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APOLLO
GUIDANCE AND NAVIGATION

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RELIABILITY AND QUALITY ASSURANCE PROGRESS REPORT

Compiled by
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December 1963

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I. INTRODUCTION

This document contains the Apollo Guidance and Navigation System reliability and quality assurance progress report for the period ending October 31, 1963. All significant events and program tasks are included which have contributed to the maintenance and improvement of the system reliability and quality. Plans for future activities to raise the product excellence to a level commensurate with system requirements are also discussed.

II. RELIABILITY PROGRESS REPORT

A. Reliability Program Administration

The task of program administration has progressed satisfactorily during this reporting period, both internally at MIT and at each participating contractor's facility. MIT has been actively engaged in various coordination and policy meetings with the contractors to ensure that each phase of the reliability program is being given proper attention. During such a meeting in August, 1963, attended by the MIT reliability staff and reliability managers from each participating contractor, the reliability and quality assurance program plans were reviewed in detail. The purpose of the review was to determine the adequacy of each contractor's effort and to define both those program elements which are not currently provided for and others which must be bolstered in order to become effective. In addition, the effects resulting from variations in the scope of each participating contractor's reliability program were also examined in order to grasp a better understanding of what action will be required to realize an adequate and necessary program. The results of this meeting will provide the basis for a proposed plan of action which will be submitted to NASA for consideration.

Meetings were also held with NASA at MSC and at MIT which included a review of the progress and status of the reliability and quality programs. Other meetings were held here with BELCOM to review the general aspects of the MIT program with special interest accorded to reliability apportionment.

The following TD's (Technical Directives) have been issued to the participating contractors during this reporting period.

Description	Date of Issue	Contractor Assigned
Navigational Base Experimentation Stress Analysis, Vibration and Shock Testing	10/22/63	ACSP
D&C Vibration, Shock, Thermal Vacuum and Peel Strength Testing	8/27/63	ACSP
Failure Effects Analysis Support to MIT	9/26/63	ACSP
Welding Process Spec. Implement.	6/7/63	ACSP
Field Operator Training	6/18/63	ACSP
Familiarization Training Program and Course for NAA, AMC, and MSC	6/19/63	ACSP
System Assembly and Test on AGE Systems 6, 7, 8, and 20	7/16/63	ACSP
Failure Effects Analysis Support to MIT	9/26/63	KIC
Special Test Equipment	6/19/63	KIC
Part and Assemblies Qualification Test Program*	7/1/63	KIC
Field Operations Training	6/18/63	KIC
Failure Effects Analysis Support to MIT	9/26/63	Raytheon
Part Qualification Test Program*	7/23/63	Raytheon
Sub-assembly Reliability and Qualification Test Program	8/20/63	Raytheon
AGC Reliability Evaluation and Demonstration*	8/23/63	Raytheon
Vendor SCD Negotiation on Reliability and QC Matters	3/26/63	Raytheon
Directive for Writing 8 Process Specifications	6/3/63	Raytheon

Description	Date of Issue	Contractor Assigned
Directive for Preparing Factory Test Plan and Description of each Test Status	5/10/63	Kollsman
Apollo Failure Report System	6/25/63	Kollsman
AGE #1 and #2 MDV Mech. Integrity and Thermal Evaluation Test	7/8/63	Kollsman
AGE #1 Optical Subsystem Thermal-Vacuum Test (83)	7/16/63	Kollsman
AGE #2 Optical Mech. Integrity Test (61)	5/7/63	Kollsman

The asterisks indicate out-of-scope TD's which contain specific tasks not included or funded for in the participating contractor's current agreements with NASA, but which are still of vital importance to the success of the program. The timeliness of conducting these efforts is a factor which is equally as important as the work itself since delays will merely increase the complexity and cost. The qualification testing of parts and sub-assemblies will provide assurance of system capability and will identify problem areas which require further attention.

B. Reliability Organization

The MIT Reliability Group has added a component specialist and a material specialist to its number during this reporting period. Although the component specialist's task is primarily one of providing assistance to the design groups in the selection and application of parts, his immediate activity is in the area of the review and release of SCD's (Specification Control Drawings). For a complete review of his activity, see Section G. 1, "Approved and Preferred Parts Program". The products of his efforts are SCD's which accurately describe the desired part and which contain adequate quality and reliability provisions.

The responsibilities of the material specialist lie chiefly in the area of providing assistance to the design groups with material and finished information and in assisting in the selection thereof in order to optimize system reliability. A tentative design guide has been prepared and issued to all Apollo MIT engineers noting certain restrictions on material usage and a qualification status on all non-metallic material known to be in use. An effective program is in progress to coordinate materials testing and qualification and to ensure system compatability among the various Apollo contractors. A preliminary listing of materials used in the G&N system has already been forwarded to NAA through NASA RASPO. In addition, a study of the behavior of materials interactions in manned spacecraft, with particular attention being placed upon electrolysis and galvanic corrosion, has been started.

C. Failure Reporting and Corrective Action

The failure reporting and corrective action program at MIT has focused the attention of responsible engineering groups on failures which have occurred during evaluation and breadboard testing on various pieces of G&N hardware. In addition to actual failures, the reporting system has been used to record areas of possible failures resulting from manufacturing

PROBLEM	CAUSE	CORRECTIVE ACTION
CRACKED STUB SHAFTS ON IMU MIDDLE AND OUTER GIMBALS	1. FAILED WHEN SUBJECTED TO VIBRATION 2. SHAFTS CRACKED BECAUSE OF STRESS RISERS (HOLES FOR REMOVING SHAFT) 3. PROBABLY FATIGUE FAILURE	1. INCREASED WEB THICKNESS 2. ELIMINATED HOLES 3. INCREASED THE RADIUS OF SHAFT-WEB INTERSECTION
IMU INTERNAL CONTAMINATION	1. SCREW INSERTS CUT INTO SCREW RESULTING IN METAL SHAVINGS-CLUNG TO AND SHORTED TORQUE MOTOR 2. LOCKING FEATURE REMOVED SCREW LUBRICANT 3. SCREW THREADS CONTAINED FOREIGN PARTICLES	ACCOMPLISHED 1. ALL OLD INSERTS WERE REMOVED, AND NEW STYLES SUBSTITUTED 2. SCREW THREADS NOW BEING CLEANED PRIOR TO INSTALLATION 3. MFG. PROCESS CHANGED TO INSURE THREADS FREE FROM CONTAMINANTS PENDING 1. LOCKING INSERTS FREE FROM LUBRICANT. 2. USE OF HELICOIL INSERTS
RUBBER ISOLATOR MATERIAL ON NAVIGATION BASE MELTED AND SHRUNK	FRICTIONAL HEATING OF RUBBER TO METAL INSERT DURING VIBRATION	BONDED THE RUBBER TO THE METAL INSERT

Fig. 1 Failure Report and Corrective Action Summary

PROBLEM	CAUSE	CORRECTIVE ACTION
HIGH TRANSMISSIBILITIES IN IMU #2	INVESTIGATING USE OF - DAMPING DEVICES - STIFFENING FOR CASE MOUNTING FLANGES	INCREASED FLANGE THICKNESS PROVIDED REDUCTION OF VIBRATION MAGNIFICATION PROBLEM IS STILL UNDER INVESTIGATION
INTERMITTENT TUNNEL DIODE	UNIT FAILED AT EQUIPMENT INITIAL ENERGIZATION. PROBABLY DUE TO MISSING INTERNAL WELD.	THESE PARTS HAVE BEEN ELIMINATED FROM THE SYSTEM.
SLIP RING CIRCUIT HAVE EXCESSIVE CONTACT NOISE	EXCESSIVE AMOUNTS OF SOLDER FLUX. OTHER PROBLEMS: 1. EDGES OF RING FLATS WERE CUT UNEVENLY 2. EXCESSIVE FREEDOM OF AXIAL MOTION OF THE SLIP RING	1. CAPSULES ARE THOROUGHLY CLEANED OF SOLDER FLUX 2. AXIAL PLAY ELIMINATED
25 IRIG SUSPENSION WINDING SHORTED TO CASE	POOR MFG. AND INSPECTION TECHNIQUES INTERNAL SPRING NOT POSITIONED PROPERLY DURING ASSEMBLY AND SOLDERING.	1. CHANGE OF ASSEMBLY TECHNIQUES 2. REINSTRUCTION OF PERSONNEL 3. SPRING AND PIN NO LONGER ENCAPSULATED TO FACILITATE VISUAL INSPECTION
TRIMPOT FILLED WITH EPOXY	PART WAS NOT HERMETICALLY SEALED	SEALED TRIMPOT IS NOW IN USE.

Fig. 2 Failure Report and Corrective Action Summary

variances, and also to initiate corrective action before the failures can occur. There have been approximately thirty such instances where the defects were noted and remedial action was taken. All failure reports are submitted to the Apollo G&N Reliability Failure Data Center for future reference and analysis.

D. Design Review Summary

The MIT Design Review Board has conducted an impartial scrutiny of designs and design reviews of component parts in order to assure that maximum consideration has been given to reliability and to offer constructive advice where applicable to further improve the design. Design reviews are not solely conducted by a formal Design Review Board, but rather are a continuous process, as evidenced by the constant flow of inputs supplied to the designer from both the Reliability Group and the various participating contractors. MIT design reviews began with the breadboarded circuits and mockups where performance, producibility, compatability, maintainability, and reliability factors were evaluated. It then continued through prototype development and is now being more formally conducted on the final hardware design before release. Each drawing was first reviewed by the originator in accordance with established review procedures before being submitted to the MIT Design Review Board for formal approval. In addition to design drawings submitted for Class A release, the Design Review Board is responsible for approving Class 1 revisions, procurement specifications, process specifications and procedures prior to their release as Class A documents. The following list reflects the current drawing and document design review status as applicable to the Block 1 configuration.

Assembly	Class A Releases	Class B Releases
IMU	97%	100%
AGC	80%	84%
OPTICS	92%	100%
PSA	71%	91%
D&C	88%	96%
CDU	98%	98%

Class A Documents Releases

Document Category	No. Reviewed
Procurement Specifications	23
Assembly Test Procedures	1
Final Test Methods	1
NASA Documents	73
TOTAL	98

Class B Documents Releases

Document Category	No. to be Reviewed
Procurement Specifications	7
Assembly Test Procedures	17
Final Test Methods	0
NASA Documents	12
TOTAL	36

In conjunction with other reviewing agencies, the MIT Reliability Group conducts its own review of all electronic circuits that are Class A released. This study is aimed at eliminating potentially unreliable applications of parts. Stress Analysis Sheets are filled out by the engineer responsible for the circuit and submitted to the Reliability Group for evaluation. If a situation is deemed inherently unreliable, a change is initiated via the "Reliability Request for Engineering Action"

Form, typical examples of which are shown in Appendix A. These changes can be in the form of component improvement, or a circuit or packaging redesign. Appendix B contains a typical example of the Stress Analysis Sheets submitted to Reliability during review. By these continuous checks and reviews, MIT is able to closely follow design progress,assuming that adequate precautions are being taken to effect the highest level of reliability potential in design.

MIT/IL Reliability has directed considerable attention to the preparation and control of Apollo G&N Specifications during this reporting period. The objective is to assure that adequate process control documentation does exist for each special process required in the manufacturing of G&N hardware. A review of the specifications prepared to date revealed some areas of duplication or close similarity between certain documents, as well as other instances where a process is no longer required. In order to reduce the confusion that might arise from such a condition and also to increase the effectiveness of the specifications, certain of the documents were cancelled and others combined.

In view of the increasing number of these specifications, a greater control is necessary. All future specification requests will be processed through the reliability group whose approval is required before the document is written or an identification number is assigned. In this connection the Reliability Group will:

Prevent the issuance of Apollo G&N Specification when ND or MIL spec exists;

Encourage the preparation of SCD's rather than ND's when appropriate;

Prepare a summary of all specifications for the general information of MIT and participating contractors.

E. Design Evaluation and Qualification Test Programs

The design evaluation of all components of the Guidance and Navigation Equipment for the Command Module is primarily the responsibility of each cognizant design group. Although evaluation tests are generally designed to prove the functional capability of the test item, they also furnish insight into its reliability and ability to function during and following anticipated use environmental conditions. During the conception of an evaluation test to prove design capability, the reliability engineers have worked closely with the design groups in establishing environmental stress levels and test sequences. Recent examples of this activity include the evaluation of the Navigation Base and of the G&N panel.

The first revision to R-389, "Requirements of and Index to Design Evaluation Qualification and Reliability Test Programs", dated July 1963, was published primarily to maintain the test index, which contains current evaluation test information. This document brings together test information from all test sources and provides a guide to the continuity of the overall test programs.

Qualification testing is being planned for all levels of the guidance equipment. System No. 11, which is a Block 1 System, will be qualified on a sub-system level. Though the initial test specification has been released, it is anticipated that revision will be required as a result of a more complete definition of the expected Command Module environmental stress levels. Recently two out-of-scope TD's were issued to establish a sub-assembly qualification test program on elements of the computer and optics. This testing will fill the gap between the complete sub-system qualification and the component parts qualification. The qualifications of the ADA (Angular Differentiating - Integrating Accelerometer) and the Bellows have been initiated.

The parts qualification program is also progressing. Again, two out-of-scope TD's were issued to bring the effort to an acceptable level. In order to minimize the number of tests, all parts appearing on the QSL (Qualified Status List) are being reviewed for applicable existing data. The environment qualification requirements are delineated by means of specifications for each particular part type (ND 1002044 - ND 1002060). Following the review of the QSL, test plans will then be generated in accordance with the qualification specification requirements for all required tests.

The Test Review Board, which was established by R-389, has been formed, and is currently functioning to coordinate and control the formal in-house test programs at MIT and at each participating contractor's facility. Since August, 1963, a meeting has been held on the first Tuesday of each month. Representatives from the reliability and engineering organizations of MIT and participating contractors have attended those meetings at MIT. It is planned that as the participating contractors' formal test programs get under way, the meeting will be scheduled more frequently, and held also at the various test locations.

The following is a list of representative subjects which have been discussed and acted upon:

> Establishment of a uniform procedure for review of parts qualification status;
>
> Review and approval of content of qualification specification;
>
> Establishment of a test axis for qualification vibration tests (in order for initiating fixture design);
>
> Study of the problem of defining dynamic environmental inputs to optical sub-system during qualification testing and recommendation of a combined IMU - Optics qualification program for shock and vibration;
>
> Review of the navigation evaluation test results;
>
> Assisting in establishing future test requirements and to define the dynamic inputs to the optical equipment;

Definition of the ground rules for qualification requirements for semi-conductor devices;

Review of entire test program for adequacy of cover and to recommend further testing where deemed necessary;

Review for approval of qualification test plans;

Establishment of a method for setting up meeting agenda so that each participating contractor's problems are given equal consideration.

F. Reliability Demonstration Program

The aspects of the Apollo program concerned with the probability of mission success and crew safety impose stringent reliability requirements on the Guidance and Navigation System. It is not possible to demonstrate attainment of these levels through specific reliability tests, but inputs from every level and description of testing together will be utilized to approach the degree of confidence required. The index of R-389 provides a means of correlating all test efforts that are necessary to accomplish this task.

There are a number of test programs that are designed to provide direct reliability data. A Block 1 AGE system has been allocated for reliability and life testing. This is presently planned as a simulated mission test which will expose the entire system to nominal environmental stress levels during approximately 3000 hours of accumulated operating time. This is an essential link in proving achievement of reliability goals.

The Apollo Guidance Computer also performs all guidance and navigation data computations in addition to providing a means of interface between astronauts and guidance functions. The high density of component parts in the computer and the functional requirements dictate extremely high reliability requirements. Proof of meeting this goal becomes difficult. To this end and in order to increase the confidence in the equipment, an out-of-scope TD was generated for a life test program on one AGC.

The inertial components, the IRIG's and PIPA's, are especially critical instruments. Their operation greatly affects the reliability of the inertial sub-system. Reliability Assurance Test Programs have been recently initiated on both these units and sub-assemblies, and actual testing is now underway. The results of these tests will assist in establishing mission reliability, determine the useful life of the instruments, and determine the effect of intermittent operation.

A test program is currently being planned on approximately twenty critical flight replacement level assemblies of the PSA. This test is being designed as a mission simulation test similar to that of the total system. Performance for nominal environmental and stress levels during thermal-vacuum exposures (as encountered in emergency situations) will be assessed. Parameter stability during life tests will also be obtained.

The above Reliability Tests, supported with data from the Evaluation, Qualification, Production Acceptance, Command Module Environmental and Flight Tests will be the basis for assessing the Apollo Guidance and Navigation System reliability achievements.

G. Parts and Materials

1. Approved and Preferred Parts Program

Major effort at the present time is being directed towards the generation of SCD's. The program of preparing preliminary SCD's, negotiating requirements with vendors, and releasing formal SCD's through the Change Control Board has been maintained on schedule. The total number of SCD's either under preparation or released by November 1, 1963, was 1126. A more detailed breakdown of status is as follows:

(a) Total No. of SCD's for flyable equipment:	515
Released Class "A":	428
Percentage released:	83.1%

(b) Total No. of SCD's for Ground Equipment:	611
Released Class "B":	512
Percentage released:	83.8%
(c) Total percentage of released SCD's:	83.5%

Note: Where parts are used in both flight and ground equipment, only the flight requirements were used in calculation of this data.

New SCD's are being initiated at the present time either by a participating contractor due to additional program requirements, or by the Reliability Group for upgrading purposes. It should be noted that such documents are also included in the above tabulations.

Parts which are being re-evaluated are (1) those which have found their way into the system, but in which there is not complete confidence, (2) those whose performance in breadboards is questionable, and (3) those which do not have sufficient reliability performance data published. Data sources consulted include IDEP GMDEP , the Marshall Space Flight Center parts list, the parts information index, and also information supplied by the participating contractors. From the inputs received, new vendors and/or parts are being recommended to replace those found to be inferior.

New SCD's are being promulgated by the Reliability Group to supersede documents which permittedthe use of undesirable materials such as cadmium and zinc.

SCD's are being reviewed for format, content, material, and reliability requirements.

SCD's are reviewed by WESCO to insure compliance with the Apollo Drawing Standard Manual E-1167. WESCO's comments are then evaluated and prompt action is taken where electrical or mechanical parameters are concerned. However, since most of WESCO changes concern format, they are not urgent. MIT thus plans to combine this type of change with others as the opportunity arises. This procedure enables MIT to process changes in an orderly, practical, and efficient manner.

The contents of the SCD's are reviewed for electrical and mechanical requirements by the cognizant engineers, and for reliability requirements by the Reliability Group. The reliability review includes burn-in and qualification requirements as well as an evaluation based on the preferred parts program.

Documents with supplementary data information, prepared by the participating contractors covering their negotiation with vendors, are being reviewed and assessed by MIT/IL Reliability. These documents contain the details of waivers and deviations requested by the vendors in order to meet the delivery schedules required by the contractors. The main areas under scrutiny are exceptions taken to the qualification document, deviations granted to the quality assurance document, and nonconformance to the lead material documents.

An assessment of these negotiated documents will be completed by MIT during the next reporting period, and action will be taken to resolve significant problem areas.

2. Exchange of Parts and Material Information

During this reporting period, MIT has continued its program of exchanging parts and material information with the associate Apollo contractors. Such information is made available to them through the NASA Resident Apollo Space Project Office located at each contractor's facilities. The following is a summary of the various MIT documents that are distributed to NAA, GAEC, AMR, MSC and NASA White Sands Missile Range for their use.

a. Qualification Status List (QSL)

A listing of all procured parts and materials used in the Apollo G&N equipment is maintained by MIT and

and published biweekly in the QSL. This document contains complete identification information on each item by including its name or description, SCD number, manufacturer, and manufacturer's type number The drawing status and qualification status is given along with the name of the participating contractor that has been assigned qualification test responsibility for the item.

Test reports, containing the results of tests showing that the item has the capability of meeting the qualification requirements specified for the parts, are then referenced. Finally, the QSL defines the level of process control required of the supplier, while also identifying the G&N assemblies where the item is used.

b. Aperture Card File

Upon release by MIT, all drawings and referenced documents that define the Apollo G&N design are reduced by microfilming process and placed on aperture cards. Complete files of these cards are maintained at each associate contractor's facility and NASA installation referenced above.

c. Standard Parts Manual

The MIT Apollo Standard Parts Manual contains a complete compilation of SCD's on parts and materials used in the G&N system design.

d. Test Program Index (R-389)

The requirements for and the indexing of the overall Apollo G&N system test effort are described and defined in the "Requirements of and Index to Design Evaluation, Qualification, and Reliability Test Program for Apollo Guidance and Navigation System," MIT Report R-389 (Rev. A). Each test has been indexed and responsibilities have been assigned for the test performance and reporting effort. Since provisions have been incorporated in this document for periodically updating the

[redacted]

contents as tests are completed, MIT, participating contractors, and NASA have a ready reference of test status.

e. Materials Listing

The materials list maintained by MIT contains a compilation of all materials and finishes used in the Apollo G&N equipment. This list has been made available to the associate contractors for their reference. When additional information is assembled, regarding material interfaces and compatibility, a formal report will be issued with a distribution including NAA and GAEC.

Upon request through the normal channels established for obtaining MIT information, the test plans and reports which are generated by MIT and by the participating contractors for the various test programs described above are also available to the associate contractors.

H. Reliability Analysis and Apportionment

1. Subsystem Reliability Analysis

During the period covered by this report, many different and varied approaches were taken to predict or assess the reliability of the Apollo Guidance and Navigation System. Various studies were conducted to analyze various design approaches and the feasibility of back-up modes from a reliability standpoint for both Command Module and LEM systems. Since these were of significance only at the time and of no historical importance, no attempt is made to describe them here. Rather, it appears more pertinent to discuss the reliability of the G&N system as it is currently envisioned for the lunar landing mission.

Reliability apportionments to G&N, as presented recently by the spacecraft contractors, are indicated below. Our analysis indicates that G&N is capable of attaining these objectives for mission success within our weight and space allocation and without requiring in-flight maintenance.

[redacted]

Vehicle	Mission Success	Crew Safety
C/M	0.98504	0.999913
LEM*	0.99476	0.999836

The basic Guidance and Navigation System consists of 5 elements and associated displays. These are the Inertial Measurement Unit (IMU), the Optics (Sextant and Telescope), the Power and Servo Assembly (PSA), the Computer (AGC), and the Coupling and Display Units (CDU). The PSA of course is the analog electronics for both IMU and Optics while the CDU is an electronic assembly to provide digital and analog conversion of information exchanged between the IMU, Optics, AGC, and other spacecraft systems.

For the purpose of this analysis, a basic nominal mission of 140 hours was assumed. The mission was divided into various operational phases consistent with the functions to be performed and operating time for each element accumulated only while it was required to perform.

At other times during the flight, equipment will be turned off or unpowered. Certain elements of the system which function continuously such as heaters, 3200 cps power supply, clock, and failure indicator were taken into consideration for operating times.

It should be noted that the current configuration of the AGC provides for four assembly trays, only two of which are required for successful operation. In the event of failure,

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*The data published by GAEC for LEM sub-systems does not define sharply the apportionments to Guidance and Navigation. The numbers shown above are our best estimates, using available data.

[redacted]

switching to the appropriate redundant tray will be accomplished by the astronaut or automatically.

Although some missions may be of duration longer than 140 hours, this was chosen as representing the nominal length of mission permiting, as it does, a reasonable period for lunar surface exploration. The time out and back when G&N equipment is utilized most will remain the same regardless of the length of lunar stay. Since G&N will be operating only intermittently during lunar operations, increasing this time period is felt not to be of major significance to G&N reliability assessment.

As can be seen, our current analysis does not depend on spares and in-flight maintenance of either C/M or LEM equipment to meet mission success requirements. Should this at some future date ever prove to be desirable, the present configuration of the G&N system is readily adaptable. Ease of producibility, testing, and field support as well as ultimate system reliability are dependent upon modularization of the complex electronics assemblies. The MIT design takes these factors into consideration whether or not-flight maintenance is in vogue.

Tables 1 through 12 are presentations of Block 2 G&N system and sub-system reliability analyses for both C/M and LEM configuration.

[redacted]

[redacted]

TABLE I
SYSTEM PART COUNT

	IMU	AGC	PSA	OPTICS	CDU(1)	DSKY(1)
Accelerometer	3					
ADA	3					
Bearing	6			58		
Blower	2					
Capacitor, Ceramic	9	31	270		20	
" Glass		10	22			2
" Mica						
" Mylar			75			
" Paper	2		64			
" Plastic	3					
" Tantalum	18	240	350		58	18
" Polystyrene	48		2			
Chopper			16		2	
Connector, Electrical	40	66	95	12	1	
Core, Ferrite		16,384				
" Tape		3,072				
" Assembly		24				
Counter				1		
Crystal		1				
Diode, General Purpose		2	450		49	
" Switch		2,077	125			507
" Zener	16	19	156			
" Power Rectifier		6			18	
Filter						
Gyro	3					
Heater	15					
Inductor		136	30		2	
Lamp			4	14		
Magnetic Amplifier	2					
Micro-Nor Gate		4,060			442	
Relay		1	25			168
Resistor, Carbon Comp	21		100		257	
" Film	109	1,878	1750			159
" Variable	6		22			1
" Wirewound	38	96	245		72	2
" Temp Sensitive		1				

[redacted]

TABLE I (CONT)
SYSTEM PART COUNT (CONT)

	IMU	AGC	PSA	OPTICS	CDU(1)	DSKY(1)
Rotating Equipment						
Motor Tach				4		
Resolver	8			6		
Synchro						
Torque Motor	6					
Saturable Reactor						
Sense Amplifier		32				
Sensor, Temperature	9					
Slip Ring	6					
Switch						19
Thermistor	6	5	3			
Thermostat	3					
Transformer	7	122	182			1
Transistor, Low Power	6	311	210		144	72
" Med Power	2	126	110			15
" Power	1	8	42			2
" Twin Pack	18	6	100			

TABLE II
FAILURE RATES

PART TYPE	DATA SOURCE	FAIL/10^6 HRS.
Accelerometer	MIT	3.0
ADA	MIT	3.0
Bearing	MIT	0.6
Blower	ACSP	2.0
Capacitor	ACSP, MIT	
Ceramic		0.1
Glass		0.1
Mica		0.05
Mylar		0.1
Paper		0.35
Plastic		0.2
Polystyrene		0.2
Tantalum		0.18
Chopper		0.5
Connector, Electrical	ACSP	0.02
Connection	MIT	0.0005
Core	IBM	0.0001
Crystal	HDBK-217	0.2
Diode		
General Purpose	ACSP	0.01
Switch	ACSP	0.01
Zener	ACSP	0.1
Gyro	MIT	10.0
Heater	MIT	0.1
Inductor	Earles	0.05
Lamp, Incandescent	HDBK-217	1.0
Magnetic Amplifier	MIT	0.5
Micro-Nor Gate	MIT	0.035
Relay	ACSP	2.0
Resistor		
Carbon Composition	ACSP	0.01
Film	ACSP	0.015
Variable	ACSP	0.4
Wirewound	ACSP	0.05

[redacted]

TABLE II (CONT)
FAILURE RATES

PART TYPE	DATA SOURCE	FAIL/10^6 HRS.
Rotating Equipment		
Motor Tach	MIT	5.0
Resolver	MIT	5.0
Torque Motor	ACSP	5.0
Sense Amplifier	MIT	0.5
Sensor, Temperature	Earles	1.0
Slip Ring	MIT	3.0
Switch	ACSP	1.0
Thermistor	HDBK-217	0.3
Transformer	ACSP	0.24
Transistor		
Low Power	ACSP	0.05
Medium Power	ACSP	0.25
Power	ACSP	0.5
Twin Pack	MIT	0.1

[redacted]

TABLE III

INERTIAL MEASURING UNIT

	n	λ	nλ
Torque Motor	6	5.0	30.0
Bearing	6	0.6	3.6
Blower	2	2.0	4.0
Slip Ring	6	3.0	18.0
Connector	34	0.02	0.68
Resolver	8	5.0	40.0
Ada	3	3.0	9.0
Thermostat	3	0.06	0.18
Switch	1	1.0	1.0
Magnetic Amplifier	2	0.5	1.0
Capacitor	2	0.35	0.7
Registor	3	0.015	0.045
Resolver Alignment Module	1	1.44	1.44
Emergency Heater Control	1	0.83	0.83
28V Regulator	1	0.4	0.4
16 PIP Assembly	3	6.807	20.421
25 IRIG Assembly	3	12.0	36.0
ADA Preamp	3	0.646	1.938
PIP Preamp	3	1.55	4.65
IRIG Preamp	1	1.968	1.968
Total IMU			175.852

MTBF = 5, 685 Hrs

[redacted]

TABLE IV

APOLLO GUIDANCE COMPUTER

Name	n	λ	nλ
Arithmetic*	16	5.094	81.504
GSA Service	1	4.681	4.681
Parity	1	5.056	5.056
Bank Register	1	5.131	5.131
Rupt Service	1	5.094	5.094
Ferrite Address	1	5.131	5.131
Telemetry	1	5.056	5.056
Ring Counter*	1	4.831	4.831
Scaler *	2	5.094	10.188
Time Pulse Counter	1	4.981	4.981
Control Pulse 1	1	4.869	4.869
Control Pulse 2	1	4.719	4.719
Control Pulse 3	1	4.719	4.719
Sequence Complex	1	4.944	4.944
Instruction Decode	1	4.007	4.007
Counter Service	1	4.869	4.869
Counter Priority	2	5.131	10.262
Alarms	1	4.007	4.007
Rate Circuits	1	4.981	4.981
Rope	6	5.021	30.126
Strand Gate	1	5.157	5.157
Strand Select	1	6.402	6.402
Rope Driver	2	11.328	22.656
Rope Sense Amplifier	2	8.497	16.994
Oscillator *	1	3.787	3.787
Erasable Memory Sense Amp.	2	8.641	17.282
Erasable Driver	2	9.445	18.89
Erasable Memory	1	3.194	3.194
Current Switch	1	17.252	17.252

---

*Continuous operation

[redacted]

TABLE IV (CONT'D.)

APOLLO GUIDANCE COMPUTER

Name	n	λ	$n\lambda$
Driver Service	1	5.099	5.099
Power Supply Control*	1	8.108	8.108
Power Switch Module*	3	2.7	2.7
Interface Type KX*	2	11.009	11.009
Interface Type YT	2	6.943	6.943
AGC Total			377.981

MTBF = 2,645 Hrs

TABLE V

COMPUTER DISPLAY AND KEYBOARD (DSKY)

	n	λ	nλ
Relay Tray*	4	0.81	3.24
Decoding Stick	3	3.68	11.04
Keyboard Module	1	21.555	21.555
Power Supply	1	2.09	2.09
Miscellaneous			2.0
DSKY Total			39.925

*Relay reliability determined to be 0.994 based on independent testing.

TABLE VI

POWER AND SERVO ASSEMBLY

	n	λ	nλ	Associated With
AC Differential Amp. and Interrogator	3	6.0 E	18.0 E	IMU Operation
Ternary Current Switch	3	5.165	15.495	IMU Alignment
DC Differential Amp.	6	2.959	17.754	IMU Operation
PIPA Calibration Module	3	1.45	4.35	IMU Operation
Pulse Torque Gyro Calibration	3	1.76	5.28	IMU Operation
Gimbal Servo Amplifier	3	1.828	5.484	IMU Operation
Gimbal Coarse Align. Amplifier	3	3.707	11.121	IMU Alignment
-28V DC Power Supply	1	3.035	3.035	IMU Operation
1% Power Amplifier (3200 CPS)*	1	6.267	6.267	Continuous Operation
Auto-Amp Control (3200 CPS)*	1	4.034	4.034	Continuous Operation
Failure Indicator (IMU-CDU)*	1	7.289	7.289	Convenience Equip.
1% Power Amplifier (800 CPS, 28V)	2	1.17	2.34	Optics & IMU
5% Power Amplifier (800 CPS, 28V)	3	2.1	6.3	Optics & IMU
Auto-Amp Control (800 CPS)	2	0.267	0.534	Optics & IMU
Pulse Torquing Power Supply	1	11.866	11.866	IMU Operation
Load Compensation - IMU	1	0.9	0.9	IMU Operation
Temp. Control Power Supply*	1	1.846	1.846	Continuous Operation
Binary Current Switch and F-B Counter	3	6.7 E	20.1 E	IMU Operation
CDU Zeroing Transformer and Relays	1	10.24	10.24	IMU Alignment
CDU Fixed Resolution T & E Mode	1	1.26	1.26	IMU Operation
IMU Temp. Indicator and Backup*	1	5.24	5.24	Continuous Operation
Temperature Controller*	1	2.9	2.9	Continuous Operation
CDU Resolver Loads	1	1.31	1.31	IMU Operation
CDU Zeroing and Lock Relays	1	4.0	4.0	IMU Alignment
Diode and Filter Module*	3	0.25	0.75	Continuous Operation
3 Volt Power Supply	1	5.0 E	5.0 E	IMU Operation
Cosecant Amplifier	1	1.595	1.595	Convenience Equip.
Resolver Drive Amplifier	1	2.184	2.184	Optics
Relays	2	12.4	24.8	Optics
Buffer Circuit	2	4.492	8.984	Convenience Equip.

TABLE VI (CONT'D.)

POWER AND SERVO ASSEMBLY

	n	λ	nλ	Associated With
Zero Optics Transformer	1	0.44	0.44	Optics
Resistor and Capacitor	1	1.29	1.29	Optics
Isolation Transformer	1	0.25	0.25	Optics
Load Compensation - Optics	1	0.8	0.8	Optics
Motor Drive Amplifier	4	1.897	7.588	Optics
PSA Total			220.626	

MTBF = 4530 Hrs

E - estimate of module failure rate

* - continuous operation

TABLE VII

POWER AND SERVO ASSEMBLY (LEM)

	n	λ	nλ	Associated With
Gimbal Servo Amplifier	3	1.828	5.484	IMU Alignment
Gimbal Coarse Align. Amplifier	3	3.707	11.121	IMU Operations
-28V DC Power Supply	1	3.035	3.035	IMU Operations
1% Power Amplifier (3200 CPS)	1	6.267	6.267	IMU Operations
Auto-Amp Control (3200 CPS)	1	4.034	4.034	IMU Operations
Temp. Control Power Supply	1	1.846	1.846	IMU Operations
1% Power Amplifier (800 CPS, 28V)	1	1.17	1.17	IMU Operations
5% Power Amplifier (800 CPS, 28V)	2	2.1	4.2	IMU Operations
Auto-Amp Control (800 CPS)	1	0.267	0.267	IMU Operations
Pulse Torquing Power Supply	1	11.866	11.866	IMU Operations
Load Compensation - IMU	1	0.9	0.9	IMU Operations
4V Power Supply	1	5.0 E	5.0 E	Convenience Equip.
Failure Indicator (IMU-CDU)	1	7.289	7.289	IMU Operations
AC Differential Amp. and Interrogator	3	6.0 E	18.0 E	IMU Operations
Binary Current Switch and F-B Counter	3	6.7 E	20.1 E	IMU Operations
DC Differential Amp.	6	2.959	17.754	IMU Operations
PIPA Calibration Module	3	1.45	4.35	IMU Operations
Pulse Torque Gyro Calibration	3	1.76	5.28	IMU Alignment
Ternary Current Switch	3	5.165	15.495	IMU Alignment
CDU Zero and Lock Relays	1	4.0	4.0	IMU Operations
CDU Fixed Resolution Transf.	1	1.26	1.26	IMU Operations
IMU Temperature Controller	1	2.9	2.9	IMU Operations
IMU Temperature Indicator and Backup	1	5.24	5.24	IMU Operations
CDU Resolver Loads	1	1.31	1.31	IMU Alignment
CDU Zeroing Transformer and Relays	1	10.24	10.24	IMU Operations
G & N Subsystem Filter	2	0.25	0.5	
PSA Total			168.908	

MTBF = 5,920 Hrs

E - estimate of module failure rate

TABLE VIII

ELECTRONIC CDU

	n	λ	$n\lambda$
Micro-Nor Gate	442	0.035	15.47
Operational Amplifiers	9	1.39	12.51
Switch Type 1	31	0.31	9.61
Switch Type 2	11	0.18	1.98
Resistor, Wirewound	72	0.05	3.6
Chopper	2	0.5	1.0
Filter	2	0.15	0.3
Transistor, Low Signal	4	0.05	0.2
CDU TOTAL			44.67

MTBF = 22,400 Hrs

TABLE IX

SEXTANT AND TELESCOPE

		Fail/10^6 Hrs
Sextant Assemblies		
Head Assembly		22.298
Shaft Axis Assembly		9.071
Eyepiece and Panel		0.240
Shaft Drive Gearbox		19.442
Base Harness		0.072
	Total Sextant	51.123
Telescope Assemblies		
Gear Cluster and Base		1.663
Shaft Drive Gearbox		22.165
Trunnion Drive Gearbox		27.901
Base Harness		0.1
Trunnion Axis Assembly		8.604
Eyepiece and Panel		8.689
Shaft Axis Assembly		11.5
	Total Telescope	80.622
	Total Optics	131.745

MTBF = 7,590 Hrs

TABLE X

LEM TELESCOPE

Assembly	Fail/10^6 Hrs
Trunnion Axis Assembly	5.7
Shaft Axis Assembly	5.0
Trunnion Drive Gearbox	15.0
Shaft Drive Gearbox	10.0
Drive Gear Cluster Assembly	1.2
Eyepiece and Panel Assembly	1.9
Differential	4.2
Total Telescope	43.0

MTBF = 23,250 Hrs

TABLE XI

[redacted]

C/M GUIDANCE AND NAVIGATION RELIABILITY

BLOCK 2 CONFIGURATION

EQUIPMENT	FAILURE RATE Fail / 10^6 Hrs.	TIME (Hrs.)	RELIABILITY Component	RELIABILITY Subsystem
Power Servo Assembly				0.994
Optics Electronics	40.9	18	0.999264	
IMU Align Electronics	40.9	2	0.999918	
IMU Full Power Electronics	106.4	31	0.996703	
IMU Continuous Operations	13.4	138	0.99815	
IMU	137.0	31		0.99575
CDU				0.9942
IMU operations (3 units)	134.0	31	0.9958	
Optics Operations (2 units)	89.34	18	0.9984	
AGC				0.999913*
Logic Tray (Full Power)	185.8	19	0.99647	
Logic Tray (Stand by)	29.1	138	0.99598	
Memory Tray (Full Power)	143.1	19	0.99728	
Memory Tray (Stand by)	20.0	138	0.99723	
Optics				0.9985
Sextant	47.1	15	0.9993	
Telescope	44.0	18	0.9992	
DSKY				0.999954**
Electronics	39.9	19	0.99924	
Relays	Relay Reliability determined by cycle operations		0.994	
G & N SYSTEM				0.9824

*Based on redundant AGC trays

**Determined for two redundant equipments

[redacted]

TABLE XII

LEM GUIDANCE AND NAVIGATION RELIABILITY

EQUIPMENT	FAILURE RATE Fail/10^6 Hrs.	TIME (HRS.)	RELIABILITY	
			Component	Subsystem
IMU	137.0	7		.999
POWER SERVO ASSEMBLY				.99986
IMU Alignment	40.8	4.75	.999806	
IMU Operations	120.8	7	.999155	
AGC	330.0	7		.99769
CDU				.99897
IMU Operations (3 Units)	134.0	7	.999062	
Radar (2 Units)	89.34	1	.999911	
OMU	43.0	1		.999957
G & N SYSTEM				.9946

The failure rates and MTBF values that are included as a part of each subsystem analysis (IMU, PSA, AGC, etc.) consider the entire unit and its possibility of failure regardless of the consequences of failure on mission success. Results of the FEA (failure effects analysis) indicate that an integral part of each subsystem are failure indicators, alarms, redundant electronics, telemetry, signal conditioning, or convenience equipments which could fail in whole or part and not necessarily detract from G & N mission success probabilities. Reliabilities of redundant electronics were calculated using standard statistical techniques. Failure rates of failure indicators, alarms, and convenience equipments were not included in the reliability evaluation unless the operation of redundant equipments required these indicators.

Tabulated below are the equipments and the circuits which were excluded from reliability calculations, and also redundant equipments whose probabilities of failure are insignificant.

The IMU failure rate reduces to an equivalent of 137 failures/10^6 hrs. when considering the failure effects of the following equipments:

Torque motors - redundant

Blowers - redundant

Thermostats - redundant

Magnetic Amplifiers - redundant

Emergency Heater Control - redundant

ADA, Gyro, and PIP Preamps - part type failure data has shown that approximately 33% of experienced failures are due to part degradation. Since degradation of this type cannot affect IMU operation, the preamp failure rates have been reduced accordingly.

Certain elements germane to C/M computer operation can be eliminated from the LEM AGC, and thus the failure rate is reduced to 330 failure/10^6 hrs. These circuits include alarms, telemetry, interface, extraneous logic, and fixed memory as it is expended during the mission.

The effective failure rate of the PSA can be reduced to approximately 200 fail/10^6 hrs. by considering the failure indicators, buffering circuits and the cosecant amplifier as incidental to mission success.

By considering the redundant operation of reticle lamps, mechanical counters and a manual SCT drive, the C/M optics failure rate is effectively 91 fail/10^6 hrs.

It should be noted that C/M, LEM D & C equipment and LEM DSKY analyses have not been included in this report since failure modes and effects of failures on mission success have not yet been established to the required degree.

Suggested alternate configurations have considered redundant PSA power supplies and/or CDU inflight maintenance using spares. In the event that one of these routes is followed, G & N reliability will be increased as shown in the following table:

	G & N Reliability
No Spares	.9824
Redundant Power Supplies	.9847
Spare CDU	.988
Spare CDU & Redundant Power Supplies	.99
CDU & PSA Spares	.9938

2. Failure Rates

Failure rates utilized in this analysis of G & N system reliability are shown in Table II with a general note as to source. A concerted attempt was made to establish new rates and use old rates obtained on similar types or equipment with which M.I.T. and participating contractors have had intimate experience. These were compared with more generally published data such as contained in MIL Handbook 217 and the Martin Company Handbook "Reliability Application and Analysis Guide." Large inconsistencies were scrutinized closely and differences resolved.

Failure rates for electronic components represent actual experience on these parts in systems where derating criteria are as shown in the following table. Similar criteria have been used in the design of G & N electronics.

TABLE XIII

Component	Stress Ratio (applied/rated)
Resistors, Carbon Comp.	0.40
Resistors, Metal Film	0.50
Resistors, Wirewound	0.40
Capacitors, Tantalum	0.60
Capacitors, Ceramic	0.20
Capacitors, Mylar	0.20
Transformers	Not to exceed temp. rating of insulation
Semiconductors	0.50 (voltage rating) Max. Junction Temp. 105°C.

In applying these failure rates in our analysis, the actual stress for each part was considered and the basic failure rate was then modified through the use of curves showing the effect on failure rate of varied stress and temperature conditions. Sample curves are included herein as Figs. 3 through 6. These are similiar if not identical to data that has been generally published in the industry.

Since the stress ratios shown in Table XIII are average values, it became convenient to establish an average basic failure rate which could be used as a reference point in determining the failure rate of components whose stress ratio differed from the average. Such a failure rate was calculated for each of the different types of components. By knowing the relationship $\lambda A = K \lambda B$ one can solve for λB where:

λA = actual failure rate achieved from field data (see Table II)

λB = basic failure rate

K = application factor, dependent on operation temperature and stress conditions. In all of our calculations, 60°C is assumed to be the operating temperature of the components.

A sample calculation to determine λB for a film resistor is as follows:

λA = 0.015, from Table II

K = Table XIII shows the average stress level of film resistors to be 0.50. The graph in Fig. 3 shows that for a 0.50 stress level and 60°C operating temperature, K equals approximately 1.2

$$\lambda B = \frac{\lambda A}{K} = \frac{0.015}{1.2} = 0.0125$$

This value then becomes the basic failure rate for film resistors. Having established a basic failure rate for this component, a sample calculation can now be shown for determining the expected failure rate. Let the power being dissipated in a 1/4W film resistor be 80 milliwatts at 60°C body temperature. The stress ratio then becomes $\frac{80 \text{ MW}}{250 \text{ MW}} = 0.32$; next, the application factor is found from the graph in Fig. 3 by using a 0.32 stress ratio at 60°C. This turns out to be about 0.9. The expected failure rate of this resistor then becomes $\lambda A = K\lambda B = (0.9)(0.0125) = 0.011/10^{6}$ hrs. There has been established a lower limit failure rate of $0.008/10^{6}$ hours for all resistors regardless of how lightly stressed they may be.

Similiar techniques are used for determining capacitor failure rates in a D.C. circuit. For A.C. applications, circuit frequency becomes a factor and different criteria are used which take this into consideration.

A junction temperature of 105°C has been established as a basis for deriving failure rates of semiconductors. For purposes of this analysis, we have conservatively assumed that each 10°C rise in junction temperature above 105°C will cause the failure to double, and that for temperatures lower than 105°C the failure rate is constant.

Sample Calculation

Let the power being dissipated in a 2N2605 transistor be 1.3w at 60°C case temperature. The thermal resistance of this device from junction to case is 40°C/w. The junction temperature is then $(40^{\circ}\mathrm{C/w}) \times (1.3\mathrm{w}) + 60^{\circ}\mathrm{C} = 112^{\circ}\mathrm{C}$.

The basic failure rate* then is obtained from Table II as $0.25/10^6$ hrs. This is now doubled because the junction temperature exceeds by 7°C the 105°C that has been established as a base. The anticipated failure rate would be $0.50/10^6$ hrs.

Appendix B contains a typical example of the stress analysis sheets made out on all circuits at the time of their submittal for design review. This particular circuit is the Failure Indicator located in the Power and Servo Assembly.

3. Circuit Stress Analysis

Work has been continuing on the reliability analysis of each electrical circuit presented for Class A release. There has also been an effort to update all previous such analyses based on revised failure rate information and circuit design changes. Following is a list of all the circuits analyzed to date:

(a) Power and Servo Assembly

Circuit	Schematic Number
-28V Power Supply	1010025
Motor Drive Preamplifier Integrator	1015112
CDU Encoder Electronics	1010034
25.6 KC Power Supply	1010029
Motor Drive Amplifier	1015116
Motor Drive Amplifier and Selector	1010035
CDU, Digital to Analog Converter	1010041

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*The failure rates listed in Table II are basic only to semiconductors; for other electronic components, the basic failure rate must be calculated as explained above.

Circuit (cont'd)	Schematic Number (cont'd)
25.6 KC Power Supply	1010029
Motor Drive Amplifier	1015116
Motor Drive Amplifier and Selector	1010041
Ternary Current Switch	1010016
2-Speed Switch	1015102
Cosecant Generator	1015148
Resolver Drive Amplifier	1015120
Buffer Circuit	1015126
1% Power Amplifier, 800 cps	1010045
Automatic Amplitude Control, 800 cps	1010044
5% Power Amplifier, 800 cps	1010046
Gimbal Servo Amplifier	1010024
Gimbal Coarse Alignment Amplifier	1010023
Interrogator	1010013
1% Power Amplifier, 3200 cps	1007044
Automatic Amplitude Control, 3200 cps	1010047
Temperature Controller Power Supply, 3200 cps	1010049

(b) IMU Mounted Electronics

IRIG Preamplifier	Schematic 1010021
ADA Preamplifier	Schematic 1010022

I. Logistics and Maintenance

During this period a report on "Statistical Decision

Theory for Logistics Planning" (E1350) was prepared for general distribution and for presentation at the annual meeting of the Operations Research Society of America. The procedures developed in this report for obtaining and using subjective estimates of failure rates, spares requirements, and shortage consequences are currently being utilized to a limited extent for Apollo maintenance analysis and spares provisioning. These same procedures are designed for eventual possible application to reliability predictions. The report illustrates how subjective estimates of component or system failure rates can be obtained in a form which measures this information as equivalent to a test program of a certain size. This technique, called Bayesian statistical analysis, can have significant use when fairly good subjective information is available and when testing of highly reliable items would be costly and time consuming.

Parts of this statistical decision theory procedure were used for the August, 1963 Apollo provisioning conference. A simplified operational version of the procedure is currently being documented for possible Electronic Data Processing Machine implementation in order to be used before updating of requirements at the next provisioning conference.

A model for computing overall mission reliability known as the contingency tree analysis has been developed. This technique includes an estimate or computation of various modes and states of failure throughout the mission. The contingent degree of mission degradation for each possible mode and state (or stage) is then evaluated. Finally, by an "averaging out and folding back" computation, the overall expected degradation, and hence mission reliability, is easily found. This and other notes on reliability computation will be published in APM 697.

J. Data Center

The Reliability Technical Data Center, an integral part of the Reliability Group, has been providing a continual supporting effort to the Engineering Design Group engaged in the Apollo Program. The following is a description of the various areas in which assistance has been given and a summary of requests fulfilled during this reporting period.

1. Maintenance of Qualification Status List, (ND 1002034). This document is updated semi-monthly and shows the current status of qualification of high reliability parts. Copies are distributed to NASA and all Apollo contractors.

2. Establishment of files and maintaining custody of original copies of G & N documents released through the CCB such as:

   Procurement Specifications (PS'S)
   Material, Parts and Process Specifications (PS'S, ND'S)
   Factory Test Plans
   Final Test Methods (FTM'S)
   Assembly Test Procedures (ATP'S)
   Specification Control Drawings (SCD'S)

3. Maintenance of Military and Federal Specification Files.

4. Custody of original Class A Apollo Drawings generated by MIT and sub-contractors.

5. Custody of Master Aperture Cards of all drawings related to Apollo G & N and associated TDRR'S, (Technical Data Release or Revision) after release from the CCB (Change Control Board).

6. Maintenance of IDEP/GMDEP Reports.

7. Maintenance of copies of all Apollo G & N waiver actions.

8. Maintenance of the "Industry File" relating to materials and components used in the Apollo G & N. Includes specifications, standards, and related reading matter from the following associations:

AMS Specs - Aerospace Material Specifications (Society of Automotive Engineers)

EIA - Electronic Industries Association

ASA - American Standards Association

NEMA - National Electrical Manuf. Association

ARINC - Aeronautical Radio, Inc.

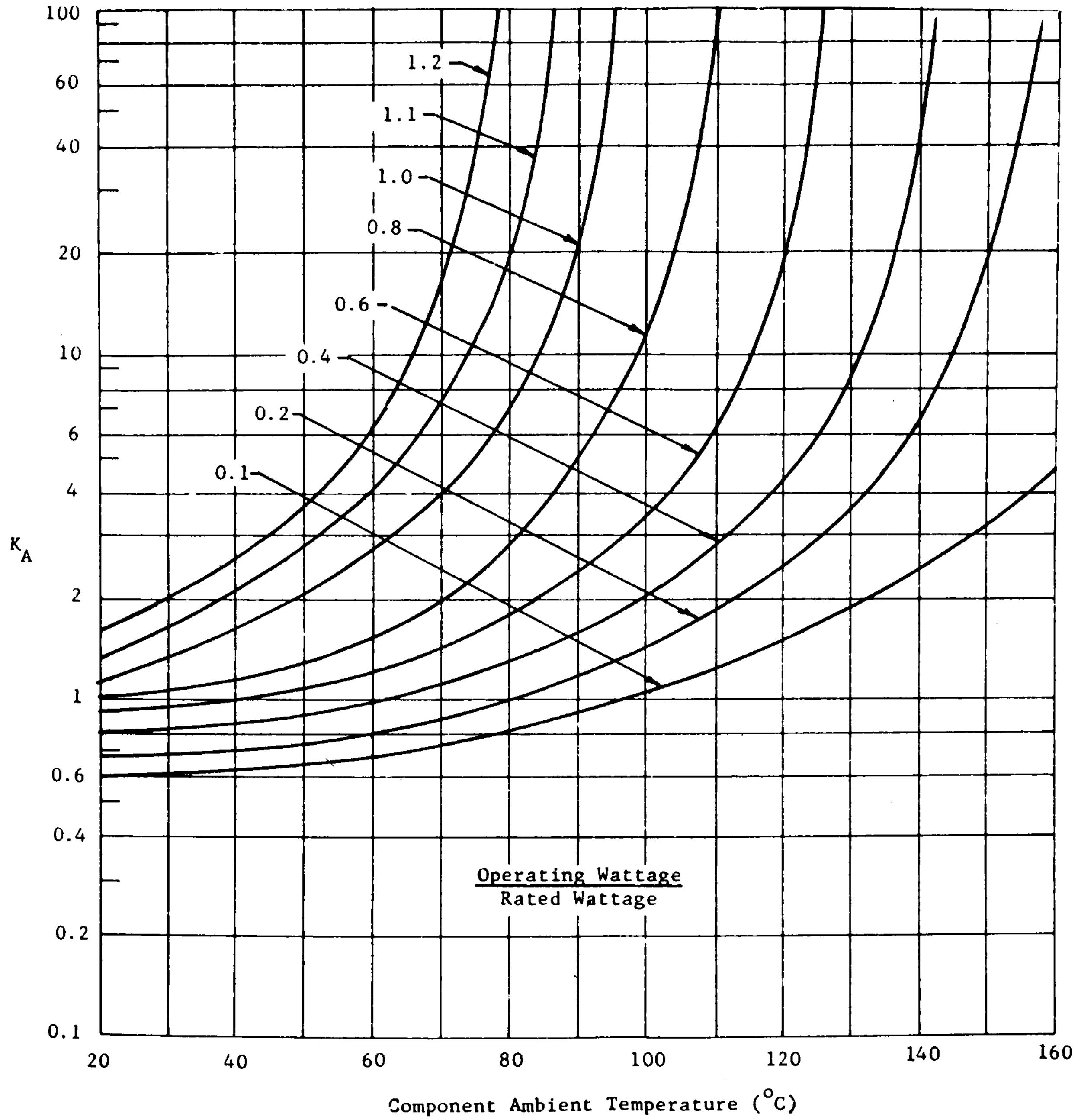
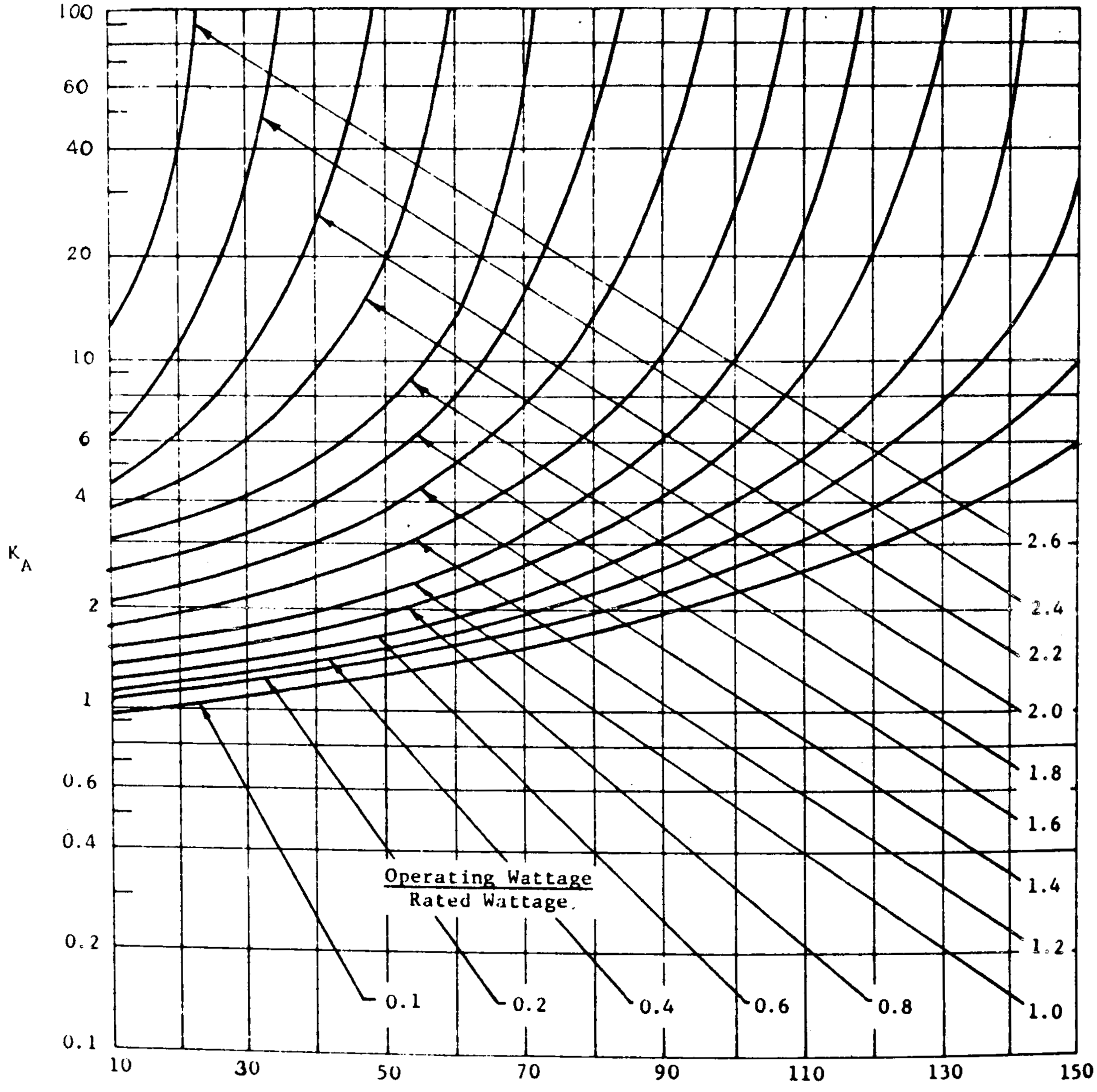


Fig. 3 Application Factors, K_A -- Resistors, Film



Component Ambient Temperature (°C)

Fig. 4 Resistors, Composition

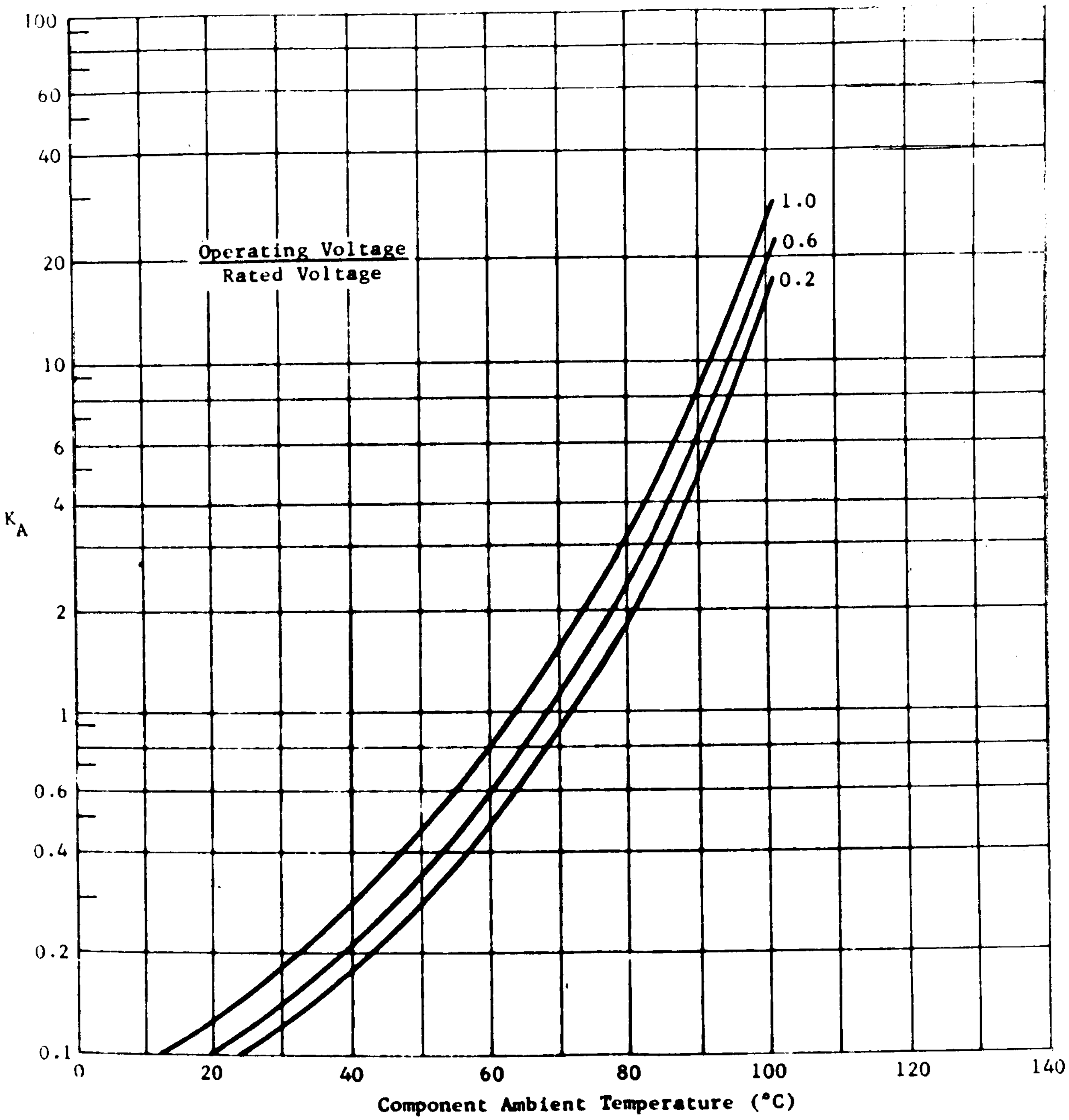


Fig. 5 Application Factors, K_A -- Capacitors, Tantalum

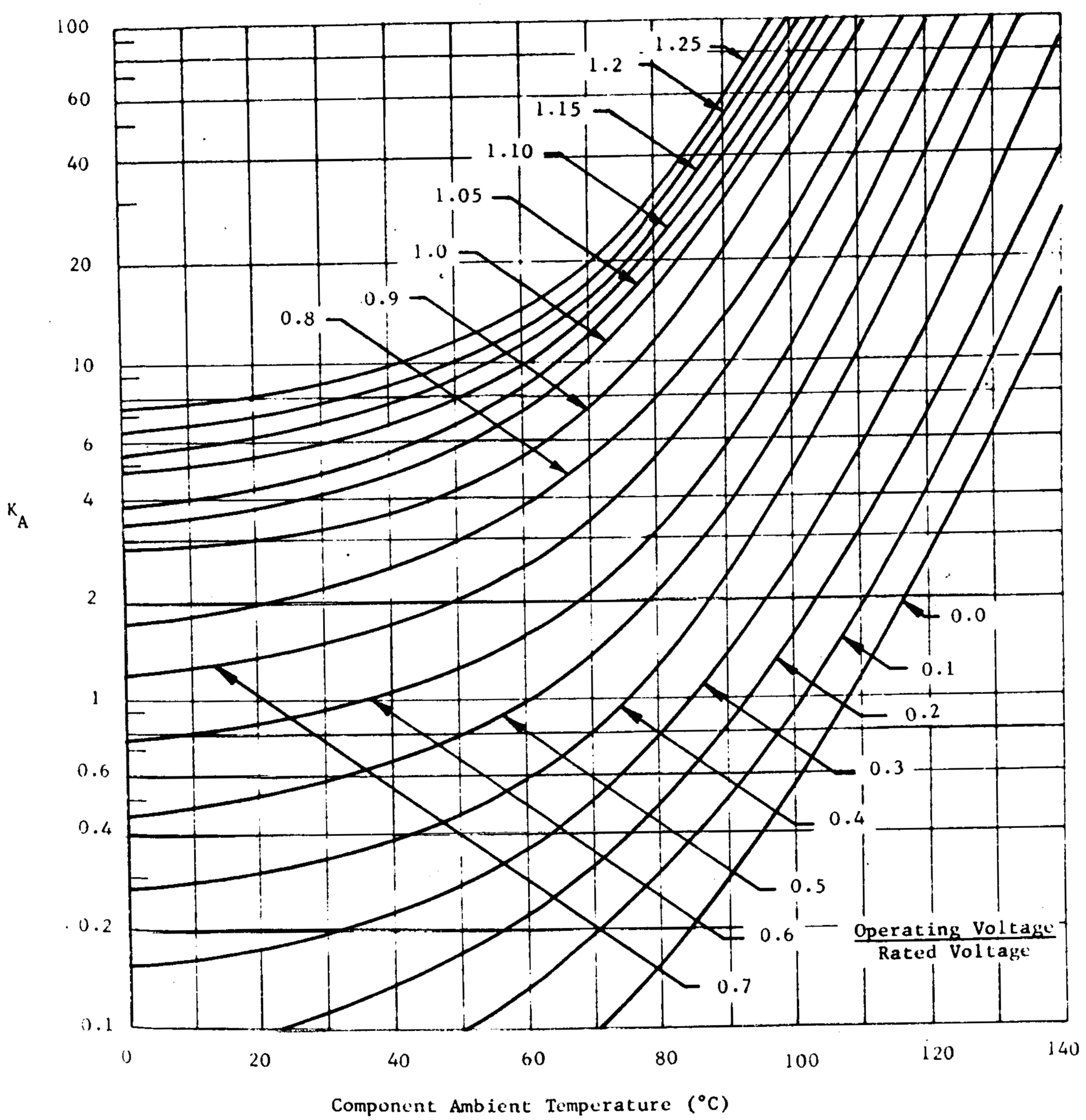


Fig. 6 Application Factors, K_A -- Capacitors, Ceramic

III QUALITY ASSURANCE PROGRESS REPORT

The Apollo G&N Quality Assurance Program has steadily increased in activity during this reporting period. The major effort of the participating contractors is in establishing the procedures and controls that will be used during the manufacturing process of the sub-systems that they are responsible for producing. The following is a summary of the progress and of the present status of the overall quality program. The details pertaining to the quality programs of each individual participating contractor are contained in their monthly progress reports.

A. Material Review

During a meeting in June at MIT, members of the participating contractors' quality organizations, MIT Reliability, and NASA RASPO agreed upon a common approach for material review activities. The procedure does not differ to any great extent from the generally accepted Material Review Board practice. Each contractor will establish an MRB and conduct reviews as required on discrepant material rejected during the manufacturing of Apollo G&N hardware. A method was developed which would permit MIT Reliability and NASA RASPO the right to review and disapprove each P.C. MRB decision. If MIT or NASA does not agree with the action taken, other action will be required. However, such notification of disapproval must be submitted to the P.C. MRB within ten days.

Each participating contractor has formalized his in-house MRB procedures and is currently conducting material reviews daily or whenever required. Besides performing reviews on all in-house discrepant material, any incoming material which is found discrepant and which has an impact on schedules is also reviewed by the board.

B Process Control

There are basically two areas in which process control is currently being applied: at the suppliers' or vendors' facilities and in the participating contractors' manufacturing operation. The suppliers and vendors of component parts and materials are required to comply with the provisions of the Apollo G&N Specification ND 1015404 which has three levels of control. Each supplier of parts and materials to be procured for use in flight hardware has been contracted by the appropriate participating contractors' quality organization and has agreed to the level of control that will be maintained over their processes. Due to the strictness of the requirements in this document, many suppliers have only reluctantly agreed to comply to the tight control features. The Apollo program will realize a major advancement in controlling the sources of parts and materials, thus enhancing the success of the mission. Future programs will of necessity be required to employ methods such as contained in ND 1015404 for the reliability requirements demanded.

Process control, within the participating contractors' facilities, is obtained through the adherence to specified military specifications or special Apollo G&N ND specifications on the manufacturing drawings. Each Apollo G&N ND specification is prepared by either MIT or the contractors, design reviewed for forement and adequacy of content, and processed by the Change Control Board for Class A release. Constant check is maintained by MIT Reliability to assure that no document is prepared which would duplicate an existing specification.

A specific example of such a process specification, jointly prepared by MIT, ACSO and Raytheon, is the "Apollo Requirements for Process Control and Fabrication of Resistance - Welded Electronic Circuit Modules and Assemblies," Apollo G&N Specification ND 1002005. Contained in this document is a coverage of equipment requirements, weld schedule determination, and required process controls.

Welding machine qualification, repeatability, and stability requirements are specified for checking the capability and accuracy of each machine employed in the fabrication of Apollo hardware. Set-up and process verification tests are described for daily exercise by the machine operator for assurance that the equipment is in good order for producing reliable quality welds. A program of periodic calibration is required by the specification for further assurance that machine drift during its production use will be held to a minimum.

The procedure for arriving at the correct weld schedule is delineated in ND 1002005. Electrical energy and electrode force levels are carefully determined by boxing in the optimum values for these prime characteristics. Along with the more elaborate metallurgical examination requirements, visual and strength criteria are also specified. Process control requirements contained in ND 1002005 apply to the ability of the machine and machine-operator combination to produce acceptable welds. This is accomplished by sample welds produced and tested prior to the commencement of daily production welding. Visual inspection of both sample and production type welds provides confidence that the welds are reliable and of good quality. Finally, all materials, in accordance with ND 1002005, must be free from foreign matter prior to being welded. In this manner, a high degree of assurance is obtained that the material being welded is in fact the same as that which was used to formulate the weld schedule.

For proper production and inspection of welded joints, a training program for both machine operators and inspectors is required by this process control document.

C. Inspection and Test Planning

Each participating contractor is currently revising his factory test plan to include the late changes and additions which inevitably arise during the early part of a production program. Test and inspection procedures and data sheets are under preparation for the various test points in the manufacturing cycle. These documents will comply in format and content as required by MIT report E 1087.

The present status of in-process test and inspection procedures at each participating contractor's facility is as follows:

Raytheon

Forty per cent of procedures and data sheets have been prepared with 100% completion anticipated by January 1, 1964.

KIC

One hundred per cent on in-process machine inspection documents completed along with 25% of assembly test and inspection sheets. Anticipated completion date: December 1, 1963.

ACSP

Sixty per cent of inspection and test sheets completed (total 1300). Anticipated completion date: January 1, 1964.

MIT is currently reviewing Assembly Test Procedures, Final Test Procedures, and Produrement Specifications for

Apollo G&N hardware. Problems thus far experienced in the review program have been centered around inadequate test descriptions and methods. MIT review comments will be submitted to the participating contractors for inclusion in the documents prior to their release.

D. Receiving Inspection

Receiving inspection of Apollo G&N parts and materials is being conducted by the participating contractors in accordance with the plans and procedures contained in their respective Quality Assurance Program Manuals. Each contractor's requirements for a receiving inspection operation are different since the subsystems for which they are responsible are different in types and quantity of parts and in materials used in manufacturing. It is expected that Raytheon will perform receiving inspection on the entire compliment of parts and materials that will be used. The Raytheon inspection equipment is now complete and operating. Certain semi-conductor devices are currently undergoing burn-in tests at Raytheon in order to provide assurance of improved stability and weed out drifters and earlier failures.

Kollsman, on the other hand, is procuring items that require the use of special testing and inspection equipment. Because of the limited use of this type of test equipment its procurement is impractical. Much of Kollsman's inspection work will therefore be performed at their suppliers'facilities with Kollsman quality personnel present to observe this work. AC Spark Plug inspection equipment requirements have not been firmed up as yet since the components they will inspect include new state-of-the-art items with increased accuracies. Smaller components of less accuracies are presently being inspected on a daily basis.

E. Procurement Documentation Review and Assessment

The various documents used for the procurement of parts and materials are reviewed in detail by the participating contractors' quality organizations before the orders are sent to the suppliers. The manufacturing drawings and SCD's are reviewed from a quality point of view to ascertain that both, specified physical and electrical characteristics and inspection and test requirements are adequate to insure a quality article. Purchase requests and purchase orders are reviewed for completeness and for the presence of any deviations that may degrade quality.

The method of procurement documentation review differs slightly within the quality organization of the P.C.'s. Raytheon and KIC quality personnel approve both the request and Purchase Order forms. Later, when the material is received, inspection is performed on only that material on which Purchase Orders were previously approved by quality assusance. In order to stay abreast of any changes, ASCP reviews all documents prior to supplier negotiation and receives all copies of deviations and waivers.

F. Supplier Rating Program

Each participating contractor has established a supplier rating program fashioned around his individual needs and situations. Since Raytheon buys in quantity, their rating system is based on percentage of lots accepted. Kollsman orders are for fewer parts and therefore their rating plans are based on the acceptability of piece parts. Kollsman is faced with a situation which makes a vendor rating program very weak. Unlike the AGC subsystem, the optical subsystem does not contain great numbers of like pieces. In consequence, Kollsman's supplier rating program will not be as effective as would like to be seen. Records will be kept, however, and a close surveillance made to uncover any indication of a slippage of quality. ACSP has found from experience that the best methods for them have proven to be supplier ratings based on the piece accepted. A considerable advantage in the rating program of ASCP has been that they have records of approximately 80% of the present suppliers from earlier programs.

G. Q. A. Audits

The program for Q. A. audits has been established during this reporting period at each participating contractor's facility. Forms, procedures, and check lists are part of each program although the details differ to some small degree. In order to assure that the maximum advantage will be gained, the audit teams are composed of quality engineers with adequate backgrounds and experience in the assigned audit areas. Quality audits are planned during the last part of October in each contractor's facility. Reports will include findings and recommended corrective action.

H. Government Furnished Property (GFP)

Although there is no definite indication that the GFP will be employed by the participating contractors, each contractor has prepared implementation plans should the occasion arise. These plans have been based on the requirements of NPC 200-2 and contain the following elements:

- Receiving and logging
- Calibration program
- Record initiation
- Use area monitored

In order to assure that such equipment will be kept in good repair throughout the period that this equipment is assigned to them, program plans will contain provisions for the preparation of specific maintenance and calibration schedules.

I. Training and Motivation

The regular MIT program for reliability training has continued during this reporting period with timely subjects being offered during the weekly Apollo seminars. The design review sessions have also provided an exceptionally good opportunity for explaining the necessity for reliability considerations in all phases of the design. It is during these reviews that the reasons for the methods and techniques of reliability can most effectively be explained. By carefully examining the design concepts and the methods deemed best to achieve the desired results, MIT engineers have gained the maximum reliability from the design reviews.

Reliability Bulletins on timely subjects and critical items are prepared for general distribution in order to insure that all MIT Apollo engineering groups are continually apprised of important reliability information.

To date the number of engineers and technicians who have attended and successfully completed the NASA soldering course from MIT is forty. It is only because the work load has increased so heavily during recent weeks at MIT that further attendance by MIT personnel will be postponed. The program has been considered very beneficial by all those who have attended the course.

MIT Reliability is continually reviewing local programs and seminars for the possible participation of MIT personnel. Such a program is being considered in the Boston area in the month of December.

The training programs conducted by the participating contractors have included courses in Field Engineering, Quality Assurance and Program Engineering. The programs include discussions on both quality and reliability subjects. Each participating contractor has taken advantage of the NASA soldering school by filling openings when the opportunity exists.

The G&N Familiarization Manual has been completed during this reporting period by AC Spark Plug with input from both Raytheon and Kollsman. Although the primary objectives of the manual are to present a course to familiarize the personnel of the contractors, (NASA, NAA, and AMR) with the G&N system the impact of such a course on reliability will be felt by all who attend the course.

APPENDIX A

SAMPLES OF THE "RELIABILITY REQUEST FOR ENGINEERING ACTION" FORMS

MIT INSTRUMENTATION LABORATORY
RELIABILITY REQUEST FOR ENGINEERING ACTION

NO. R-5

TO: R. Bottolfson RM: W6-379 GROUP Pace

FROM: W. Beaton EXT. 30-302

DATE: July 11, 1963 PROJECT Apollo

SUBJECT: Buffer Amp. Circuit-Schematic #1015126

REQUEST:

Replace CR 1, Motorola diode with SCD #1010265-13 for present circuit configuration or modify circuit to reduce electrical stress on this part to at least 50% of rated.

REASON:

The failure rate of semi-conductor devices is generally constant up to a junction temperature of 105°C. From this point it usually doubles for every 10°C rise. CR 1 in its present application has a failure rate which is about 100 times higher than that desired because of its high junction temperature.

REPLY:

DOCUMENTS AFFECTED:

EFFECTIVITY (IF APPLICABLE):

DATE: ______ SIGNATURE ______

PINK RETAINED BY:
ORIGINATOR

TP 7183-5

MIT INSTRUMENTATION LABORATORY

RELIABILITY REQUEST FOR ENGINEERING ACTION

NO. R-6

TO:	Frank Shewczyk	RM:	W7-367	GROUP	#37 EMD
FROM:	E. T. Driscoll	EXT.	30-324		
DATE:	July 31, 1963	PROJECT	Apollo		

SUBJECT: Heatsink Drawing #1015689

REQUEST: 1) Increase depth of hole in heatsink to allowable limit for transformer T2.

REASON: Present depth doesn't allow adequate room for transformer leads to properly align for mylar film without danger of shorting out transformer.

REPLY:

DOCUMENTS AFFECTED:

EFFECTIVITY (IF APPLICABLE):

DATE: ____________________ SIGNATURE ____________________

TP7183-5

PINK RETAINED BY:
ORIGINATOR

MIT INSTRUMENTATION LABORATORY

RELIABILITY REQUEST FOR ENGINEERING ACTION

NO. R-7

TO: E. R. Schildkraut RM: W5-166 GROUP PIP Elect.

FROM: W. Beaton EXT. 30-302 M.S.#23

DATE: Sept. 12, 1963 PROJECT Apollo

SUBJECT: D. C. Amp. & PVR #1010008

REQUEST: 1) Replace CR-3 with 1010286-14
CR-4 with 1010286-15
CR-5 with 1010265-15

2) Redesign circuit or spec Q2 and Q3 at 100 BVCEO. Both of these transistors are Fairchild 2N2060.

REASON: Siode junction temperatures are excessive from a reliability standpoint. CR-5 exceeds by 52° C manufacturers rating. Replacement of this diode with 1010265-15 is strongly recommended.

Q2 and Q3 are either at manufacturers rating for VCER or over it.

REPLY:

DOCUMENTS AFFECTED:

EFFECTIVITY (IF APPLICABLE):

DATE: ____________ SIGNATURE ____________

TP 7183-5

PINK RETAINED BY:
ORIGINATOR

MIT INSTRUMENTATION LABORATORY

RELIABILITY REQUEST FOR ENGINEERING ACTION

NO. R-9

TO: S. Katz RM: W7-302 GROUP Mech. Des.

FROM: W. Beaton EXT. 30-302

DATE: Oct. 10, 1963 PROJECT Apollo

SUBJECT: Temperature Controls

REQUEST: 1) Change CR14 in temp. control amp. #1001533 from 1010372 to 1010286-002

2) Change CR11 in indicating bridge amp. #1001650 from 1010372 to 1010286-002

REASON: 1) Dissipating too much power for reliable operation.

2) " " " " " " "

REPLY:

DOCUMENTS AFFECTED:

EFFECTIVITY (IF APPLICABLE):

DATE: SIGNATURE

TP 7183-5

PINK RETAINED BY:
ORIGINATOR

APPENDIX B

SAMPLE STRESS ANALYSIS SHEET

ELECTRONIC COMPONENT STRESS ANALYSIS

Assembly: FAILURE INDICATOR

Sheet 1 of 6
Dwg. No. 1010033

Date: Sept. 25 [illegible]
Prepared by: [illegible]
Ambient Air Temperature:

Circuit Symbol	Part Description: Vendor	Part No.	Type	Value	Other Characteristics	Rated: Power Dissipation Watts or MW*	Voltage	Operating Temperature*	Insulation Class (Magnetic Devices)	Applied: Calculated	Measured	Power Dissipation Watts or MW	Voltage	Operating Temp*	Duty Cycle	Optional: Stress Ratio	Failure Rate (10^6 Hrs.)	Remarks
											Error not Present	Error Present						
R1	CORNING	1006750	M.O.F.	3300	2%	1/4 W					120mw	0		60°C		.480	.015	
R2				6.2K							135mw	0				.540	.015	
R3				3.6K							120mw	0				.520	.015	
R4				47K							10mw	0				.34	[illegible]	
R5				68K							13mw	0				.052	.005	
R6				62K							11.5mw	4mw				.06	.009	
R7				62K							13mw	<1mw				.052	.009	
R8				1000							25mw	0				.135	.009	
R9	↓	↓	↓	51K	↓	↓					0	<1mw				[illegible]	.009	
R10	Allen-Bradley	1010369	C.C.	680K	5%	1/8 W					0	<1mw				[illegible]	[illegible]	
R11	CORNING	1006750	M.O.F.	62K		1/4 W					0	2.5mw				.012	.003	
R12				100K							0	9mw				[illegible]	[illegible]	
R13		↓		5100		↓					1mw	1mw				.004	[illegible]	
R14		1006760		1000		1/2 w					2.35mw	2.35mw				.450	[illegible]	
R15		1006750		51K		1/4 w					0	<1mw				.004	[illegible]	
R16				10K							0	22.5mw				.045	[illegible]	
R17				5100							0	<1mw				[illegible]	[illegible]	
R18				1000							0	49mw				.250	[illegible]	
R19				7500							65mw	65mw				.260	[illegible]	
R20	↓	↓	↓	3000	↓	↓					0	200				1.29	.30	
R21	DALE	[illegible]	W.W.	620	1%	750mw					0	160mw				.85	[illegible]	
R22	[illegible]	1006750	M.O.F.	1000	2%	1/4 W					0	[illegible]				[illegible]	.009	
R23	DALE	[illegible]	W.W.	620	1%	750mw					0	[illegible]				.85	.25	
R24	[illegible]	1006750	M.O.F.	1000	2%	1/4 W					0	25mw				.100	[illegible]	

Total Failure Rate (λ): .905

λ = 7.2[illegible]

MTBF $\frac{1}{\lambda} \times 10^6$ Hrs.

* For semi-conductors, use power dissipation at junction, collector or base, and case or body temperatures uniformly for both rated and applied conditions. Note which is used.

MIT Instrumentation Laboratory ECS 7/62

TP#6262

ELECTRONIC COMPONENT STRESS ANALYSIS

Sheet 2 of 6
Dwg. No. 1010037

Assembly: FAILURE INDICATOR

Date: Sept. 25, 1963
Prepared by: [illegible]
Ambient Air Temperature: ______

Part Description						Rated				Applied							Optional	Remarks
Circuit Symbol	Vendor	Part No.	Type	Value	Other Characteristics	Power Dissipation Watts or MW*	Voltage	Operating Temperature*	Insulation Class (Magnetic Devices)	Calculated	Measured	Power Dissipation Watts or MW	Voltage	Operating Temp*	Duty Cycle	Stress Ratio	Failure Rate (10⁶ Hrs.)	
											Error not present	Error present						
R25	DALE	1010604	WW	620	1%	750mW					0	6mw		60°c		.85	.20	
R26	CORNING	1006750	M.F.	1000	2%	¼ w					0	25mw				.10	.009	
R27		↓		200		↓					0	8mw				.132	.009	
R28		1006760		4700		[illegible]					[illegible]	0				.44	.015	
R29		1006750		4700		¼ w					[illegible]	0				.88	.03	
R30				4700							130mw	0				.52	.015	
R31				1000							25mw	–				.10	.009	
R32				51K							0	[illegible]				.004	.008	
R33				62K							10.5mw	11mw				.06	.009	
R34				62K							13mw	[illegible]				.052	.009	
R35	↓	↓	↓	62K	↓	↓					0	[illegible]				.012	[illegible]	
R36	Allen Bradley	1010369	C.C.	680K	5%	⅓ w					0	[illegible]				.008	[illegible]	
R37	CORNING	1006750	M.F.	100K	2%	¼ w					0	2mw				.036	.008	
R38		1006750		5100		¼ w					125mw	[illegible]				.50	.015	
R39		1006760		1000		½ w					[illegible]	[illegible]				.45	.015	
R40		1006750		10K		½ w					0	[illegible]				.09	.009	
R41				100K							0	[illegible]				.004	[illegible]	
R42				5100							0	[illegible]				.004	[illegible]	
R43				2000							0	5mw				.10	.009	
R44		↓		7500		↓					66mw	5mw				.26	.01	
R45		1006760		3000		½ w					0	[illegible]				.60	.016	
R46		1006750		10K		¼ w					0	2.5mw				.01	[illegible]	
~~R47~~		—														—	—	
R48	↓	1006750	↓	100K	↓	↓					0	2mw				.036	[illegible]	

Total Failure Rate (λ): .442

MTBF $\frac{1}{\lambda} \times 10^6$ Hrs.

* For semi-conductors, use power dissipation at junction, collector or base, and case or body temperatures uniformly for both rated and applied conditions. Note which is used.

MIT Instrumentation Laboratory ECS 7/62

TP#6262

ELECTRONIC COMPO*ENT STRESS ANALYSIS

Sheet 3 of 6
Dwg. No. 1010133

Assembly: FAILURE INDICATOR

Date: Sept. 2[illegible]
Prepared by: [illegible]
Ambient Air Temperature: ______

	Part Description					Rated				Applied						Optional		Remarks
Circuit Symbol	Vendor	Part No.	Type	Value	Other Characteristics	Power Dissipation Watts or MW*	Voltage	Operating Temperature*	Insulation Class (Magnetic Devices)	Calculated	Measured	Power Dissipation Watts or MW	Voltage	Operating Temp*	Duty Cycle	Stress Ratio	Failure Rate (10^6 Hrs.)	
											Error not present	Error present						
R49	CORNING	1006750	M.J.F.	62K	2%	1/4W					0	4mw		60°C		.016	.008	
R50		1006750		5100		1/4W					125mw	125mw				.500	.015	
R51		1006760		1000		1/2W					225mw	225mw				.450	.015	
R52		1006750		10K							0	22.5mw				.090	.009	
R53				100K							0	<1mw				.004	.008	
R54				5100							0	<1mw				.004	.008	
R55				1000							0	49mw				.200	.01	
R56		↓		7500		↓					1.6mw	1.6mw				.260	.012	
R57	↓	1006753	↓	3000	↓	1/2W					0	300mw				.600	.016	
C1	SPRAGUE	1006755	S.T.	1	10%		35V				30VDC	15VDC				.86	.253	
C2				1							25VDC	15VDC				.80	.24	
C3				1							0	.6VDC				.017	.005	
C4				47							0	15VDC				.43	.129	
C5				0.1							30VDC	15VDC				.86	.258	
C6				1							25VDC	15VDC				.72	.216	
C7				1							0	5VDC				.143	.043	
C8				47							0	15VDC				.43	.129	
C9				1							0	5VDC				.143	.043	
C10				47							0	15VDC				.43	.129	
C11				8.2							0	15VDC				.43	.129	
C12	↓	↓	↓	8.2	↓		↓				0	26VDC				.74	.222	
CR1	RAYTHEON	1010325	FAST SWITCH	1N660		250mw					<1mw	0				<.1	.01	
CR2											<1mw	0					.01	
CR3	↓	↓	↓	↓		↓					0	<1mw				↓	.01	

Total Failure Rate (λ): 1.932

MTBF $\frac{1}{\lambda} \times 10^6$ Hrs.

* For semi-conductors, use power dissipation at junction, collector or base, and case or body temperatures uniformly for both rated and applied conditions. Note which is used.

MIT Instrumentation Laboratory ECS 7/62

ELECTRONIC COMPONENT STRESS ANALYSIS

Assembly: FAILURE INDICATOR

Sheet 4 of 6
Dwg. No. 1010033

Date: SEPT 25, 1967
Prepared by: E. [illegible]
Ambient Air Temperature: ______

	Part Description					· 1				Applied						Optional		Remarks
Circuit Symbol	Vendor	Part No.	Type	Value	Other Characteristics	Power Dissipation Watts or MW*	Voltage	Operating Temperatur	lation Class (gnetic Devices)	Calculated	Measured Error not present	Power Dissipation Watts or MW Error present	Voltage	Operating Temp*	Duty Cycle	Stress Ratio	Failure Rate (10^6 Hrs.)	
CR4	RAYTHEON	1010385	SWITCH	1N660		250mW					0	<1mw		60°C J		<.1	.01	
CR5											0	<1mw					.01	
CR6											<1mw	<1mw					.01	
CR7											<1mw	<1mw					.01	
CR8				1N660							0	<1mw					.01	
CR9	HUGHES	1010372	ZENER	HZ8537							25mw	25mw				.10	.10	
CR10	MOTOROLA	1010286	ZENER	1N965		400mw					225mw	225mw		130°C J		.56	.60	
CR11	HUGHES	1010372	ZENER	HZ8545		250mw					80mw	80mw		100°C J		.32	.10	
CR12	RAYTHEON	1010385	SWITCH	1N660							0	6mw		60°C J		<.1	.01	
CR13											0	6mw					.01	
CR14											0	6mw					.01	
CR15											0	6mw					.01	
CR16											0	6mw					.01	
CR17											0	6mw					.01	
CR18											0	6mw					.01	
CR19											0	3mw					.01	
CR20											0	3.6mw					.01	
CR21											0	3mw					.01	
CR22											0	3.6mw					.01	
CR23											0	3mw					.01	
CR24											0	3.6mw					.01	
CR25											0	3mw					.01	
CR26											0	3.6mw					.01	
CR27											<1mw	<1mw					.01	

Total Failure Rate (λ): 1.010

MTBF $\frac{1}{\lambda} \times 10^6$ Hrs.

* For semi-conductors, use power dissipation at junction, collector or base, and case or body temperatures uniformly for both rated and applied conditions. Note which is used.

MIT Instrumentation Laboratory ECS 7/62

TP#6262

ELECTRONIC COMPONENT STRESS ANALYSIS

Assembly: FAILURE INDICATOR

Sheet 5 of 6
Dwg. No. 1010033

Date: SEPT 25, [illegible]
Prepared by: E. C[illegible]
Ambient Air Temperature:

Circuit Symbol	Part Description					Ratd				Applied							Optional	Remarks
	Vendor	Part No.	Type	Value	Other Characteristics	Power Dissipation Watts or MW*	Voltage	Operating Temperature	Insulation Class (Magnetic Devices)	Calculated Error not present	Measured Error Present	Power Dissipation Watts or MW	Voltage	Operating Temp*	Duty Cycle	Stress Ratio	Failure Rate (10^6 Hrs.)	
CR28	RAYTHEON	1010385	SWITCH	1N660		250mw				<1mw	<1mw		60°C J		<.10	.01		
CR29										0	<1mw					.01		
CR30										0	<1mw					.01		
CR31										0	<1mw					.01		
CR32										0	<1mw					.01		
CR33				1N660						0	<1mw					.01		
CR34	HUGHES	1010372	ZENER	HZ8533						25mw	25mw				.10	.10		
CR35	MOTOROLA	1010286		1N965		400mw				225mw	225mw		130°C J		.56	.60		
CR36	HUGHES	1010372		HZ8545		250mw				80mw	80mw		100°C J		.32	.10		
CR37	RAYTHEON	1010385	SWITCH	1N660						0	6mw				<.10	.01		
CR38										0	<1mw					.01		
CR39										0	<1mw					.01		
CR40				1N660						0	<1mw					.01		
CR41	HUGHES	1010372	ZENER	HZ8538						25mw	25mw				.10	.10		
CR42	MOTOROLA	1010286		1N965		400mw				225mw	225mw		130°C J		.56	.60		
CR43	HUGHES	1010372		HZ8545		250mw				80mw	80mw		100°C J		.32	.10		
CR44	RAYTHEON	1010385	SWITCH	1N660						0	6mw				<.10	.01		
CR45										0	6mw					.01		
CR46										0	6mw					.01		
Q1	T I	1010397	NPN	2N930		600mw				0	<1mw		60°C J		<.1	.05		
Q2	FAIRCHILD	1010285	PNP	2N722		400mw				0	1.5mw		60°C J		<.1	.05		
Q3	T. I.	1010397	NPN	2N930		600mw				0	105mw		76°C J		.175	.05		
Q4	FAIRCHILD	1010285	PNP	2N722		400mw				0	[illegible]		6[illegible]		<.10	.05		
Q5	FAIRCHILD	1006752	NPN	2N914		1.2W				0	20mw		[illegible]		<.10	.05		

Total Failure Rate (λ): 1.880

MTBF $\frac{1}{\lambda} \times 10^6$ Hrs.

* For semi-conductors, use power dissipation at junction, collector or base, and case or body temperatures uniformly for both rated and applied conditions. Note which is used.

MIT Instrumentation Laboratory ECS 7/62

ELECTRONIC COMPONENT STRESS ANALYSIS

Assembly: FAILURE INDICATOR

Sheet 6 of 6
Dwg. No. 1010033

Date: SEPT. 25, 1963
Prepared by: E. CUSSON [illegible]
Ambient Air Temperature: ______

	Part Description					Rated				Applied						Optional		Remarks
Circuit Symbol	Vendor	Part No.	Type	Value	Other Characteristics	Power Dissipation Watts or MW*	Voltage	Operating Temperature*	Insulation Class (Magnetic Devices)	Calculated	Measured Error not present	Power Dissipation Watts or MW Error present	Voltage	Operating Temp*	Duty Cycle	Stress Ratio	Failure Rate (10⁶ Hrs.)	
Q6	T.I.	1010397	NPN	2N930		600mw					0	2.1mw		60°C J		<.10	.05	
Q7	FAIRCHILD	1010285	PNP	2N722		400mw					0	1.5mw		60°C J		<.10	.05	
Q8	T.I.	1010397	NPN	2N930		600mw					0	105mw		86°C J		.175	.05	
Q9	FAIRCHILD	1010285	PNP	2N722		400mw					0	21.mw		60°C J		<.10	.05	
Q10	T.I.	1010397	NPN	2N930		600mw					0	<1mw				<.10	.05	
Q11	FAIRCHILD	1010285	PNP	2N722		400mw					0	1.5mw				<.10	.05	
Q12	T.I.	1010397	NPN	2N930		600mw					0	105mw				.175	.05	
Q13	FAIRCHILD	1010285	PNP	2N722		400mw					0	21mw				<.10	.05	
T1		1010467		DO-T18		100mw					11.2mw	0				.112	.24	
T2		1010467		DO-T18		100mw					11.2mw	0				.112	.24	
T3		1010466		DO-T500		378mw					0	24mw				<.1	.24	

Total Failure Rate (λ): 1.120

MTBF $\frac{1}{\lambda} \times 10^6$ Hrs.

* For semi-conductors, use power dissipation at juntion, collector or base, and case or body temperatures uniformly for both rated and applied conditions. Note which is used.

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