Array consists of 4 identical Solar Panels.



Each Panel consists of,



[1] This reliability figure does not consider the reliability of the solar panel deployment mechanism. Deployment mechanisms are covered as part of the Structures and Mechanisms subsystem.

SOLAR ARRAY (continued)

The failure rate for a single solar cell is $\lambda = 0.1 \times 10^{-6}$/hr. [2] Then the reliability of a single solar cell for the 30 day photographic mission is $R_{cell} = e^{-\lambda t} = e^{-(0.1 \times 10^{-6})(748)} \cong .9999252$

The single cell failure rate includes an allowance for the solder joints and interconnections between the separate cells and modules.

According to estimates of the spacecraft power requirements, there will be a 5% surplus of average power available from the solar array at the end of 30 days. It is assumed that the panels do not fail internally shorted to ground. Then, as a conservative estimate, a solar panel will provide sufficient power if the following three conditions exist:

a. None of the 26 (26 = 3 x 6 + 8) one hundred four row solar cell strings have more than four failed cells. This condition ensures no more than a 4% power drop in the panel.

b. None of the 6 or 8 cell modules has more than one failed cell. This condition ensures there is no excess current through any single solar cell, and the total current is not limited by excessive resistance in a module.

c. None of the four sets of 2 parallel diodes fail.

$$R_a = \left[\sum_{i=0}^{4} \binom{104}{i} (R_{cell})^{104-i} (1 - R_{cell})^{i} \right]^{26} \geq .9992$$

$$R_b = \left[\sum_{i=0}^{1} \binom{6}{i} (R_{cell})^{6-i} (1 - R_{cell})^{i} \right]^{416} \geq .9999$$

$$R_c = e^{-n\lambda t} = e^{-4(.05 \times 10^{-6})(748)} \cong .9999$$

$$R_{Solar\ Panel} = R_a R_b R_c = .999$$

$$R_{Solar\ Array} = (.999)^4 = .996$$

[2] R. A. Brenan and F. D. Mason "Calculation of Optimally Reliable Solar Cell Arrays" "IEEE Transactions on Component Parts, Vol. CP-11 June, 1964.

SOLAR ARRAY (continued)

To examine the reliability of the solar panels in more detail, the probabilities of encountering specific numbers of failed solar cells can be readily calculated. Using the binomial theorem,

$$(a + b)^n = \sum_{k=0}^{n} \binom{n}{k} a^{n-k} b^k,$$

and the probability of failure of a single solar cell = .9999252,

$$\text{results in} \quad \sum_{k=0}^{10,816} \binom{10,816}{k} (.9999252)^{10,816-k} (.0000748)^k$$

The first seven terms in this series are tabulated below:

k	$P_{\text{exactly } k}$	$P_{k \text{ or less}}$
0	.44528	.4453
1	.36028	.8056
2	.14574	.9513
3	.03930	.9906
4	.00795	.9985
5	.00128	.9998
6	.00017	.9999+

$P_{\text{exactly } k}$ = the probability that there will be exactly k failed solar cells during the 30 day photo mission.

$P_{k \text{ or less}}$ = the probability that there will be k or less failed solar cells during the 30 day photo mission.

From the table it can be seen that there is a probability of .9999 that there will be no more than 6 failed solar cells in the entire solar array. Six cells represent less than one tenth of one percent of the total solar array.

Power Subsystem - D2-100116

Battery Module (Gulton) RCA Drawing 1756837

Function: Provide Spacecraft power when solar panels are not in sunlight

Predicted R = .9998 (for the 30 day E-1 photographic mission)

Given: 1. Two 10 cell 12 ampere hour batteries
2. The thirty day mission will require approximately 200 charge-discharge cycles.
3. 30°C ambient, 35% depth of discharge, 208 minute cycle.

Assumption: Spacecraft batteries follow a normal failure distribution.

Then: The battery predicted inherent reliability (R) for the 30 day mission is given by,

$$R = 1 - \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{-\frac{\mu-n}{\sigma}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} dx,$$

where R = Reliability for 30 day mission
μ = MCTF = mean cycles to failure of the battery
n = Number of charge-discharge cycles in mission
σ = Standard deviation of the number of charge-discharge cycles to failure at given conditions.

For a 10 cell Ni Cd battery under cycling conditions which are at least as stringent as the Lunar Orbiter conditions, the following values of the parameters are obtained: [1]

μ = 3300 cycles to failure
σ = 825 cycles.

These values result in a predicted inherent reliability of

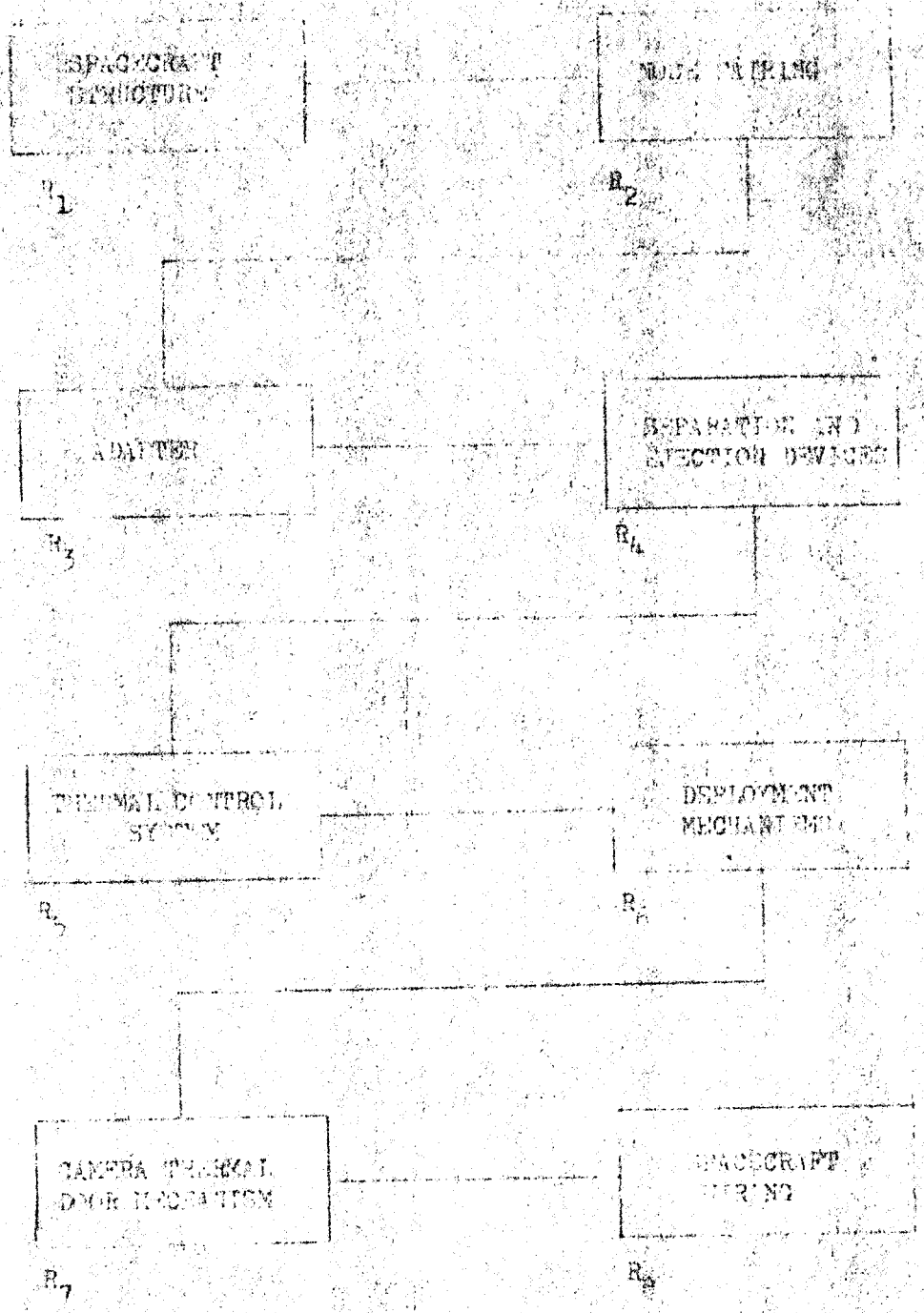
R = .9999

for the 10 cell battery for the 200 cycle (30 day) mission.

For two batteries, the Reliability will be:

$$R_2 = (.9999)\ (.9999) = .9998$$

[1] See ASD-TDR-63-394 "Alkalene Battery Evaluation Report" and NASA SP-5004 "Space Batteries.



$R_0 = R_1\ R_2\ R_3\ R_4\ R_5\ R_6\ R_7\ R_8$

STRUCTURE, MECHANISM AND
[illegible] - RELIABILITY BLOCK DIAGRAM

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Spacecraft Structure	K= 140 D= 1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = approaches 0 f=	.000004	.000012	.000029	.000023	.000032	$\sum f$ = .000100 R = .9999
Nose Fairing 1	K= 1 D= 1	K=1 D=0	K=1 D=0	K=1 D=0	K=1 D=0	
λ = .001/launch f =	.001					$\sum f$ = .001 R = .999
Adapter 1	K= 1 D= 1	K=1 D=0	K=1 D=0	K=1 D=0	K=1 D=0	
λ = .001/launch f=	.001					$\sum f$ = .001 R = .999
Separation & Ejection Devices 1	K= 1 D= 2cy	K=1 D=0	K=1 D=0	K=1 D=0	K=1 D=0	
λ = .0006/cy and .0007/cy f=	.0013					$\sum f$ = .0013 R = .9987
Thermal Control System	K= 140 D= 1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = approaches 0 2 f=	.000004	.000012	.000029	.000023	.000032	$\sum f$ = .000100 R = .9999
Deployment Mechanisms	K= 140 D= 1	K=1 D=1cy	K=1 D=0	K=1 D=0	K=1 D=0	
λ = .0018 f=	.0001 3	.001800	-	-	-	$\sum f$ = .0019 R = .998
Camera Thermal Door Mechanism	K= 140 D= 1	K=1 D=1	K=1 D=1	K=1 D=.6	K=1 D=.2	
λ = 1.25 x 10^{-6}/hr. f=	.000035	.000112	.000272	.000129	.000060	$\sum f$ = .000608 R = .9994

1 See respective equipment pages for explanation of launch and boost K factor of 1.

2 Does not consider the probability of failure due to micrometeoroids or solar flares. These probabilities will be considered in the Operational Mission Model.

3 See Page 42

RELIABILITY SUMMARY (SHEET 1 OF 2)

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Spacecraft Wiring	K= 140 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
λ = .0000013 f=	.000036	.000117	.000283	.000224	.000312	Σf = .000972 R = .9990
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
Column Sum	.003479	.002053	.000613	.000399	.000436	
Column Reliability	.9966	.9980	.9994	.9996	.9996	
Cumulative Sum	.003479	.005532	.006145	.006544	.006980	.006980
Cumulative Reliability	.9966	.9945	.9939	.9935	.9930	R = .9930

STRUCTURE MECHANISMS & INTEGRATION ELEMENTS SUBSYSTEM - SUMMARY RELIABILITY (SHEET 2 OF 2)

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Lunar Orbiter - Structures and Mechanisms Subsystem

Structure - Drawing # .25 - 51625

Function: This functional block consists of the spacecraft basic structural trusses and equipment mounting plates

Predicted λ approaches 0

Source of failure rate data: Engineering judgement. This block includes only structural, passive items. No moving parts or electrical parts are included. The safety factors are adequate to assure structural integrety throughout the mission. The structure will be tested prior to flight to verify that the design requirements are met.

Lunar Orbiter - Structures, Mechanisms Integration Elements Subsystem H

Nose Fairing (Shroud) - GFE

Function: The nose fairing consists of a shroud and nose cap. Its purpose is to protect the spacecraft during the prelaunch, launch and boost portions of the mission. This nose fairing is Government Furnished Equipment.

Predicted Reliability = .999

Source of Failure Rate Data: Lockheed reliability estimate and analysis report for Mariner C Vehicles 6931, 6932. Report Number SP-3802-64-2 dated 28 May 1964, Page A-1.

Lunar Orbiter - Structures and Mechanisms Subsystem

Adapter - GFE

G

Function: The adapter consists of a payload adapter, and a diaphragm seal. Its function is to adapt the nose fairing and spacecraft to the Agena D. The adapter is Government Furnished Equipment.

Predicted Reliability = .999

Source of Failure rate data: Lockheed Reliability estimate and analysis report for Mariner C Vehicles 6931, 6932. Report Number SP-3802-64-2, dated 28 May 1964, Page A-1.

Lunar Orbiter - Structures and Mechanisms Subsystem

Separation and Ejection Devices

1. Nose Fairing Separation and Ejection Devices

Function: The nose fairing separation device consists of two V-band straps held together by two explosive bolts. Function of either one or both of these explosive bolts will separate the nose fairing from the adapter. The ejection device is four pair of preloaded springs. The separation and ejection devices are Government Furnished Equipment.

Predicted λ = .0006/cy

Part	λ		n	n λ
V Band Straps	.0001	1	2	.0002/cy
Explosive Bolts	.0002	2	2 (in parallel)	.0000/cy
Ejection Device	.0001	2	4	.0004/cy

2. Spacecraft Separation and Ejection Devices

Function: The spacecraft is separated from the adapter in the same manner as the nose fairing. In addition there is a 50 pin inflight disconnect.

Predicted λ = .0007/cy

Part			n	n
V Band Strap	.0001	1	2	.0002/cy
Explosive Bolts	.0002	2	2 (in parallel)	.0000/cy
Ejection Device	.0001	2	4	.0004/cy
Inflight Disconnect	.000002/cy/pin	3	50 pins	.0001/cy
			TOTAL	.0007/cy

Source of failure rate data:

1 Lockheed Reliability estimate and analysis report for Mariner C Vehicle 6931, 6932. Report Number SP-3802-64-2 dated 28 May 1964.

2 AVCO Reliability Series - Failure Rates. April 1962, Page 70 and 81.

3 AVCO Reliability Series - Failure Rates. Page 72

NOTE: The failure rates are based on use after launch and boost. Therefore the launch and boost environmental K factor of 140 is not needed because one cycle of operation includes survival of launch and boost.

Lunar Orbiter - Structures and Mechanisms Subsystem

Thermal Control System - Drawing Number 25-50918

Function: The thermal control system consists of the S/C paint, coatings, and aluminized-Mylar shroud. Its purpose is to provide thermal control to the spacecraft interior.

Predicted $\lambda \rightarrow 0+$

Source of failure rate data: The elements of the thermal control system are all passive elements, and these elements are basically structural. The thermal control system will be tested prior to flight to assure the design requirements are met. The probability that the thermal control system will be affected by micrometeoroids and/or solar radiation will be considered in the Operational Mathematical Model.

Lunar Orbiter

Camera Thermal Door Mechanism

Function: This functional block consists of an electrically operated door through the spacecraft thermal shroud. Its purpose is to act as a lens cap when the Photographic Subsystem is not taking photographs.

Predicted $\lambda = 1.25 \times 10^{-6}$/hr.

Part Type	$\lambda \times 10^{-6}$		n	$n\lambda$
Gears	.05	1	4	$.20 \times 10^{-6}$
Motor, stepper	.75	2	1	.75
Bearings	.05	3	6	.30
			TOTAL	1.25×10^{-6}

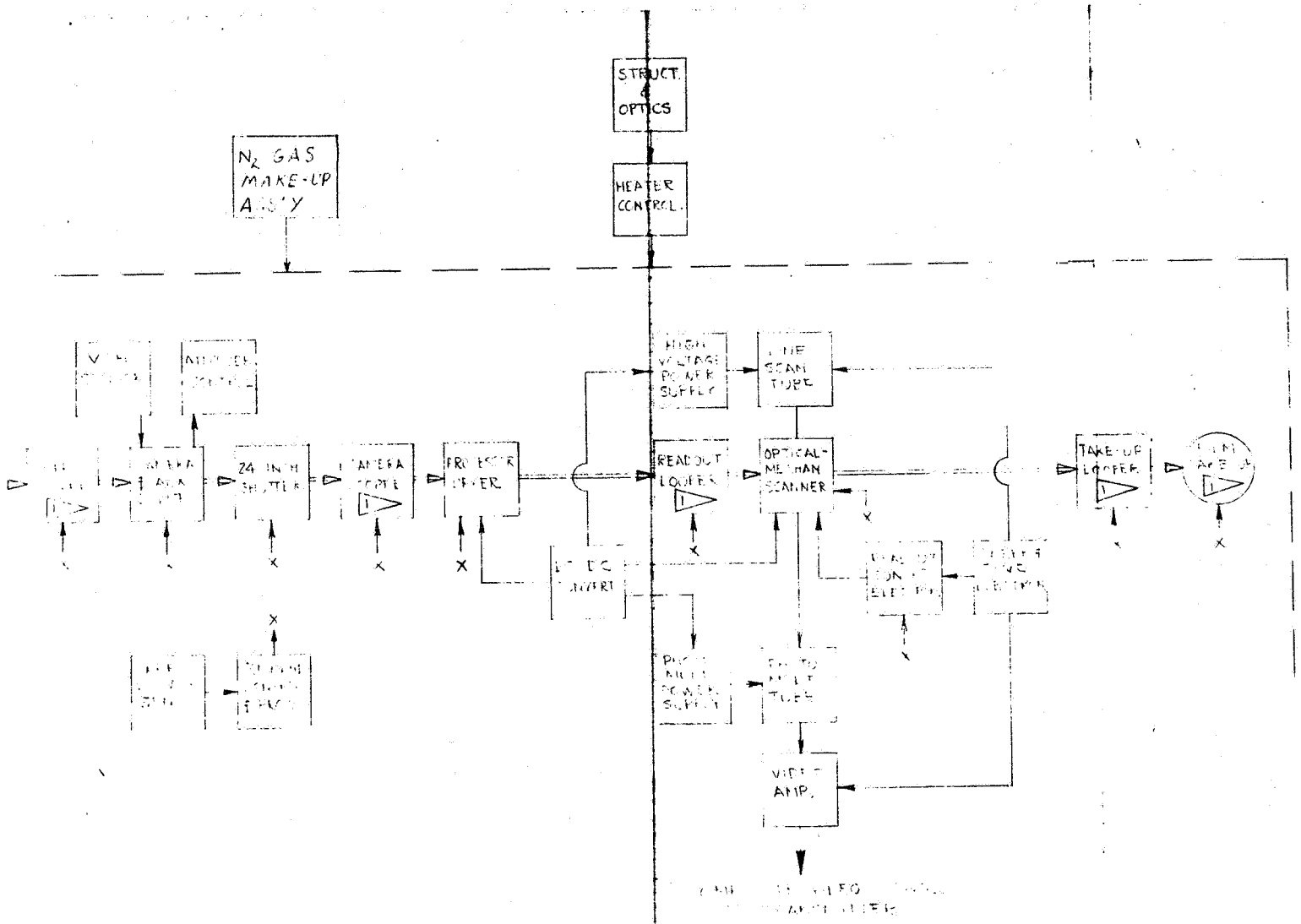
Source of failure rate data:

1 - AVCO Reliability Data Series - P 75

2 - AVCO Reliability Data Series - P 79

3 - Engineering judgement

NOTE: The camera thermal door also has an emergency mode of operation. This consists of a squib actuated device which can be commanded to permanently open the door in case of failure.



FILM PATH

FILM HANDLING MECHANISM

	INITIALS	DATE	REV BY INITIALS	DATE	TITLE	MODEL
CALC	RP	12-5-64			[illegible]	
CHECK						
APPD						
APPD						

REV LTR B

U3 4011 5000 REV. 9-64

BOEING NO. D2-100255

SH P 43.1

Lunar Orbiter Structures, Mechanisms, Integration Elements Subsystem

Spacecraft Wiring - Drawing # 25-[illegible] and 15

Function: This functional block consists of the spacecraft wiring harness, it contains [illegible] connectors using approximately [illegible] pins.

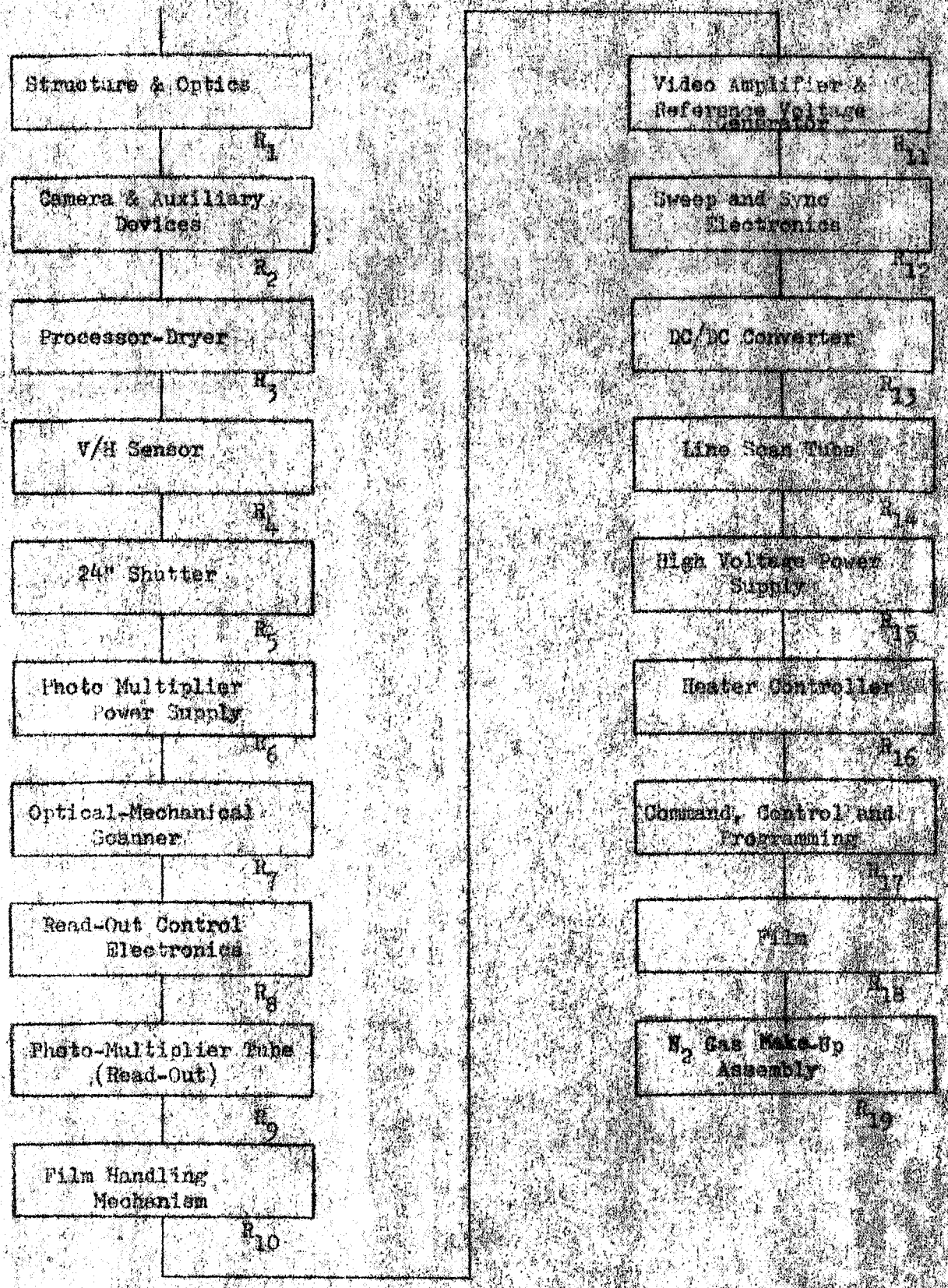
Predicted λ = [illegible] 10^{-6}/hr.

Part Type	λ 10^{-6}/hr.		n	$n\lambda$
Connector	.001/pin	1 →	[illegible] pins	[illegible] x 10^{-6}/hr.
Connector-Coaxial	.[illegible]/pin	2 →	10 pins	.03[illegible]

TOTAL [illegible] x 10^{-6}

1 → See Section [illegible].

2 → AVCO Reliability Data Series - Failure Rate - Page [illegible].



$$R_{Total} = R_1 R_2 R_3 \cdot \cdot \cdot R_{18} R_{19}$$

PHOTOGRAPHIC SUBSYSTEM - RELIABILITY BLOCK DIAGRAM

Lunar Orbiter - Structure and Mechanisms Subsystem

Deployment Mechanisms - Drawings 25-50932, 33, and 34

Function: 1. Solar Panel Deployment - The solar panels deployment is initiated by two pinpullers and four actuators.

2. Hi Gain Antenna Deployment - The hi gain antenna is deployed by one pinpuller and one actuator.

3. Lo Gain Antenna Deployment - The low gain antenna is deployed by one pinpuller and one actuator.

Predicted λ = .0018/cy, plus a probability = .9999 that the mechanisms will survive launch and boost.

Part	λ		n	$n\lambda$
Pinpuller	.0002/cy	1	4	.0008/cy
Actuator	.0001/cy	1	6	.0006/cy
Solar Panel Linkage	.0002/cy	2	1	.0002/cy
Hi Gain Antenna Linkage	.0001/cy	2	1	.0001/cy
Lo Gain Antenna Linkage	.0001/cy	2	1	.0001/cy
			TOTAL	.0018/cy

Source of failure rate data: 1 > AVCO Reliability Data Series - Failure Rates, April 1962, Page 69

2 > Engineering judgement

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Read-Out Control Electronics	K= 140 D= 1	K= 1 D= .20	K= 1 D= .21	K= 1 D= .60	K= 1 D= .66	
λ = .000001	f= .000028	.000018	.000046	.000103	.000158	Σf = .000353 R = .9997
Photo Multiplier (Read-Out)	K= 140 D= 1	K= 1 D= .20	K= 1 D= .21	K= 1 D= .60	K= 1 D= .66	
λ = .000010	f = .000280	.000180	.000436	.001030	.001580	Σf = .003506 R = .9965
Film Handling Mechanism	K= 140 D= 1	K= 1 D= .20	K= 1 D= .21	K= 1 D= .26	K= 1 D= .20	
λ = .000081	f= .002268	.001458	.003726	.003622	.003888	Σf = .014962 R = .9851
Video Amplifier & Reference Voltage Generator	K= 140 D= 1	K= 1 D= .20	K= 1 D= .21	K= 1 D= .60	K= 1 D= .66	
λ = .000001	f= .000028	.000018	.000046	.000103	.000158	Σf = .000353 R = .9997
Sweep and Sync Electronics	K= 140 D= 1	K= 1 D= .20	K= 1 D= .21	K= 1 D= .60	K= 1 D= .66	
λ = .000003	f= .000084	.000054	.000138	.000309	.000474	Σf = .001059 R = .9990
DC/DC Converter	K= 140 D= 1	K= 1 D= .20	K= 1 D= .21	K= 1 D= .60	K= 1 D= .66	
λ = .000008	f= .000224	.000144	.000368	.000824	.001264	Σf = .002824 R = .9972
Line Scan Tube	K= 140 D= 1	K= 1 D= .20	K= 1 D= .21	K= 1 D= .60	K= 1 D= .66	
λ = .000030	f= .000840	.000540	.001380	.003090	.004740	Σf = .010590 R = .9895

PHOTOGRAPHIC SUBSYSTEM - RELIABILITY SUMMARY (SHEET 2 OF 3)

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Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Structure & Optics	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = .000009 f=	.000252	.000808	.001962	.001548	.002160	Σf = .006730 R = .9933
Camera & Auxiliary Devices	K=140 D=1	K=1 D=.20	K=1 D=.20	K=1 D=.20	K=1 D=0	
λ = .000129 f =	.003612	.002193	.005676	.004386	-	Σf = .015867 R = .9842
Processor-Dryer	K=140 D=1	K=1 D=.20	K=1 D=.21	K=1 D=.26	K=1 D=0	
λ = .000067 f=	.001876	.001206	.003082	.003008	-	Σf = .009172 R = .9909
V/H Sensor	K=140 D=1	K=1 D=.20	K=1 D=.20	K=1 D=.20	K=1 D=0	
λ = .000076 f=	.002128	.001368	.003343	.002584	-	Σf = .009423 R = .9906
24" Shutter	K=140 D=1	K=1 D=.20	K=1 D=.20	K=1 D=0	K=1 D=	
λ = .000037 f=	.001036	.000666	.001628	.001258	-	Σf = .004588 R = .9955
Photo Multiplier Power Supply	K=140 D=1	K=1 D=.20	K=1 D=.21	K=1 D=.60	K=1 D=.66	
λ = .000001 f=	.000028	.000018	.000046	.000103	.000158	Σf = .000353 R = .9997
Optical-Mechanical Scanner	K=140 D=1	K=1 D=.20	K=1 D=.21	K=1 D=.60	K=1 D=.66	
λ = .000029 f=	.000812	.000522	.001334	.002987	.004582	Σf = .010237 R = .9898

PHOTOGRAPHIC SUBSYSTEM - RELIABILITY SUMMARY (SHEET 1 OF 3)

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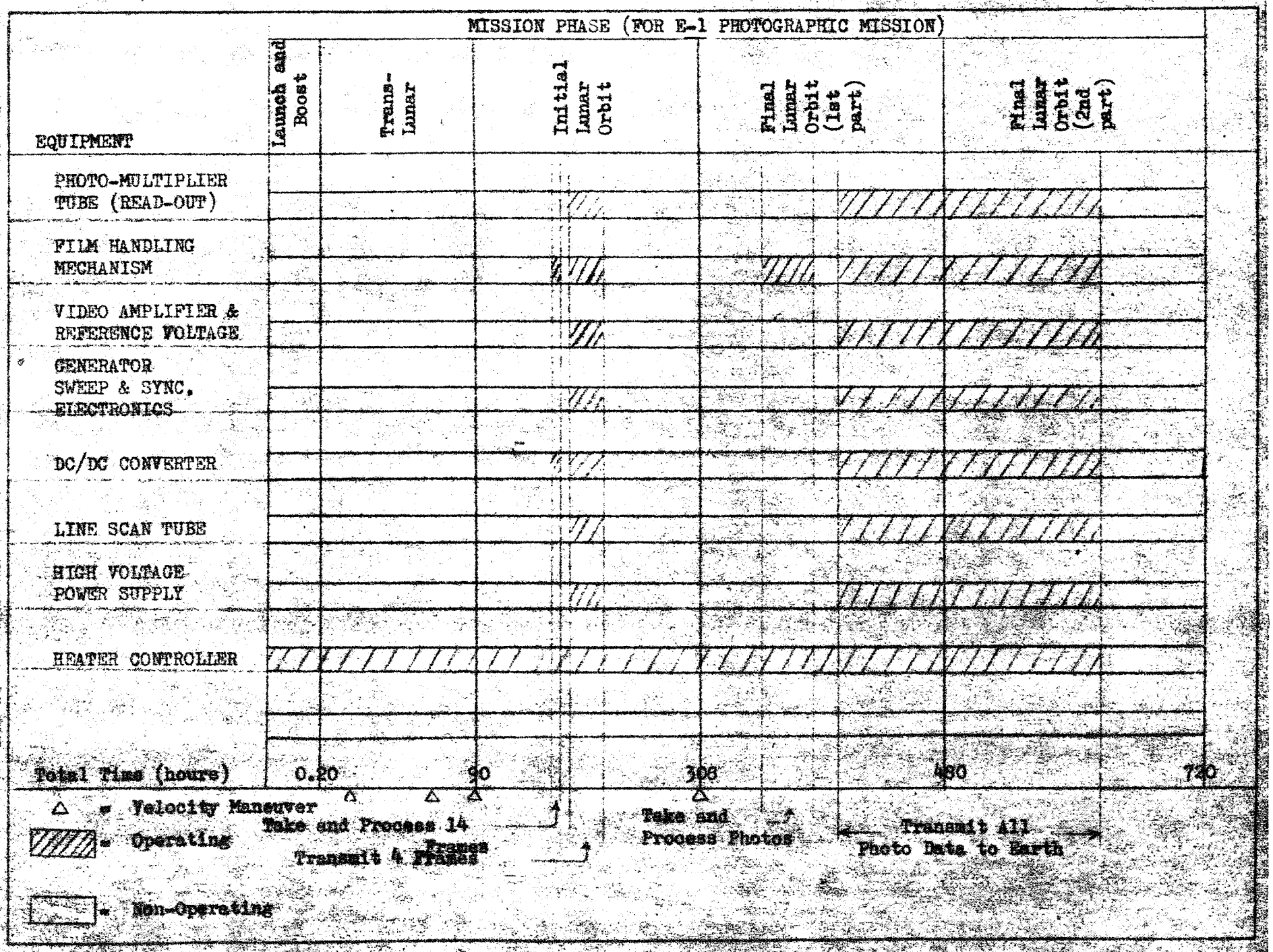
MISSION PHASE (FOR E-1 PHOTOGRAPHIC MISSION)
EQUIPMENT
Launch and Boost
Trans-Lunar
Initial Lunar Orbit
Final Lunar Orbit (1st part)
Final Lunar Orbit (2nd part)
PHOTO-MULTIPLIER TUBE (READ-OUT)
FILM HANDLING MECHANISM
VIDEO AMPLIFIER & REFERENCE VOLTAGE
GENERATOR SWEEP & SYNC. ELECTRONICS
DC/DC CONVERTER
LINE SCAN TUBE
HIGH VOLTAGE POWER SUPPLY
HEATER CONTROLLER
Total Time (hours)
0.20
90
308
480
720
= Velocity Maneuver
= Operating
= Non-Operating
Take and Process 14 Frames
Transmit 4 Frames
Take and Process Photos
Transmit All Photo Data to Earth

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
High Voltage Power Supply	K=140 D=1	K=1 D=20	K=1 D=21	K=1 D=60	K=1 D=.66	
λ = .000002 f=	.000046	.000036	.000092	.000206	.000316	Σf = .000706 R = .9993
Heater Controller	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = .000002 f=	.000056	.000180	.000436	.000344	.000480	Σf = .001496 R = .9986
Command, Control & Programming	K=140 D=1	K=1 D=20	K=1 D=21	K=1 D=60	K=1 D=.66	
λ = .000006 f=	.000168	.000108	.000264	.000618	.000948	Σf = .002106 R = .9979
Film	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = .0000013 f=	.000036	.000023	.000283	.000224	.000312	Σf = .000878 R = .9991
N_2 Gas Make-Up Assembly	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = .000001 f=	.000028	.000090	.000218	.000172	.000240	Σf = .000748 R = .9993
	K= D=	K= D=	K= D=	K= D=	K= D=	
λ = f=						Σf = R =
Column Sum	.013840	.009630	.024504	.026519	.021458	
Column Reliability	.9862	.9904	.9758	.9738	.9787	
Cumulative Sum	.013840	.023470	.047974	.074493	.095951	.095951
Cumulative Reliability	.9862	.9769	.9531	.9282	.9085	R = .9085

PHOTOGRAPHIC SUBSYSTEM - RELIABILITY SUMMARY (SHEET 3 OF 3)

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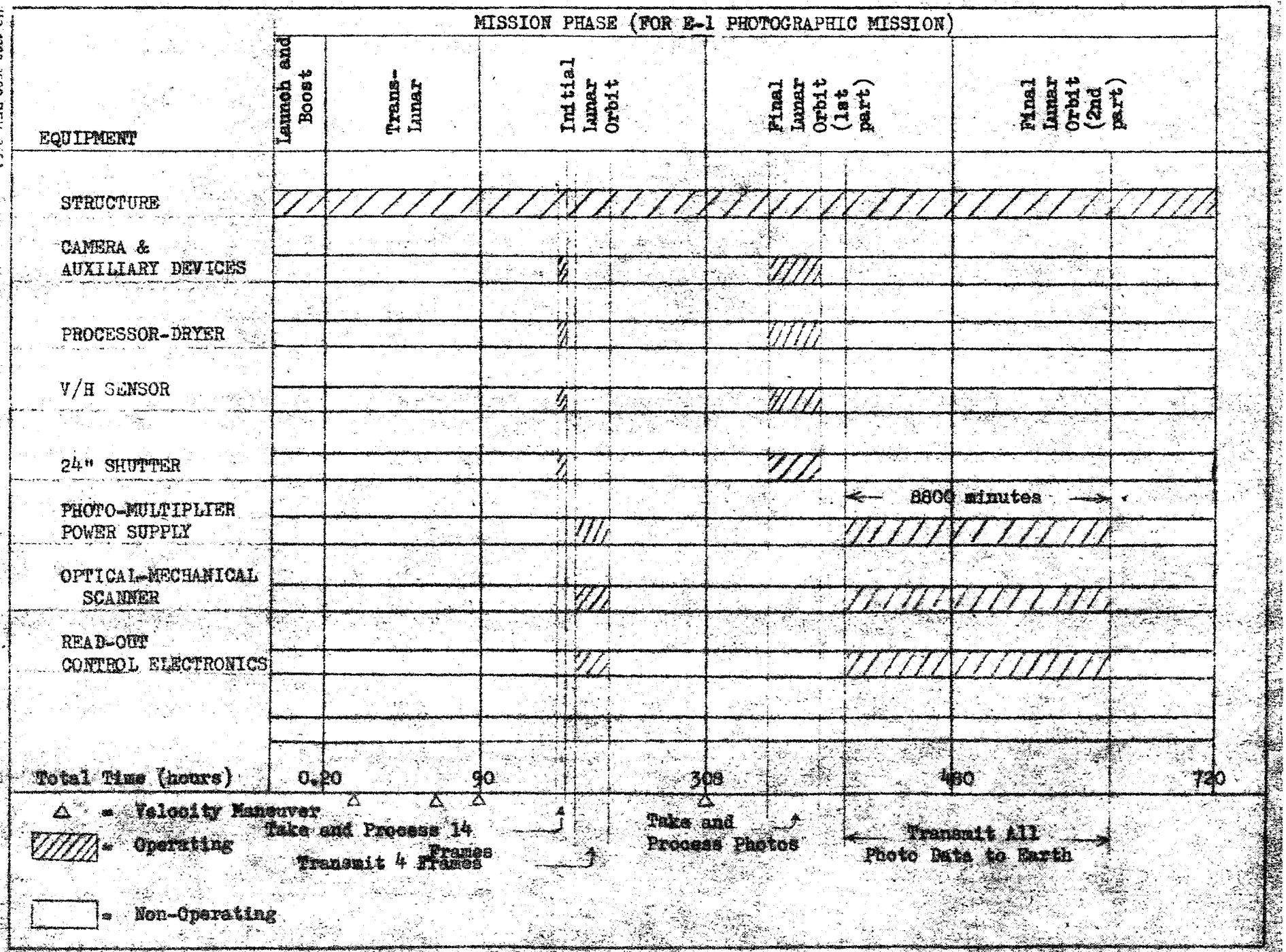
Source of Failure Rate Data used in the Lunar Orbiter Photo Subsystem

Part	Derating	$\lambda \times 10^6$	Source
Bearings	20%	.20	(2)
Brake	-	5.00	(4)
Bushing (Ball)	20%	.20	(2)
Capacitor	50% & 40°C	.011	(1) Section 2 Page 3
Choke	100% & 30°C	.10	(1) Section 9 Page 4
Clutch	-	5.00	(4)
Connector	-	.09	(4)
Diode (Gen. Purpose)	TJ = 30°C	.002	(1) Section 6 Page 4
Diode (Med. Power)	TJ = 44°C	.05	(1) Section 6 Page 3
Diode (SCR)	TJ = 90°C	.10	(1) Section 6 Page 3
Encoder	100% & 25°C	1.00	(1) Section 1 Page 7 & Section 12 Page 2
Filter	50% & 40°C	.011	(1) Section 2, Page 3
Fuse	-	.50	(1) Section 15, Page 2
Gears	20%	.40	(2)
Heater	-	5.00	(5)
Inductor	100% & 30°C	.10	(1) Section 9 Page 4
Lamp (Indicator)	-	1.00	(4)
Line Scan Tube	-	30.00	(4)
Mag. Amplifier	-	.50	(1) Section 15 Page 2
Motor A.C.	-	15.00	(6)
Motor D.C.	-	15.00	(6)
Photo Mult. Tube	-	10.00	(4)
Potentiometer	50% & 25°C	1.00	(1) Section 11 Page 7
Reducer (Speed)	20%	.40	(2)
Relay	100% & 25°C	.50	(1) Section 10 Page 4
Resistor	50% & 25°C	.001	(1) Section 11 Page 2
Solenoid	-	.20	(1) Section 15 Page 2
Switch	100% & 25°C	1.00	(1) Section 12 Page 2
Tachometer	-	10.00	(4)
Thermistor	-	.30	(4)
Transformer	-	.15 to 1.00	(4)
Transistor (Gen. Purpose)	TJ = 75°C	.01	(1) Section 14 Page 2
Transistor (Hi Power)	TJ = 90°C	.05	(1) Section 14 Page 8

(1) BC-14134 "Minuteman Electronic Part Failure Rates" Volume I - latest revision July 1964

(2) λ = 1.00/million hours was provided by Eastman Kodak from data supplied by NASA notebook dated 31 January 1963. Due to very light loading, low 2.N, controlled environment, ideal operating conditions, and wide latitude of allowable performance, this failure rate was reduced by a factor of .5.


MISSION PHASE (FOR E-1 PHOTOGRAPHIC MISSION)
EQUIPMENT
Launch and Boost
Trans-Lunar
Initial Lunar Orbit
Final Lunar Orbit (1st part)
Final Lunar Orbit (2nd part)
STRUCTURE
CAMERA & AUXILIARY DEVICES
PROCESSOR-DRYER
V/H SENSOR
24" SHUTTER
PHOTO-MULTIPLIER POWER SUPPLY
OPTICAL-MECHANICAL SCANNER
READ-OUT CONTROL ELECTRONICS
8800 minutes
Total Time (hours)
0.20
90
308
480
720
Velocity Maneuver
Operating
Take and Process 14 Frames
Transmit 4 Frames
Take and Process Photos
Transmit All Photo Data to Earth
Non-Operating

Lunar Orbiter - Photo Subsystem

Structure and Optics

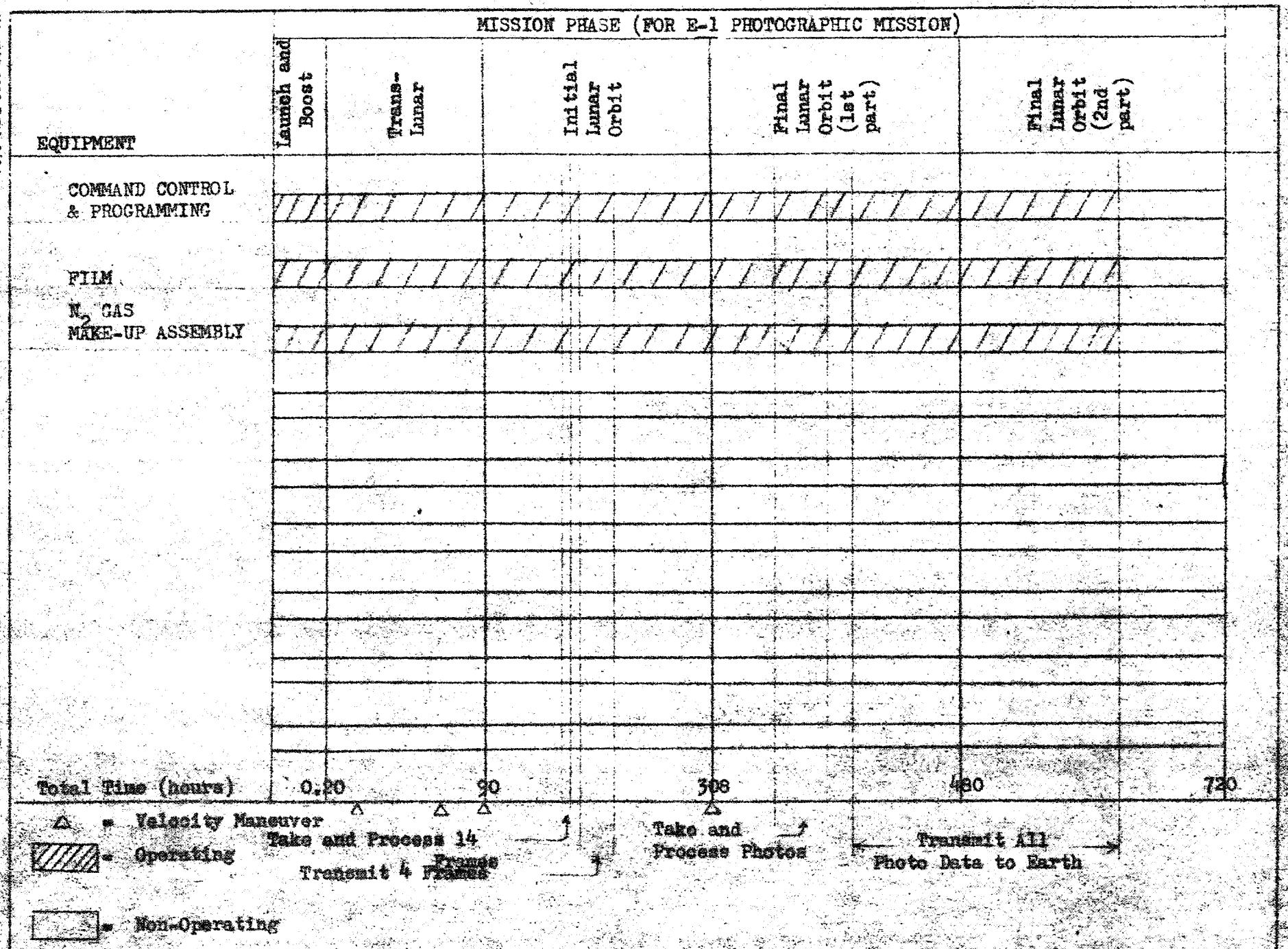
Function: This functional block includes the basic structure pressure shell, pressure seals and exhaust valve.

Predicted λ = .000009/hr

Part Type	n	$\lambda/10^6$		$n\lambda$
Optics	1	1	1	1
Internal Structure	1	1	1	1
Pressure Shell	1	1	1	1
Shell Seal	1	5	2	5
Exhaust Valve	1	1	2	1
			TOTAL	9×10^{-6}

Source of failure rate data: 1 → Engineering Judgement

2 → AVCO Reliability Data Series



US 4288 2000 REV 1/3/64 PHOTOGRAPHIC SUBSYSTEM - SEQUENCE TIME BAR GRAPHS

REV SYM C

BOEING NO. D2-100255

Lunar Orbiter - Photo Subsystem

Processor-Dryer - Eastman Kodak Specification No. 12[illegible]-107

Function:

Predicted $\lambda = 66.71$

Part Type	n	$\lambda/10^6$ hr	$n\lambda$
Capacitors	9	.011	$.10 \times 10^{-6}$
Diodes	2	.002	.02
Motors D.C.	1	15.00	15.00
Resistors	32	.001	.03
Thermistors	5	.30	1.50
Transistors	17	.01	.17
Heater	2	5.00	10.00
Connectors	1	.09	.09
Switches	2	1.00	2.00
Fuses	2	.50	1.00
Bearings	64	.20	10.00
Motor A.C.	1	15.00	15.00
Clutch	1	5.00	5.00
Encoders	4	1.00	4.00
Gears	5	.40	2.00
		TOTAL	66.71×10^{-6}

(3) λ = 2.0/million hours provided by Eastman Kodak from the RADC Notebook, dated 31 January 1963 has been reduced by a factor of 5. Many of the gears serve only a controlling function, transmitting a fraction of allowable power. As cam drives these gears are intermittently loaded for short portions of their operating cycles.

(4) This failure rate supplied by Eastman Kodak (see Photo Subsystem Monthly Technical Status Report 3 November 1964) and derived from RADC Notebook dated 31 January 1963.

(5) Failure rate supplied by Eastman Kodak. No other source of data for this item has been determined.

(6) Based on data from unpublished Minuteman field data available through the Boeing reliability data central.

E

Lunar Orbiter - Photo Subsystem

24" Shutter - Eastman Kodak Specification No. 1225-130

Function:

Predicted $\lambda = 37.40 \times 10^{-6}$/hr

Part Type	n	$\lambda/10^6$	$n\lambda$
Switch	6	1.00	6.00×10^{-6}
Clutch	1	5.00	5.00
Brake	1	5.00	5.00
Relay	5	.50	2.50
Solenoid	1	.20	.20
Motor, D.C.	1	15.00	15.00
S.C.R.	1	.10	.10
Gears	1	.40	.40
Reducers	2	.40	.80
Ball Bearings	12	.20	2.40
		TOTAL	37.40×10^{-6}

Lunar Orbiter - Photo Subsystem

Camera and Auxiliary Devices - Eastman Kodak Specification No. 1225-106

Assumption:

Predicted $\lambda = 128.84 \times 10^{-6}$/hr

Part Type	n	$\lambda/10^6$hr	n λ
Connector	2	.09	$.18 \times 10^{-6}$
Diodes	74	.002	.15
Filter	6	.011	.07
Motors, D-C	5	15.00	75.00
Resistors	144	.001	.14
Transistors	44	.01	.44
Transformer	1	1.00	1.00
Sounders	5	1.00	5.00
Lamps, Indicator	21	1.00	21.00
Brake	1	2.00	2.00
Capacitor	36	.011	.36
Bearings	65	.20	13.00
Switch	3	1.00	3.00
Relay	1	.50	.50
Gears	10	.40	4.00
		209.1	128.84×10^{-6}

Lunar Orbiter - Photo Subsystem

Optical - Mechanical Counter - Eastman Kodak Specification No. 1/75-132

Function:

Predicted λ = 23.80 x 10^{-6}

Part Type	n	$\lambda/10^6$	$n\lambda$
Motor	1	15.00	15.00 x 10^{-6}
Switches	1	1.00	1.00
Bearings	31	.20	6.20
Clutch	1	5.00	5.00
Gears	4	.40	1.60
			TOTAL 23.80 x 10^{-6}

E

Lunar Grotter - Photo Subsystem

V/H Sensor - Eastman Kodak Specification No. 1225-105

Function:

Predicted λ = 76.26 x 10^{-6}/hr

Part Type	n	$\lambda/10^{-6}$	$n\lambda$
Capacitors	99	.011	1.10 x 10^{-6}
Connectors	3	.09	.27
Diodes	15	.002	.03
Tachometer	1	10.00	10.00
Motors, D.C.	4	15.00	45.00
Potentiometers	1	1.00	1.00
Relays	1	.50	.50
Resistors	371	.001	.33
Transformers	1	1.00	1.00
Transistors	143	.01	1.43
[illegible]	1	10.00	10.00
[illegible]	15	[illegible]	[illegible]
Gears	6	.40	.40
		TOTAL	76.26 x 10^{-6}

Lunar Orbiter - Photo Subsystem

Photomultiplier Tube (Read-out) - Eastman Kodak Specification No. 12[illegible]5-121

Constant

Predicted $\lambda = 10.0 \times 10^{-6}$

Lunar Orbiter - Photo Subsystem

Photomultiplier Power Supply - Eastman Kodak Specification No. [illegible]-125

Function:

Predicted $\lambda = .89 \times 10^{-6}$/hr

Part Type	n	$\lambda/10^{-6}$	$n\lambda$
Capacitors	2	.011	$.02 \times 10^{-6}$
Connectors	2	.09	.18
Diodes	2	.05	.10
Resistors	13	.001	.01
Transformers	2	.25	.50
Transistors	8	.01	.08
		TOTAL	$.89 \times 10^{-6}$

Lunar Orbiter - Photo Subsystem

Video Amplifier and Reference Voltage Generator

Function:

Predicted $\lambda = 1.19 \times 10^{-6}$/hr.

Part Type	n	$\lambda/10^6$	$n\lambda$
Capacitors	39	.011	$.43 \times 10^{-6}$
Connectors	1	.09	.09
Diodes	40	.002	.08
Resistors	156	.001	.15
Transistors	44	.004	.04
		TOTAL	1.19×10^{-6}

Lunar Orbiter - Photo Subsystem

Read-Out Control Electronics - Eastman Kodak Specification No. 1225-133

Function:

Predicted λ - 1.07×10^{-6}/hr

Part Type	n	$\lambda/10^{6}$	$n\lambda$
Capacitors	20	.011	$.22 \times 10^{-6}$
Connectors	1	.09	.09
Diodes	14	.002	.03
Resistors	20	.001	.03
Relay	1	.50	.50
Transistors	20	.01	.20
		TOTAL	1.07

Lunar Orbiter - Photo Subsystem

DC/DC Converter - Eastman Kodak Specification No. 1225-136

Function:

Predicted: $\lambda = 8.26 \times 10^{-6}$/hr

Part Type	n	$\lambda/10^{-6}$	$n\lambda$
Capacitors	18	.011	$.20 \times 10^{-6}$
Connectors	2	.09	.18
Diodes 1	54	.05	2.70
Relays	1	.50	.50
Resistors	79	.001	.08
Transistors 1	33	.05	1.65
Transformers	7	various	1.[illegible]3
Inductors	7	.10	.70
Sec. Amplifier	2	.50	1.00
		TOTAL	8.26×10^{-6}

1 → Consider Hi Power

Lunar Orbiter - Photo Subsystem

Film Handling Mechanism - Eastman Kodak Specification No. 1238-209

Function:

Predicted λ - 80.51 x 10^{-6}/hr.

Part Type	n	$\lambda/10^6$	$n\lambda$
Connectors	3	.09	.27 x 10^{-6}
Diodes	1	.002	.002
Filters	4	.011	.04
Motors, D.C.	2	15.00	30.00
Potentiometers	3	1.00	3.00
Switches	4	1.00	4.00
Ball Bearings	89	.20	17.80
Clutches	1	5.00	5.00
Gears	23	.40	9.20
Ball Bushings	1	.20	.20
Brake	2	5.00	10.00
Speed Reducer	1	.40	.40
			80.51 x 10^{-6}

Lunar Orbiter - Photo Subsystem

High Voltage Power Supply - Eastman Kodak Specification No. 1225-111

Function:

Predicted $\lambda = 2.16 \times 10^{-6}$/hr

Part Type		n	$\lambda/10^6$	$n\lambda$
Capacitors		19	.011	$.21 \times 10^{-6}$
Connectors		2	.09	.18
Diodes	1	17	.05	.85
Resistors		22	.001	.02
Transformers		2	.25	.50
Transistors	1	6	.05	.30
Inductors		1	.10	.10
			TOTAL	2.16×10^{-6}

1 - Consider Hi Power

Lunar Orbiter - Photo Subsystem

Sweep and Sync Electronics - Eastman Kodak Specification No. 1285-124

Function:

Predicted $\lambda = 3.04 \times 10^{-6}$/hr

Part Type	n	$\lambda/10^6$	$n\lambda$
Capacitors	62	.011	$.68 \times 10^{-6}$
Connectors	1	.09	.09
Diodes	56	.002	.11
Resistors	194	.001	.19
Thermistors	1	.30	.30
Transformers	1	1.00	1.00
Coils	2	.10	.20
Potentiometers	47	.01	.47
		TOTAL	3.04×10^{-6}

Lunar Orbiter - Photo Subsystem

Command, Control and Programming - Eastman Kodak Specification No. 1225-134

Function:

Predicted λ = 6.01 x 10^{-6}/hr

Part Type	n	$\lambda/10^6$	$n\lambda$
Capacitors	152	.011	1.67 x 10^{-6}
Connectors	3	.09	.27
Diodes	348	.002	.70
Resistors	712	.001	.71
Transformers	5	.15	.75
Transistors	191	.01	1.91
		TOTAL	6.01 x 10^{-6}

E ↓

Lunar Orbiter - Photo Subsystem

Line Scan Tube - Eastman Kodak Specification No. 1285-116

Function:

Predicted $\lambda = 30 \times 10^{-6}$/hr

Source of Failure Rate Data: Eastman Kodak letter 1-002909-RM, no other source available

Lunar Orbiter - Photo Subsystem

N_2 Gas Make-up Assembly - Eastman Kodak Specification W1225-133

Function: To maintain N_2 pressurization within the Photographic Subsystem.

Predicted $\lambda = 1.07 \times 10^{-6}$/hr.

Part Type	n	$\lambda/10^6$	$n\lambda$
Gas Storage Tank	1	.07	.07
Pressure Control Valve (includes Absolute Pressure Regulator, Flow Control Valve, Fill Valve, Rupture Safety Disk)	1	1.0	1.0
		Total	1.07×10^{-6}

E

Lunar Orbiter - Photo Subsystem

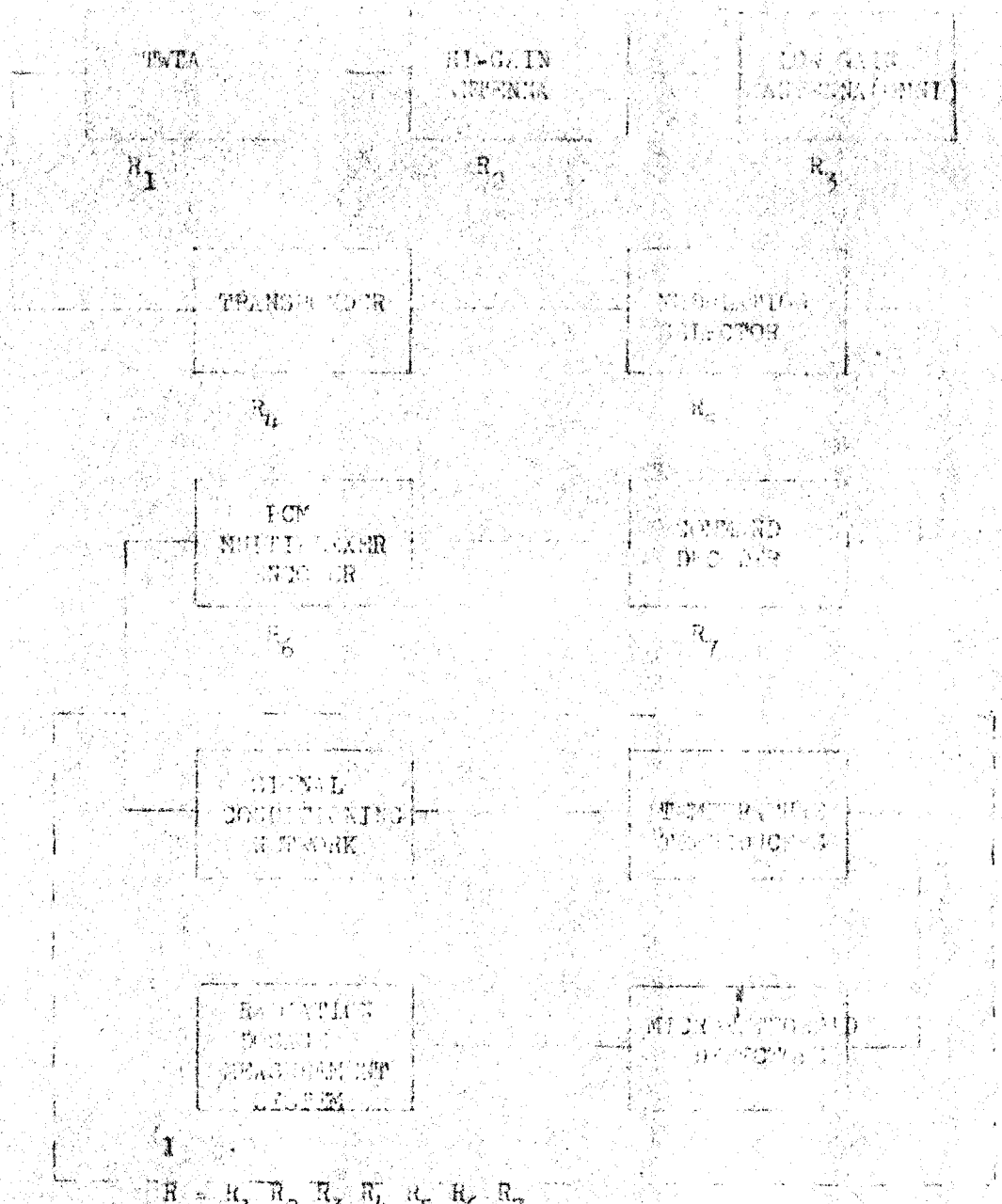
Heater Controller - Eastman Kodak Specification No. 1225-116

Function:

Predicted $\lambda = 1.62 \times 10^{-6}$/hr

Part Type		n	$\lambda/10^6$	$n\lambda$
Capacitors		1	.011	$.01 \times 10^{-6}$
Diodes	1	1	.05	.05
Fuses		2	.50	1.00
Resistors		11	.001	.01
Thermistors		1	.30	.30
Transistors	1	5	.05	.25
				TOTAL 1.62×10^{-6}

1 → Consider HI Power



$R = R_1 R_2 R_3 R_4 R_5 R_6 R_7$

1 Equipment within dotted lines is not mission critical for the 30 day E-1 photographic mission.

COMMUNICATIONS SUBSYSTEM - RELIABILITY BLOCK DIAGRAM

Lunar Orbiter - Photo Subsystem

Film

Function:

Reliability = 0.999 (Operational Phases) [1]
= 0.999 (Launch Phase) [1]

Mission Reliability = (0.999) (0.999) = 0.998

[1] Eastman Kodak (Ref: L-000825-KU).

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Omni Antenna	K= 140 D= 1	K=1 D=1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
$\lambda = 0.1 \times 10^{-6}$ f=	.000003	.000009	.000022	.000017	.000024	Σf = .000075 R = .9998
PCM Multiplexer Encoder	K= 140 D= 1	K=1 D=1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
$\lambda = 21.4 \times 10^{-6}$ f=	.000600	.001924	.004671	.003685	.005148	Σf = .016023 R = .9841
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
λ = f=	K= D=	K= D=	K= D=	K= D=	K= D=	Σf = R =
Column Sum	.002181	.006169	.015077	.012605	.017755	
Column Reliability	.9978	.9939	.9850	.9875	.9825	
Cumulative Sum	.002181	.008350	.023427	.036032	.053787	.053787
Cumulative Reliability	.9978	.9917	.9769	.9646	.9476	R = .9476

COMMUNICATIONS SUBSYSTEM - RELIABILITY SUMMARY (SHEET 2 OF 3)

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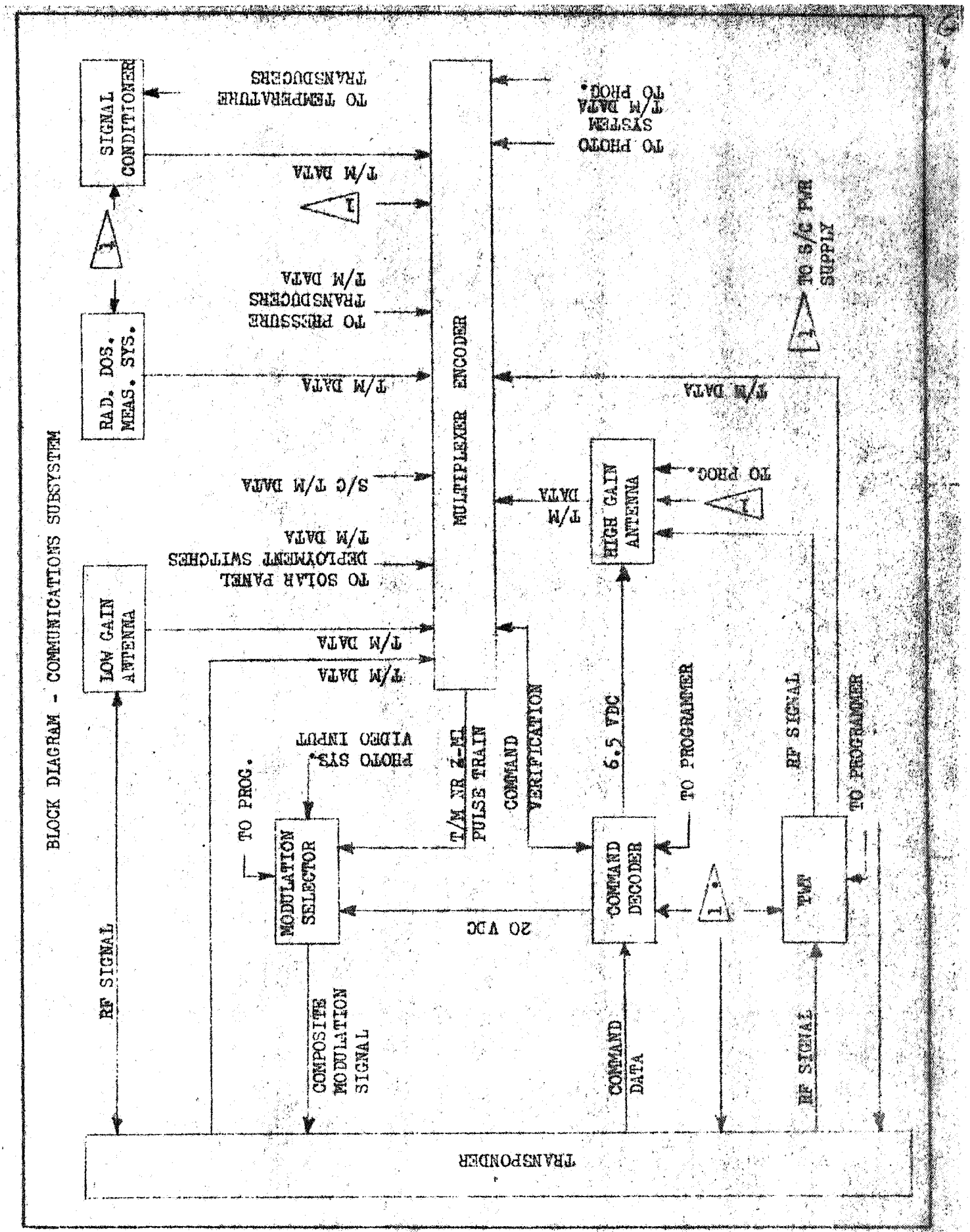
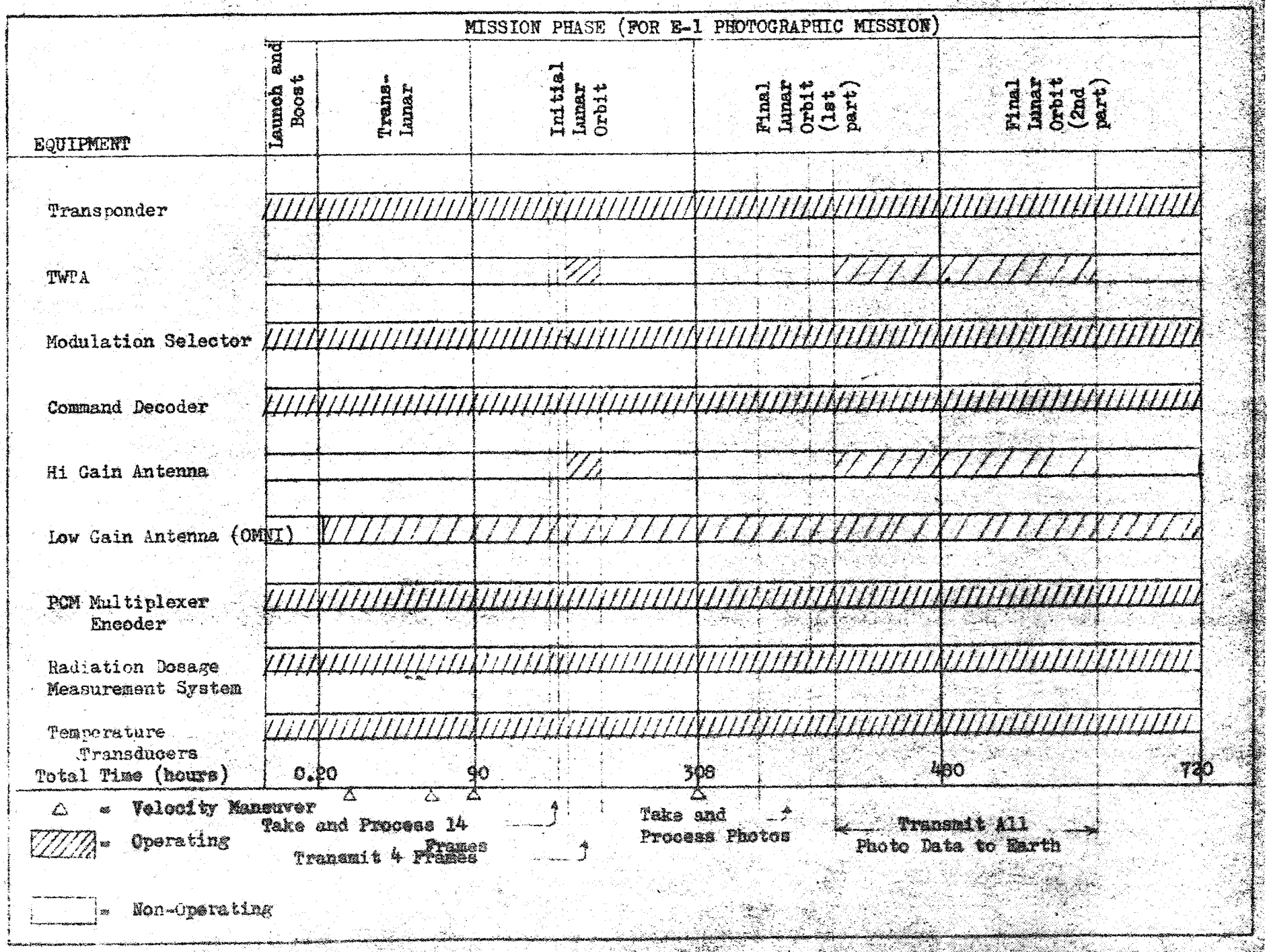


U3 4288 2000 REV. 3/64 COMMUNICATIONS SUBSYSTEM FUNCTIONAL BLOCK DIAGRAM


MISSION PHASE (FOR E-1 PHOTOGRAPHIC MISSION)
EQUIPMENT
Launch and Boost
Trans-Lunar
Initial Lunar Orbit
Final Lunar Orbit (1st part)
Final Lunar Orbit (2nd part)
Transponder
TWTA
Modulation Selector
Command Decoder
Hi Gain Antenna
Low Gain Antenna (OMNI)
PCM Multiplexer Encoder
Radiation Dosage Measurement System
Temperature Transducers
Total Time (hours)
0.20
90
308
480
720
= Velocity Maneuver
= Operating
Take and Process 14 Frames
Transmit 4 Frames
Take and Process Photos
Transmit All Photo Data to Earth
= Non-Operating

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Transponder	K= 140 D= 1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = 32.45 x 10^{-6} f=	.000909	.002914	.007074	.005521	.007768	$\sum f$ = .024266 R = .9760
TWTA	K= 140 D= 1	K=1 D=.2	K=1 D=.2	K=1 D=.60	K=1 D=.66	
λ = 11.5 x 10^{-6} f=	.000322	.000207	.000506	.001137	.001922	$\sum f$ = .004044 R = .9960
Modulation Selector	K= 140 D= 1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = 5.3 x 10^{-6} f=	.000148	.000476	.001155	.000912	.001272	$\sum f$ = .003963 R = .9941
Command Decoder	K= 140 D= 1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = [1] f=	.000037	.000120	.000291	.000231	.000321	$\sum f$ = .001000 R = .9990
Hi-Gain Antenna (and Control Electronics)	K= 140 D= 1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = 3.77 x 10^{-6} f=	.000106	.000339	.000822	.000643	.000905	$\sum f$ = .002820 R = .9972
Secondary Power Supply (Comm. Package "A")	K= 140 D= 1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = 2.0 x 10^{-6} f=	.000056	.000180	.000536	.000574	.000430	$\sum f$ = .001596 R = .9984
	K= D=	K= D=	K= D=	K= D=	K= D=	
λ = f=						$\sum f$ = R =

[1] - See Page 63

COMMUNICATIONS SUBSYSTEM- RELIABILITY SUMMARY (SHEET 1 OF)

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Lunar Orbiter - Communications Subsystem

Transponder 10-70052

Function: To provide a phase-locked S-band receiver, a telemetry transmitter and a turn-around lunar ranging loop.

Predicted $\lambda = 32.45 \times 10^{-6}$

Part Type	n	$\lambda \times 10^{-6}$	1	$n\lambda$
Capacitor				
Ceramic	197	.018		3.546×10^{-6}
Variable-Air	69	.05		3.450
Glass	98	.076		7.448
Solid Tantalum	33	.002		.066
Paper	10	.068		.680
Tantalum Foil	4	.002		.008
Variable Glass	2	.05		.100
Resistor				
Carbon Composition	343	.001		.343
Metal Film	114	.0001		.012
Transistor				
Silicon, Gen.Purpose	91	.05		4.550
Power	2	.05		.100
Diode				
Gen. Purpose	85	.005		.25
Power	1	.02		.020
Zener	5	.05		.250
Thermistor	1	.03		.030
RF Coil	72	.012		.864
Filter	24	.035		.430
Transformer	48	.15		7.200
Crystal, quartz	2	.03		.060
Relay	2	.06		.120
Connector RF	35	.03		1.050
RF Cavity	3	.1		.300
Solder Joints	1200	.0008		.960
Connector	31 pins	.001/pin		.031
			TOTAL	32.45

1 — See Section 9.0

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Radiation Dosage Measurement System	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
$\lambda = 11.02 \times 10^{-6}$/hr f=	.000309	.000986	.002402	.001895	.002645	$\sum f$ = .008237 R = .992
Temperature Transducers	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
$\lambda = .232 \times 10^{-6}$/hr. f=	.000006	.000021	.000051	.000040	.000056	$\sum f$ = .000174 R = .999
Signal Conditioner	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
$\lambda = .12 \times 10^{-6}$/hr. f=	.000003	.000010	.000026	.000020	.000023	$\sum f$ = .000087 R = .999
Micrometeoroid Detectors	K=140 D=1	K=1 D=1	K=1 D=1	K=1 D=1	K=1 D=1	
λ = f=						$\sum f$ = R = .998
	K= D=	K= D=	K= D=	K= D=	K= D=	
λ = f=						$\sum f$ = R =
	K= D=	K= D=	K= D=	K= D=	K= D=	
λ = f=						$\sum f$ = R =
Column Sum						
Column Reliability						
Cumulative Sum						
Cumulative Reliability						R = .939 [1]

[1] The equipments on this page do not contribute to gathering the M-1 mission photographic data. Therefore this reliability is not considered when calculating the M-1 mission reliability.

COMMUNICATION SUBSYSTEM - RELIABILITY SUMMARY (SHEET 3 OF 3)

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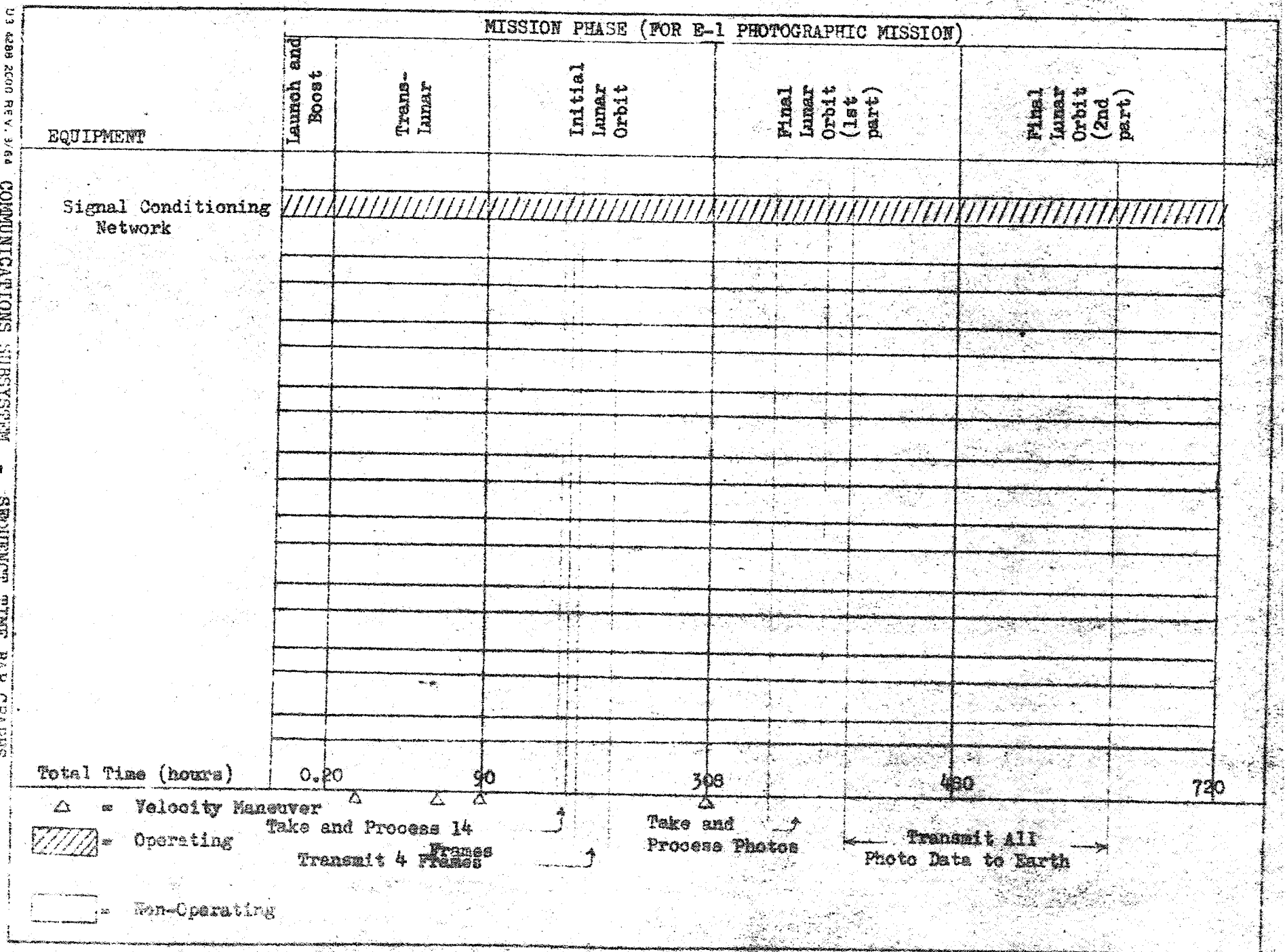
Lunar Orbiter - Communications Subsystem (continued)

Part Type	$\lambda/10^6$hr	[1]	n	n λ
TELEMETRY				
Capacitor	.002		10	.020
Resistor	.001		15	.015
Diode	.025		15	.375
Xtals & Others	.067		6	.400
			SUBTOTAL	0.81
Traveling Wave Tube	7.3	[2]	1	7.3
			TOTAL	11.48

[1] See Section 9.0

[2] Based on supplier data presented at Preliminary Design Review


MISSION PHASE (FOR E-1 PHOTOGRAPHIC MISSION)
EQUIPMENT
Launch and Boost
Trans-Lunar
Initial Lunar Orbit
Final Lunar Orbit (1st part)
Final Lunar Orbit (2nd part)
Signal Conditioning Network
Total Time (hours)
0.20
90
308
480
720
Take and Process 14 Frames
Transmit 4 Frames
Take and Process Photos
Transmit All Photo Data to Earth
= Velocity Maneuver
= Operating
= Non-Operating

Lunar Orbiter - Communication Subsystem

Secondary Power Supply for Communication Package "A" RCA Drawing # 1756494

Function: Provide regulated power to the modulator selector, command decoder, and antenna control electronics.

Predicted $\lambda = 2.0 \times 10^{-6}$

Part Type	n	$\lambda \times 10^{-6}$ [1]	$n\lambda$
Transistor			
Si, General Purpose	12	.05	$.60 \times 10^{-6}$
Inductor	5	.03	.15
Capacitor			
Solid Tantalum	16	.003	.032
Resistor			
Variable-wire wound	1	.4	.40
Carbon Composition	25	.001	.025
Power, wire wound	2	.006	.012
Metal Film	9	.0001	.001
Diode			
Si, General Purpose	18	.005	.090
Transformer	1	.2	.20
Fuse	5	.05 [2]	.25
Solder Joint	280	.0008	.224
Connector	31 pins	.001/pin	.031
		TOTAL	2.01×10^{-6}

1 See Section 9.0

2 AVCO Reliability Data Series - Failure Rates, Page 74.

G-1

Lunar Orbiter - Communications Subsystem

Traveling Wave Tube Amplifier (TWTA) 10-70051

Function: Used with the high gain antenna during the high power mode to provide for transmission of photographic data simultaneously with performance and environmental data.

Predicted $\lambda = 11.5 \times 10^{-6}$/hr.

Part Type	$\lambda/10^6$hr	[1]	n	n
POWER SUPPLY				
Resistor				
Power-WW	.006		13	.078
Metal Film	.0001		38	.004
Carbon Composition	.001		1	.001
Capacitor				
Ceramic	.02		5	.10
Tantalum Foil	.002		4	.008
Solid Tantalum	.002		12	.024
Mica	.004		5	.020
Transistor				
Power	.05		6	.30
General Purpose	.05		10	.50
Diode				
Power	.02		5	.10
Medium Power	.03		30	.90
Zener	.05		7	.35
Transformer	.142		3	.426
Choke	.035		5	.175
Saturable Reactors	.05		3	.15
Solder Joints	.0008		300	.24
			SUBTOTAL	3.57

[1] See Section 9.0

Lunar Orbiter - Communications Subsystem

High Gain Antenna and Position Controller 10-70050

Function: Used with the TTA during the high power mode to provide for the transmission of photographic data simultaneously with performance and environmental data.

Predicted $\lambda = 3.77 \times 10^{-6}$

Part Type	n	$\lambda \times 10^{-6}$ |3		$n\lambda$
Structure	1	approaches 0	1	0×10^{-6}
Gear	3	.10	2	.30
Bearing	4	.40	2	1.60
Encoder	1	.22	2	.22
Motor, Stepper	1	.22	2	.22
Capacitor, Solid Tantalum	4	.002		.008
Diode				
Silicon, Gen Purpose	24	.005		.120
Transistor, Si, Gen. Purpose	4	.05		.20
Resistor				
Metal Film	12	.001		.012
Carbon Composition	2	.001		.002
Power, Wire Wound	2	.006		.012
Relay	4	.237		1.0[illegible]
Connector, Coaxial	1	.003/pin		.003
Connector	44 pins	.001/pin		.044
			TOTAL	$3.[illegible] \times 10^{-6}$

1 This reliability figure does not consider the reliability of the antenna deployment mechanism. Deployment mechanisms are covered as part of the structures and mechanisms subsystem.

2 AVCO Reliability Data Series - Failure Rate [illegible], 72, [illegible].

3 See Section 9.0 for electronic part failure rates.

Lunar Orbiter - Communication Subsystem

Command Decoder 10-70061

Function: To accept the phase - demodulated output from the transponder and provide electronic circuits to demodulate coded subcarriers, decode spacecraft identity, provide digital command storage, and provide serial command word outputs upon interrogation.

Predicted $\lambda = 7.3 \times 10^{-6}$ (one channel), R = .999 [2]

Part Type	$\lambda/10^6$ hr [1]	n	$n\lambda$
Capacitor			
Solid T_a	.002	11	.022
Diode			
Si Switch	.005	18	.09
Zener	.05	3	.15
Resistor			
Metal Film	.0001	80	.008
Transistor			
Si Switch	.05	25	1.25
Digital Logic Circuits	.087 [3]	65	5.655
Connector	.001/pin	111 pins	.111
		TOTAL	7.286

[1] See Section 9.0

[2] $R_{1\ channel} = e^{-\lambda t} = e^{-7.3 \times 10^{-6} \times 748} = .995$

With dual channel redundancy,

$R_{Total} = 1 - (1-.995)^2 \cong .999.$

[3] Failure rate based on Fairchild, MIT and in-house test data

Lunar Orbiter - Communications Subsystem

PCM Multiplexer - Encoder 10-72000

Function: To sequentially sample, condition and combine analog and digital information into a PCM pulse train for subsequent transmission from the spacecraft to earth.

Predicted λ = 21.43×10^{-6}/hr.

Part Type	n	$\times 10^{-6}$ [1]	$n\lambda$
Transistor			
Switch	400	.02	8.00
Gate	40	.05	2.00
Diode			
Logic	1909	.0006	1.145
Zener	9	.05	.45
Power	12	.02	.24
Resistor			
Composition	1315	.001	1.315
Metal Film	52	.0001	.005
Capacitor			
Ceramic	241	.018	4.338
Tantalum	39	.002	.078
Plastic	3	.068	.204
Transformer			
Pulse	57	.02	1.40
Power	2	.15	.30
Solder Joints	2451	.0008	1.96
		TOTAL	21.43

[1] See Section 9.0

Lunar Orbiter - Communications Subsystem

Low Gain Antenna (OMNI) - D2-100190

Function: Used with the transponder to transmit performance telemetry and ranging information, and to receive commands from the DSIF.

Predicted $\lambda = 0.1 \times 10^{-6}$

Part Type	$\lambda \times 10^{-6}$		n	$n\lambda$
Structure	approaches 0	1	1	0×10^{-6}
Bellows	.09	2	1	.09
Connector Coaxial	.003/pin	2	1	.003
			TOTAL	$.09 \times 10^{-6}$

1 - This reliability figure does not consider the reliability of the antenna deployment mechanism. Deployment mechanisms are covered as part of the structures and mechanisms subsystems.

2 - AVCO Reliability Data Series - Failure Rate, Pages 70 and 72

Lunar Orbiter - Communications Subsystem

Signal Conditioner D2-100193

Function: To take the output of the temperature transducers and transform it such that it can be accepted by the multiplexer encoder.

Predicted $\lambda = .12/10^6$ hrs.

Part Type	n	$\lambda \times 10^{-6}$ [1]	$n\lambda$
Precision Metal Film Resistor	18	.0001	$.0018 \times 10^{-6}$
Solid Tantalum Capacitor	8	.002	.0160
Zener Diode	1	.05	.05
Solder Joints	23	.001	.023
Welded Joints	43	.001	.0043
Connector	25 pins	.001/pin	.025
		TOTAL	$.120 \times 10^{-6}$

[1] See Section 9.0 for failure rate data.

Lunar Orbiter - Communications Subsystem

Radiation Dosage Measurement System 10-72003

Function: To semi-quantitatively ascertain the spacecraft exposure to energetic particles and gamma radiation.

Predicted $\lambda = 11.02 \times 10^{-6}$/hr.

Part Type	n	$\lambda \times 10^{-6}$ [1]	$n\lambda$
Photomultiplier Tube	2	.50	1.0
Diodes			
Si, Gen Purpose	83	.005	.415
Zener	7	.05	.350
Capacitor			
Ceramic	74	.018	1.133
Tantalum	10	.002	.020
Glass	4	.076	.304
Resistor			
Metal Film	173	.0001	.017
Carbon Film	3	.014	.042
Transistor			
Si Lo-Power	44	.05	2.200
Si Gen. Purpose	4	.05	.200
Logic Circuits	43	.10	4.300
Inductor	5	.035	.165
Transformer	1	.142	.142
Connector	11 pins	.001/pin	.011
Solder Joints	900	.0008	.720
		TOTAL	11.019

[1] - See Section 9.0

Lunar Orbiter - Communications Subsystem

Temperature Transducers

Function: To provide data on spacecraft subsystem operating temperatures.

Predicted $\lambda = .232 \times 10^{-6}$/hr

Part Type	n	$\lambda \times 10^{-6}$		$n\lambda$
Thermistor	7	.03	1	.21
Solder Joint	28	.0008	2	.022
			TOTAL	$.232 \times 10^{-6}$

Source of Failure Rate Data

1 - AVCO Reliability Data Series, Page 83

2 - See Section 9.0

Lunar Orbiter - Communications Subsystem

Micrometeoroid Detectors - D2-100188

Function: To sense the presence of micrometeoroids in the lunar environment. These detectors are OFF.

Predicted Reliability = .998 [1]

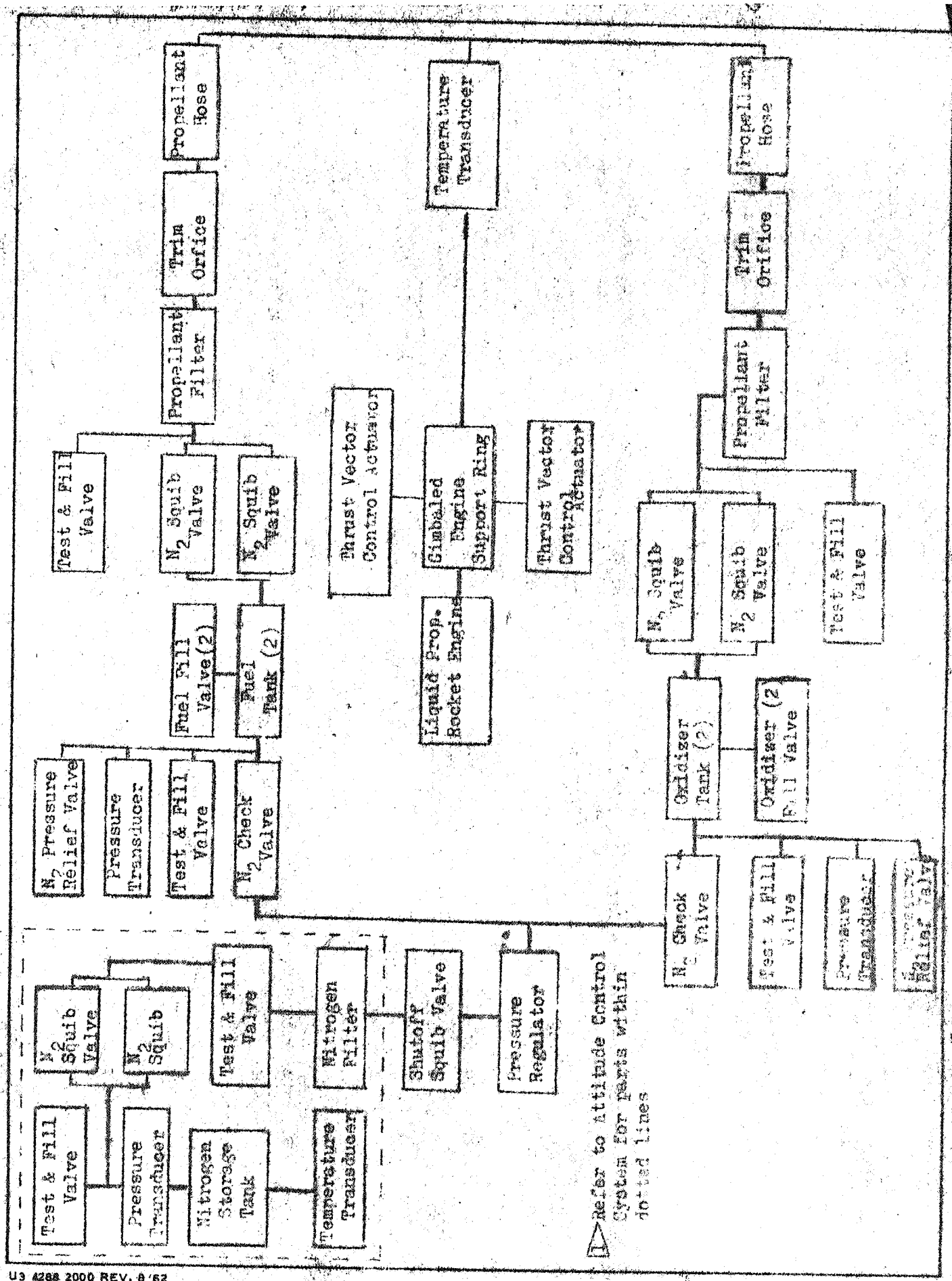
[1] These detectors are not mission critical for the 30-day E-1 photographic mission. Reliability analysis for this equipment will be included as soon as the data is received from NASA.

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Mechanical Parts	K= 140 D= 1	K= 1 D= 1	K=1 D=1	K=1 D=0	K=1 D=0	
λ= .0000057 f=	.000160	.000512	.001243	-	-	Σf = .001913 R = .9981
Rocket Engine	K= 140 D= 0	K=1 D=2cy	K=1 D=1cy	K=1 D=1cy	K=1 D=0	
λ= .0005/cy f=	1 .001000	.001000	.000500	.000500	-	Σf = .003000 R = .9970
Thrust Vector Control Actuators	K= 140 D= 1cy	K= 1 D= 3cy	K= 1 D= 1cy	K= 1 D= 1cy	K= 1 D= 0	
λ= .000004/cy f=	2 .000004	.000012	.000004	.000004	-	Σf = .000024 R = .9999
	K= D=	K= D=	K= D=	K= D=	K= D=	
λ= f=						Σf = R =
	K= D=	K= D=	K= D=	K= D=	K= D=	
λ= f=						Σf = R =
	K= D=	K= D=	K= D=	K= D=	K= D=	
λ= f=						Σf = R =
Column Sum	.001164	.001524	.001747	.000504	-	
Column Reliability	.9989	.9985	.9983	.9995	-	
Cumulative Sum	.001164	.002688	.004435	.004939	.004939	.004939
Cumulative Reliability	.9989	.9974	.9954	.9951	.9951	R = .9951

1 > See Page 73

2 > See Page 72

VELOCITY CONTROL SUBSYSTEM - RELIABILITY SUMMARY (SHEET 1 OF 1)



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VELOCITY CONTROL SUBSYSTEM - FUNCTIONAL BLOCK DIAGRAM

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PAGE

Lunar Orbiter - Velocity Control Subsystem

Mechanical Parts

Function: Mechanical parts provide functional control of propellant feed and pressurization for the rocket engine.

Prediction λ = .0000057/hr. + .000004/cycle for actuators

Part Type	$\lambda/10^6$hr	n	$n\lambda$
N_2 Pressure Regulator	.90	1	.90
N_2 Check Valve	.11	2	.22
N_2 Pressure Relief Valve	.22	2	.44
Pressure Transducer	.70	2	1.40
Test and Fill Valve	.11	4	.40
Oxidiser Tank	.20	2	.40
Fuel Tank	.20	2	.40
Oxidizer Fill Valve	.11	2	.22
Fuel Fill Valve	.11	2	.22
Propellant Squib Valve Assembly (2 valves in parallel = 1 assembly)	negligible	2	-
Propellant Filter	.08	2	.16
Trim Orifice	.05	2	.10
Propellant Hose	.05	2	.10
Temperature Transducer	.30	1	.30
Gimbaled Engine Bearing	.16	1	.16
Tubing and Fittings for Subsystem	.22	1	.22
		TOTAL	5.68×10^{-6}/hr

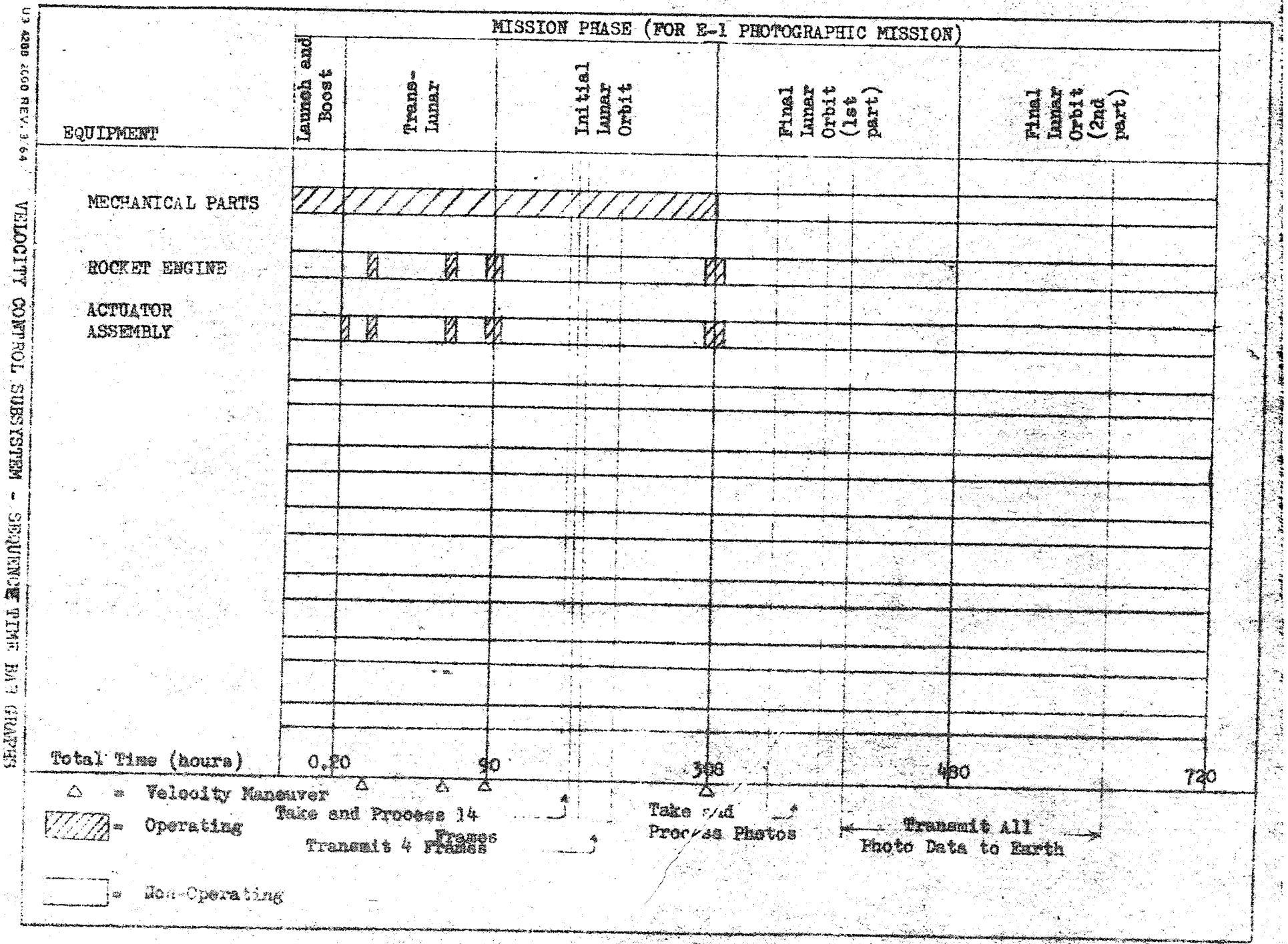
Thrust Vector Control Actuator 2×10^{-6}/cycle 2 4×10^{-6}/cycle

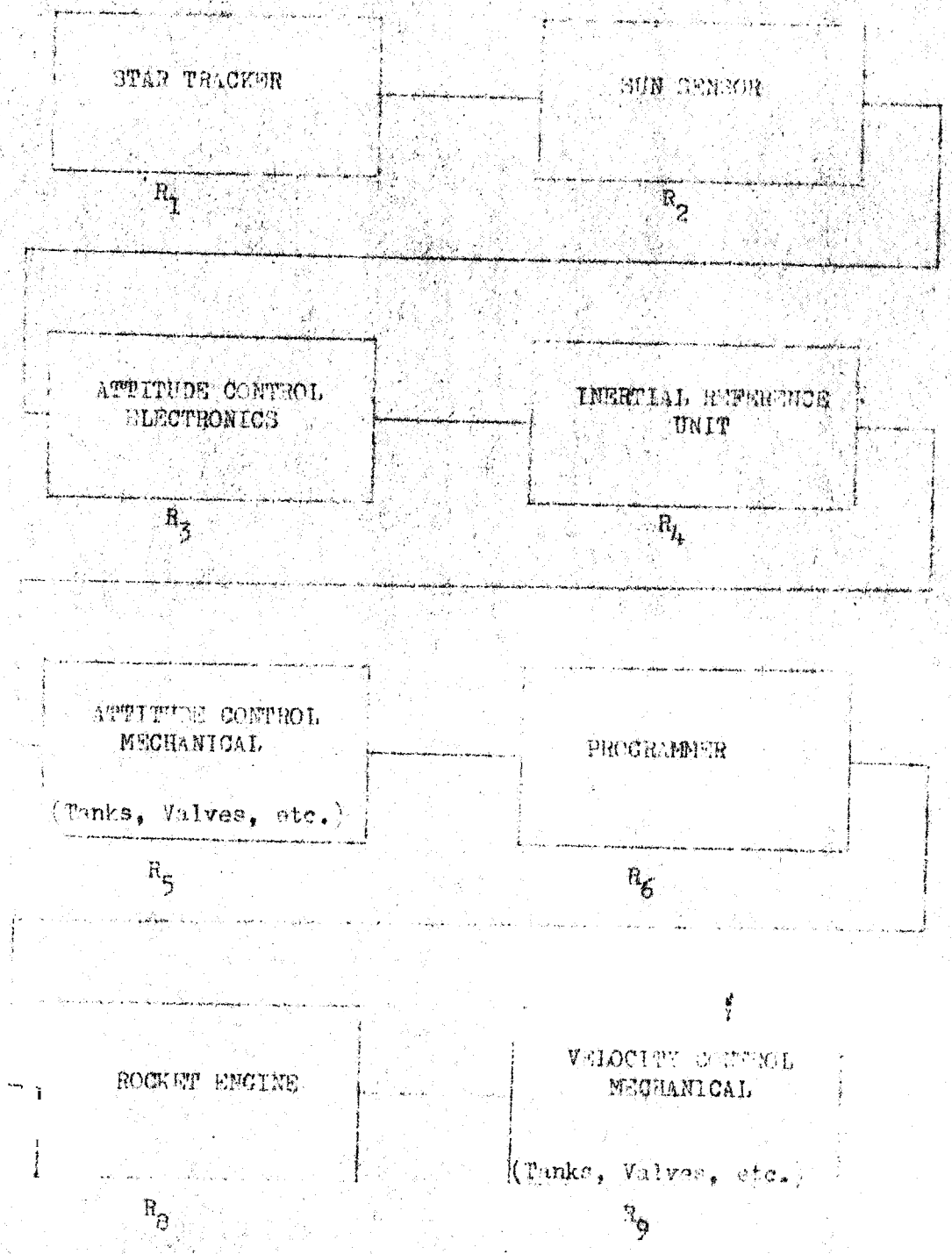
The Velocity Control System also contains a normally open squib valve which is used to close off the nitrogen supply from the velocity control subsystem after the final velocity maneuver. The mission unreliability, Q, of this squib valve is equal to the probability that the squib valve fails to close times the probability the velocity system leaks or fails. Given the failure rate of the squib valve is .000015/cy.

$Q = Q_{\text{squib valve}} \times Q_{\text{velocity subsystem}} = .000015 \times (\text{unk}) \leq .000015,$

which is negligible.

Source of data: AVCO Reliability Data Series, Experience Retention Files, Supplier Reliability Analyses


MISSION PHASE (FOR E-1 PHOTOGRAPHIC MISSION)
EQUIPMENT
Launch and Boost
Trans-Lunar
Initial Lunar Orbit
Final Lunar Orbit (1st part)
Final Lunar Orbit (2nd part)
MECHANICAL PARTS
ROCKET ENGINE
ACTUATOR ASSEMBLY
Total Time (hours)
0.20
90
308
480
720
= Velocity Maneuver
= Operating
= Non-Operating
Take and Process 14 Frames
Transmit 4 Frames
Take and Process Photos
Transmit All Photo Data to Earth



$R = R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9$

VELOCITY AND ATTITUDE CONTROL SUBSYSTEMS - RELIABILITY BLOCK DIAGRAM
(INCLUDING PROGRAMMER)

Lunar Orbiter - Velocity Control Subsystem

Rocket Engine Unit

Function: Engine provides reaction thrust for mid-course corrections and Lunar Orbit injection.

Predicted λ = .0005/cy plus a probability of .001 that the engine will not survive launch and boost.

Source of Data: Engine (M[illegible]-109X[illegible]) procured from Marquardt. Their reliability estimate was .997 for the Lunar Orbiter mission which gives an equivalent failure rate of .0005/cy. for each firing, plus a probability of .999 the engine will survive launch and boost.

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Inertial Reference Unit (Except Accelerometer)	K= 140 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
$\lambda = 141.24 \times 10^{-6}$/hr f=	.003955	.012683	.030790	.024293	.033898	$\sum f$ = .105619 R = .8998
Inertial Reference Unit (Accelerometer & its Electronic Module)	K= 140 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 0	K= 1 D= 0	
$\lambda = 12.54 \times 10^{-6}$/hr f=	.000351	.001126	.002734	-	-	$\sum f$ = .004211 R = .9958
Attitude Control Electronics	K= 140 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
$\lambda = 9.4 \times 10^{-6}$ f=	.000263	.000844	.002049	.001617	.002256	$\sum f$ = .007029 R = .9930
Sun Sensor	K= 140 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
$\lambda = 0.66 \times 10^{-6}$ f=	.000017	.000057	.000137	.000108	.000151	$\sum f$ = .000470 R = .9995
Star Tracker	K= 140 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
$\lambda = 6.8 \times 10^{-6}$ f=	.000190	.000611	.001482	.001170	.001632	$\sum f$ = [illegible] R = [illegible]
	K= D=	K= D=	K= D=	K= D=	K= D=	
$\lambda =$ f=						$\sum f$ = R =
	K= D=	K= D=	K= D=	K= D=	K= D=	
$\lambda =$ f=						$\sum f$ = R =

ATTITUDE CONTROL SUBSYSTEM - RELIABILITY SUMMARY (SHEET 1 OF [illegible])

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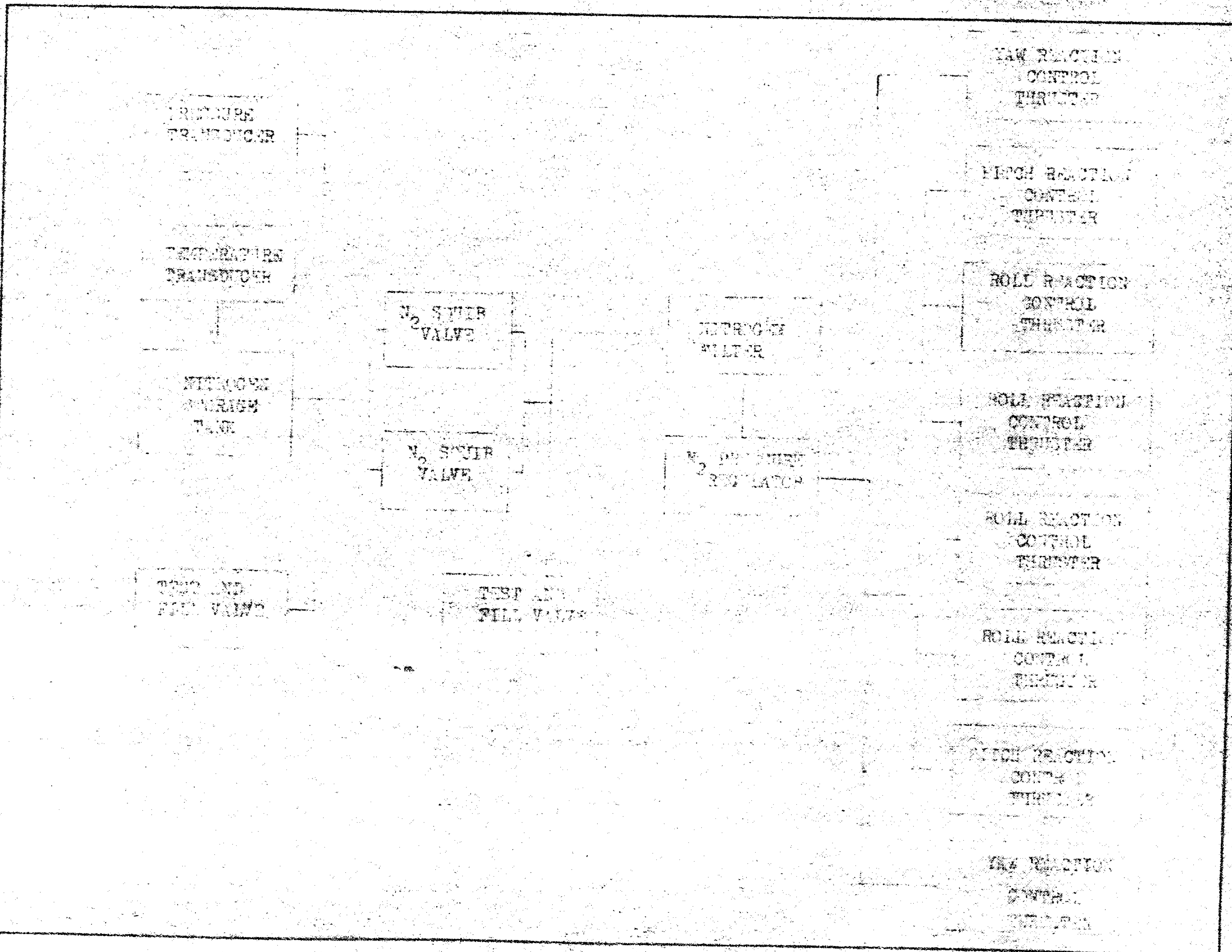
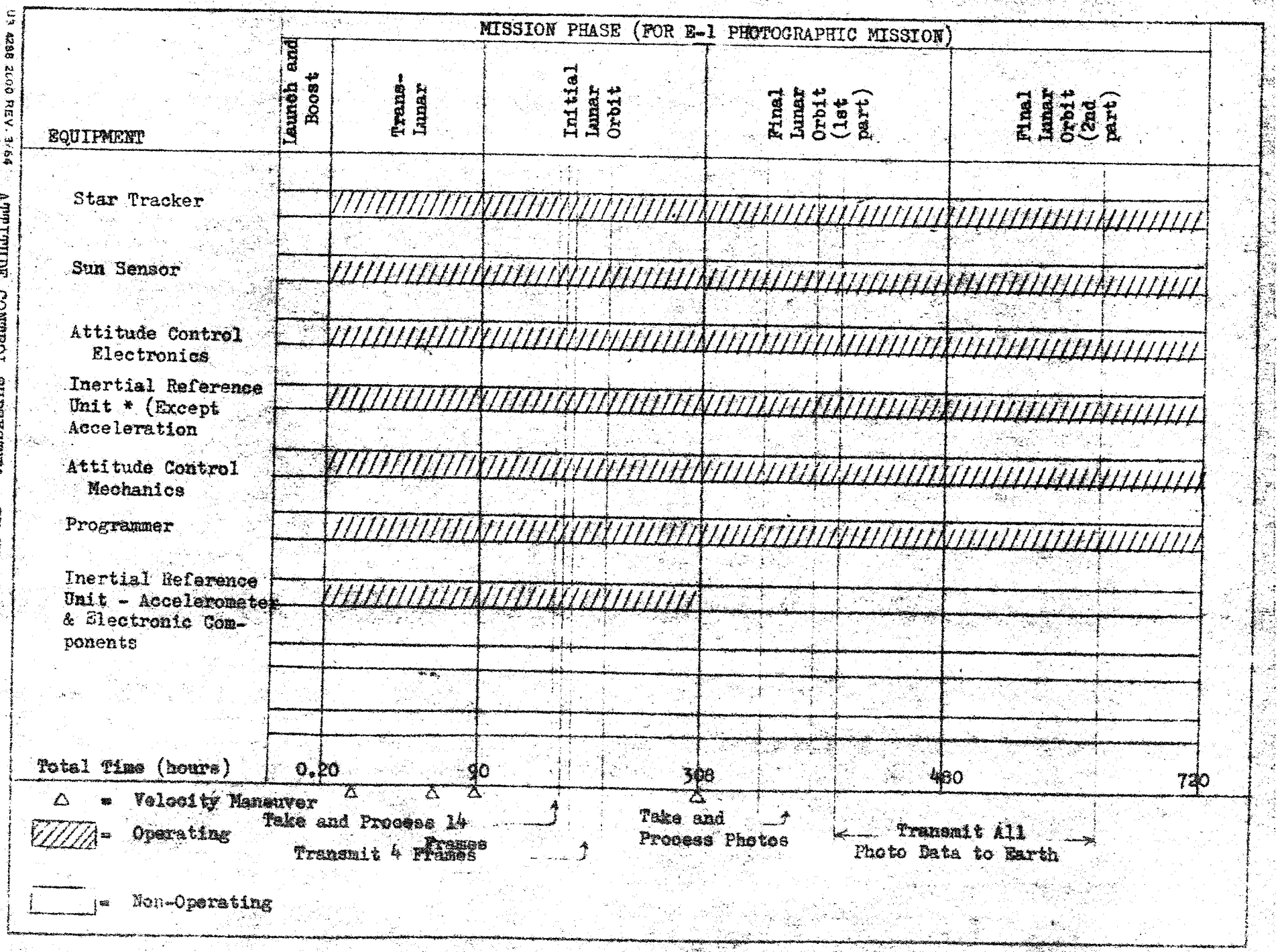

YAW REACTION
CONTROL
THRUSTER
PITCH REACTION
CONTROL
THRUSTER
ROLL REACTION
CONTROL
THRUSTER
ROLL REACTION
CONTROL
THRUSTER
ROLL REACTION
CONTROL
THRUSTER
ROLL REACTION
CONTROL
THRUSTER
PITCH REACTION
YAW REACTION
PRESSURE
TRANSDUCER
TEMPERATURE
TRANSDUCER
NITROGEN
STORAGE
TANK
N_2 SHUTOFF
VALVE
N_2 SHUTOFF
VALVE
NITROGEN
FILTER
N_2 PRESSURE
REGULATOR
TEST AND
FILL VALVE
TEST AND
FILL VALVE



U3 4288 2000 REV. 3-64 ATTITUDE CONTROL SUBSYSTEM - SEQUENCE TIME BAR GRAPH

REV SYM G

BOEING NO. D2-10255

Equipment	Mission Phase: Launch and Boost	Trans-Lunar	Initial Lunar Orbit	Final Orbit (1st part)	Final Orbit (2nd part)	30 Day Photographic Mission Total
Time in Mission Phase (hours)	0.20	89.8	218	172	240	720 hours
Mechanical Parts	K= 140 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
$\lambda = 11.3 \times 10^{-6}$ f=	.000316	.001017	.002463	.001944	.002712	$\sum f =$ .004452 R = .9916
Programmer (Including Magnetic Memory)	K= 140 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	K= 1 D= 1	
$\lambda = 73.08 \times 10^{-6}$ f=	.002046	.006563	.015931	.017539		$\sum f =$ .04649 R = .9967
	K= D=	K= D=	K= D=	K= D=	K= D=	
$\lambda =$ f=						$\sum f =$ R =
	K= D=	K= D=	K= D=	K= D=	K= D=	
$\lambda =$ f=						$\sum f =$ R =
	K= D=	K= D=	K= D=	K= D=	K= D=	
$\lambda =$ f=						$\sum f =$ R =
	K= D=	K= D=	K= D=	K= D=	K= D=	
$\lambda =$ f=						$\sum f =$ R =
Column Sum	.007138	.022901	.055536	.041702	.058188	
Column Reliability	.9929	.9774	.9459	.9592	.9[illegible]	
Cumulative Sum	.007138	.030039	.085625	.127327	.1[illegible]515	.185515
Cumulative Reliability	.9929	.9704	.9180	.8805	.8[illegible]6	R=.8306

ATTITUDE CONTROL SUBSYSTEM - RELIABILITY SUMMARY (SHEET 2 OF 2)

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IRU (continued)

The failure rate of the IRU is broken down into two parts:

IRU (except accelerometer)	141.24×10^{-6}
Accelerometer and its Electronic Module	12.54
	153.78

The accelerometer and its electronic module are required to operate only until the final velocity maneuver.

1 - See Section 9.0

2 - Failure rate obtained from manufacturers data

Lunar Orbiter - Attitude Control Subsystem

Inertial Reference Unit (IRU)

Function: To provide three axis attitude reference for attitude control, and to measure spacecraft acceleration for velocity control.

Predicted $\lambda = 141.24 \times 10^{-6}/hr$

Part Type	n	λ [1]	$n\lambda$
Capacitor			
Tantalum	169	.002	.338
Ceramic, Glass	123	.02	2.460
Paper, etc.			
Variable	1	.05	.050
Resistor			
Metal Film	775	.0001	.078
Wirewound	56	.016	.896
Variable	17	.40	6.800
Transistor			
Switch	54	.02	1.080
Small Signal	170	.02	3.400
Power	3	.05	.150
General Purpose	31	.05	1.550
Crystal	1	.05	.050
Transformer			
Signal	51	.056	2.856
Power	1	.142	.142
Diode			
General Purpose	79	.005	.395
Zener	48	.05	.240
Power	1	.02	.020
Inductor - RF	11	.012	.132
Microcircuits	9	.10	.900
Accelerometer	1	10.00 [2]	10.000
Gyro Units	3	40.00 [2]	120.000
Solder Joints	2800	.0008	2.240
		TOTAL	$153.777 \times 10^{-6}/hr$

Lunar Orbiter - Attitude Control Subsystem

Canopus Tracker

Function: Identifies and locks on the star Canopus providing roll stability.

Predicted $\lambda = 6.8 \times 10^{-6}$

Part Type	$\lambda/10^6$	1	n	$n\lambda$
Capacitor				
Solid T_a	.002		38	$.076 \times 10^{-6}$
Ceramic	.018		25	.450
Resistor				
Metal Film	.0001		220	.022
Diode				
Computer	.001		22	.022
General Purpose	.005		20	.100
Zener	.05		2	.100
Power	.02		2	.040
Transistor				
Switch	.02		65	1.300
Choke - RF	.035		4	.140
Tube - Image Director	4.00	2	1	4.00
Solder Joints	.0008		700	.56
			TOTAL	6.81×10^{-6}

1 See Section 9.0

2 Supplier estimate

Lunar Orbiter - Attitude Control Subsystem

Attitude Control Electronics

Function: Provides functional control of thruster assemblies for all pitch and yaw corrections of spacecraft during mission.

Predicted $\lambda = 0.4 \times 10^{-6}$/hr.

Part Type	n	λ [1]	nλ
Capacitor			
Solid Tantalum	19	.002	.038 $\times 10^{-6}$
Glass	30	[illegible]	[illegible]
Ceramic	12	.002	[illegible]
Diode			
Zener	19	.05	[illegible]
Si-General Purpose	17	.005	.085
Si-Computer	47	.001	.047
Resistor			
Metal Film	667	.0001	.067
Precision, Wirewound	66	.016	1.056
Transistor			
Si-Small Signal	[illegible]	.003	[illegible]
Si-General Purpose	12	.05	.600
Si-Switch	65	.05	3.250
Si-Power	6	.05	[illegible]
Thermistor	1	.05	.050
Welded Joints	2100	.001	[illegible]
Connectors	105 pins	.001/pin	.105
		TOTAL	[illegible] $\times 10^{-6}$

[1] See Section 2.0

Lunar Orbiter - Attitude Control Subsystem

Mechanical Parts (Reaction Control)

Function: Provides storage and control of the nitrogen gas for the thrusters

Predicted $\lambda = 11.3 \times 10^{-6}$/hr

Part Type	n	$\lambda/10^6$	$n\lambda/10^6$
Nitrogen Tank	1	.07	.07
Temperature Transducer	1	.30	.30
Pressure Transducer	1	.70	.70
Test and Fill Valve	2	.11	.22
Nitrogen Squib Valve Assembly (2 valves in parallel = 1 assembly)	1	negligible	-
Nitrogen Filter	1	.08	.08
N_2 Pressure Regulator	1	.90	.90
Reaction Control Thruster Assembly (.05 pounds) with Solenoid Valve			
Yaw	2	1.1	2.20
Pitch and Roll	2	3.3	6.60
Tubing and Fittings for Subsystem	1	.22	.22
		TOTAL	11.29

Source of failure rate data: Boeing Experience Retention Files, AVCO Reliability Data Series, Supplier Reliability Analyses.

Lunar Orbiter - Attitude Control Subsystem

Sun Sensor 10-70064

Function: Determines the sun aspect angle providing yaw and pitch stability.

Predicted λ = .00000063/hr.

Part Type	n	$\lambda/10^6$	$n\lambda/10^6$
Fine Eye			
FE-5A	4	.0718	.2872
Resistor	2	.0095	.0190
Course Eye			
CE-3	4	.0718	.2872
Resistor	4	.0095	.0380
		Total	.6314

Source of failure rate data: TN65-63 dated January 7, 1965; Title, "Reliability Prediction for Eyeblock Assembly of the Boeing Lunar Orbiter Sun Sensor" from the supplier, Ball Brothers Research Corporation. TN65-63 quotes: "Failure rate list is reported on IDEP No. 347.20.00.00-04-01, dated May, 1962. The eye elements are considered to be equivalent to a diode. . . In all cases, predictions are made on the basis that the eye element and resistor power dissipation will be less than 15% of rated."

Lunar Orbiter - Flight Control Assembly

Programmer (except Magnetic Memory)

Function: Provide flight programmer capability for the spacecraft. Store flight data. Provide data to identify spacecraft attitude during photo exposure operations.

Predicted λ = 4.92 x 10^{-6}

Part Type	n	λ [1]	$n\lambda$
Capacitor			
Plastic	2	.07	.140 x 10^{-6}
Solid Tantalum	12	.002	.024
Tantalum Foil	15	.0015	.023
Glass	16[illegible]	.002	.324
Ceramic	2[illegible]	.002	.04[illegible]
Diode			
Zener	25	.05	1.250
Si-General Purpose	[illegible]	.005	.040
Si-Power	7	.020	.140
Si-Medium Power	11	.03	.330
Si-Computer	4[illegible]	.001	.465
Resistor			
Metal Film	1083	.[illegible]001	.108
Precision, Wirewound	1[illegible]	.01[illegible]	2.608
Power, Wirewound	38	.006	.228
Transistor			
Si-Small Signal	[illegible]	.003	.120
Si-General Purpose	[illegible]7	.05	3.[illegible]
Si-Switch	[illegible]	.05	3.450
Si-Power	[illegible]4	.05	[illegible]
Thermistor	1	.05	[illegible]
Relay	[illegible]	.06	.1[illegible]0
Filter - RFI	7	.012	[illegible]
Microcircuits	[illegible]7	.087 [2]	[illegible]
Solder Joints	3[illegible]0	.0008	[illegible]
Weld Joints	3[illegible]0	.001	[illegible]
Connectors	[illegible]3 pins	.0[illegible]1/pin	.1[illegible]
		TOTAL	[illegible]

1 See Section 8.0

2 Based on MIT and in-house [illegible] data

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Lunar Orbiter - Flight Control Assembly

Programmer Redundant Clock

Predicted R = .9[illegible]9+

Part Type	n	λ	$n\lambda$
Diode			
Si-Power	1	.02	.020 x 10^{-6}
Zener	2	.05	.1[illegible]
Si-Switch	9	.005	.045
Transistor			
Si-Switch	10	.05	.[illegible]
Resistor			
Metal Film	31	.0001	.003
Capacitor			
Solid Tantalum	3	.002	.006
Glass	13	.03	.260
Glass-Variable	1	.08	.080
Crystal-Quartz	1	.05	.[illegible]
Thermistor	2	.02	.04[illegible]
Solder Joint	2[illegible]	.[illegible]	.1[illegible]
		TOTAL	1.[illegible] x 10^{-6}

1 - See Section 9.0

2 The programmer uses two clocks in parallel redundancy.

$R_1 = e^{-\lambda t} = e^{-1.[illegible] \times 10^{-6}(750\ hrs)} = e^{-.[illegible]} = .[illegible]$

$1 - R_1 = .001$

R_2 in parallel $= 1 - (1 - R_1)^2 = 1 - (.001)^2 = .[illegible]$, which [illegible].

Lunar Orbiter - Flight Control Assembly

Programmer Magnetic Memory

Predicted $\lambda = 3.16 \times 10^{-6}$/hr.

Part Type	n	$\lambda \times 10^{-6}$ [1]	nλ
Transistor			
Si-General Purpose	12	.05	3.10 x10^{-6}
Si-Switch	24	.02	.480
Resistor			
Metal Film	129	.0001	.013
Capacitor			
Solid Ta	9	.002	.018
Ceramic[a]	18	.018	.324
Glass	9	.08	.720
Diode			
Si-General Purpose	107	.007	.535
Zener	7	.05	.350
Si-Switch	42	.005	.150
Transformer			
Pulse	5	.20	1.000
Loop Core	173	.0001 [2]	.017
Loop Core (in matrix)	2400	.0001	.240
Solder Joints	1700	.0003	.510
Weld Joints	1700	.001	1.700
		TOTAL	.157 x 10^{-6}

1 See Section 9.0

2 Failure rate data from manufacturer

8.0 List of Symbols and Abbreviations

Symbol or Abbreviation	Definition
D	Adjusted Duty Cycle
K	Environmental Weighting Factor
t	Time Duration of the Mission Phase
R	Reliability
Q	Unreliability = 1- Reliability
λ	Failure Rate (in failures per hour or failures per cycle, as applicable)
f	$f = \lambda KDt$. That is, f is the product of the failure rate, K factor, duty cycle and time of the mission phase in hours
cy	Cycle
hr	Hour
min.	Minute(s)
NASA LOPO	National Aeronautics and Space Administration Lunar Orbiter Project Office
S/C	Spacecraft
n	Number of parts

7.0 References

A. Lunar Orbiter Subsystem Documents

1. D2-100101-1 "Spacecraft Subsystem Environmental Criteria Specifications - Lunar Orbiter Project."

2. D2-100151 "Reliability Program Plan - Lunar Orbiter."

3. D2-100110 "Spacecraft Subsystem - Design Criteria Specification - Lunar Orbiter."

B. Reliability Technology Sources

1. D2-3246 "Design Reliability Methods Manual."

C. Failure Rate Data Sources

1. MIL-HDBK-217 "Reliability Stress Analysis for Electronic Equipment" (WEPS) 31 December 1961.

2. MIL-R-3811XX, Series of MIL-Specifications on High Reliability Parts

3. D2-22571, "Manufacturers Reliability Data."

4. D2-22963 "Failure Rates by Mode of Failure - Multi-Use Hardware" (Not yet released).

5. D2-100102 "Approval Parts, Materials, Components and Processes - Lunar Orbiter."

6. D2-100173 "Parts, Components and Materials Qualification Status List - Lunar Orbiter."

7. AVCO "Reliability Engineering Data Series - Failure Rate" by D. Earls and M. Eddins, AVCO Corporation, April 1962.

8. RCA - Satellite Standards Manual

9. Data Central - The Boeing Company Aero-Space Division, Reliability Central. This includes Minuteman, Dyna-Soar, B-52, Saturn SIC, and other Boeing-generated data as well as data obtained from suppliers and manufacturers.

10. D2-14134 "Minuteman Electronic Part Failure Rates"

11. D2-23210-1, -2, "Reliability Data Standards"

12. D2-20473, "Minuteman Failure Rate, Mode, Cause and Maintenance Data"

Part Type	Failure Rate ($\lambda/10^6$ hrs) D2-20473	T4-776.01/111
Capacitor		
Fixed, Ceramic	.018	
Fixed, Electrolytic Solid Tantalum	.002	.00075
Fixed, Electrolytic Tantalum Foil	.0015	.0011
Fixed, Electrolytic Etched Aluminum	.03	
Fixed, Glass Dielectric	.076	.00036
Fixed, Mica	.004	
Fixed, Paper Plastic, Foil	.068	.00092
Diode		
Silicon, Computer	.0006	.0012
Silicon, Controlled Rectifier	.041	
Silicon, General Purpose	.005	.00077
Silicon, Medium Power	.03	.029
Silicon, Power	.02	.0034
Silicon, Zener	.047	
Filter		
Choke, Power Supply Ripple	.035	
RFI	.012	
Relay		
Intermediate Level (3-10 amp)	.257	
Low Level (0-2 amp)	.059	
Resistor		
Fixed, Carbon Composition	.001	.00016
Fixed, Carbon Film	.014	.016
Fixed, Metal Film	.0001	.00063
Fixed, Precision, Wirewound	.016	.0042
Fixed, Power, Wirewound	.006	.00092
Variable	.402	
Transformer		
Audio	.056	
Magnetic Logic, Toroidal	.02/coil	
Power	.142	
Pulse	.203	
Transistor		
Germanium, Power	.039	.040
Germanium, Switch	.018	.038
Silicon, Power	.051	
Silicon, Switch	.051	.00098
Silicon, Small Signal		.0032

9.0 Failure Rate Data

The failure rate data in this section are compiled from use in the Minuteman weapon system. Two sources are listed, Boeing Document D2-20477, "Minuteman Failure Rate, Mode, Cause and Maintenance Data", (Not yet released for publication), and Autonetics Document T4-776.01/3111, "Minuteman High-Reliability Component Parts Demonstrated Failure Rates".

The failure rate information in D2-20477 was compiled from Minuteman ground equipment for which Boeing was responsible. The design of the equipment was subjected to failure mode, effect and criticality analyses, reliability predictions, parts derating and other reliability disciplines similar to those imposed on the Lunar Orbiter. Therefore the part failure rates can be used without the necessity of applying derating factors, because derating is inherent to the data. As usual, an environmental weighting factor (K factor) of 1 is used when transposing failure rate data from ground equipment use to spacecraft.

Similar statements can be made about the information in the Autonetics Document T4-776.01/3111. In this case data on flight operational hardware is also included. Thus the proven success record of Minuteman lends assurance to the validity of the data.

The differences between the failure rates from the two sources is primarily due to differences in the total number of part hours accumulated. Both sources list failure rates at the 60% confidence level.

Failure rates on other parts and equipment used in more than one subsystem will be included in this section as necessary.

Part Type (continued)	Failure Rate $\lambda/10^6$ hrs
Connections	
Connector (includes two Crimp Connections)	.001/pin
Solder Joint, Hand	.0008
Solder Joint, Machine	.00004
Welded Joint	.001