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**ADDENDUM TO
EIGHTH
RELIABILITY ASSESSMENT
FOR THE
ORBITING GEOPHYSICAL
OBSERVATORIES**

PRC R-1055A

28 JUNE 1968

PREPARED FOR
NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER



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Prepared for

**National Aeronautics and Space Administration
Goddard Space Flight Center
Under Contract NAS 5-9443**

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FOREWORD

This report supplements the reliability assessment effort documented in PRC R-1055, Eighth Reliability Assessment for the Orbiting Geophysical Observatories, 29 December 1967. The work for both reports was performed by Planning Research Corporation under contract NAS5-9443, awarded by the Goddard Space Flight Center of the National Aeronautics and Space Administration. The 29 December report covers all reliability assessment activities during calendar year 1967. It extends coverage through the first 6 months of 1968, and briefly summarizes all of Planning Research Corporation's independent reliability assessment efforts regarding the Orbiting Geophysical Observatories.

ABSTRACT

The monthly FOOGO Failure Review Board meetings to monitor the performance level in hardware development, fabrication, and test procedures during the report period are summarized. This failure reporting and follow-up program is generally quite effective in isolating and solving problem areas. Participation in the OGO E launch readiness review and the OGO F pre-environmental critique is reported, as well as the design review of the Momentum Control Assembly for OGO F. No significant problems were detected in these activities. A brief review of the in-orbit failure rates for the OGO spacecraft and the "transmitter" anomaly of OGO V is reported; the observed failure rates are generally lower than those used in prediction activities. A possible source of the OGO V transmitter difficulties and a potential solution to the problem are suggested.

A brief summary of the entire independent reliability assessment activity on the OGO project is presented.

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I. INTRODUCTION

This document concludes the report on the eighth of a series of reliability assessments of the Orbiting Geophysical Observatories conducted by Planning Research Corporation for the Goddard Space Flight Center, National Aeronautics and Space Administration. The contractual period of the study was from 25 January 1967 to 28 June 1968. Work performed during calendar year 1967 is reported in PRC R-1055; reported herein (PRC R-1055A) is the effort expended from 29 December 1967 to 28 June 1968.

The primary objectives of this assessment, as with all previous assessments, are delineated in Reference 1 and can be briefly summarized as follows:

- o To provide NASA with objective and independent estimates of OGO spacecraft system reliability.
- o To assist NASA in establishing reliability goals for the spacecraft system and major subsystems.
- o To act as technical advisor to NASA in OGO reliability matters.

To fulfill these objectives in the eighth assessment, three tasks were assigned. The first required a reliability analysis of five specific OGO design changes implemented during the assessment period. These analyses are reported in their entirety in PRC R-1055. The second specified PRC attendance at the monthly FOOGO Failure Review Board meetings and the provision to GSFC of comments and recommendations pertinent to this activity. The third task, on-call consulting, provided for technical services in specific reliability problem areas not anticipated at the beginning of the assessment period.

The remainder of this report is divided into two sections, the first of which covers all work performed under the last two of the above tasks during the final 6 months of the assessment period; efforts occurring under these tasks in 1967 are reported in PRC R-1055. The

second section presents an overview of all independent assessment activities performed by PRC during the eight assessment periods beginning in October 1961 and terminating with this report.

II. ADDITIONAL EIGHTH ASSESSMENT EFFORT

A. Failure Review Board Meetings

During the report period (January to June 1968), the eighth assessment task providing for a continuous review of the level of performance in hardware development, fabrication, and test procedures was fulfilled, as in the preceding period, by attendance at, and independent reporting of, the monthly Failure Review Board meetings (FRBM's) held at the spacecraft contractor's plant. Reporting is accomplished by means of monthly technical letters recording PRC's observations of the FRBM's and review of associated documentation.

In summary, specific comments were offered on 20 failure reports representing 8 problem areas during the assessment period. For two of the "problem" areas, the comments adduced additional support for a position or action taken by the FRB; in two others, the comments involved suggested improvements in procedures.

For the other four problem areas, comments were of a cautionary nature, indicating a case-by-case closure of individual failure reports with no real resolution to the problem presented by the failures. This procedure is probably unavoidable in some cases due to trade-offs of time, cost, and reliability; moreover, the incidence of such cases is quite low in relation to the total number of failure reports processed. Nevertheless, it is incumbent on the independent reliability assessment contractor to point out this situation when it exists.

These four areas representing problems not yet totally resolved are (1) leakage of solenoid valves, (2) oscillation of the bistables, (3) tape recorder bit dropout, and (4) yaw reaction wheel stalled power out of tolerance. No pattern has been detected among the failure reports, however, that would indicate the necessity for systematic program changes. The conduct of the meetings and the procedures utilized are, in general, felt to be quite satisfactory.

B. Launch Readiness Review, OGO E

PRC reviewed the pertinent documentation and participated in the launch readiness review meeting for OGO E held at the spacecraft contractor's facilities on January 16, 17, and 18, 1968. On the basis of the information presented during the review and prior assessment activities, the following comments were transmitted via technical letter C68-5623, dated 30 January 1968.

The overall conduct and documentation for this review generally conformed to the recommendations made by PRC (letter C67-4373, 28 June 1967) at the conclusion of the OGO E Pre-Environmental Test Critique and OGO D Launch Readiness Review; that is, detailed handouts of agenda items were provided to participants prior to the meeting, and the discussion of "assembly histories" was focused on problem areas. All areas appeared to have been adequately and efficiently covered.

With respect to the discussions of battery capacity (in relation to maximum allowable eclipse time) and system thermal performance, it was suggested that it might be productive to examine these two areas together. If, for example, some experiments must be shut down in eclipse because of battery capacity and during sunlight due to thermal problems, rather detrimental effects on the overall data gathering function could result, even if the same experiments are not involved. The decision as to which experiments to cycle is a function of the duration of shutdown, the data gathering relationships of the cycled experiments, the period between eclipses and full sunlight, experiment reliability, etc. The development of an optimal cycling strategy might be enhanced if some consideration were given to these and other factors under both conditions that might require cycling.¹

C. Momentum Control Assembly Design Review

The Momentum Control Assembly (MCA) design review package was briefly reviewed by PRC prior to attendance at the design review

¹Reference 13, containing the preliminary experiment operations plan for OGO F, appears to have implemented the intent of this recommendation, particularly with respect to power availability.

meeting held on 2 April 1968. Based on the meeting and the design review package, no significant deficiencies in the design or implementation approach of the MCA were noted.

During the design review meeting there was some discussion concerning the possible addition of a series of redundant diodes to existing relay coil transient suppression diodes in the Control Switching Assembly (CSA). The purpose of the proposed additional diodes would be to improve reliability by making the failure of one diode in the shorted condition harmless. On the basis of information presented, and considering the likely failure modes of these diodes, the use of additional diodes for units of new design or manufacture was recommended. However, since there is no reason to believe that the present circuitry is less reliable than proven spacecraft equipment, PRC recommended against modifying the CSA solely for the purpose of adding redundant diodes.¹

D. Pre-Environmental Critique, OGO F

PRC reviewed the pertinent documentation and participated in the pre-environmental critique of OGO F held at the spacecraft contractor's facilities on May 7, 8, and 9, 1968. On the basis of the information presented during the review and prior assessment activities, the following comments were transmitted via technical letter C68-5720, dated May 1968.

The overall conduct and documentation for this critique were generally satisfactory, although distribution of the documentation prior to the meeting would have been desirable. Coverage of all areas and action items taken during the meeting appeared to be adequate.

Two of the problem areas discussed during the meeting, however, are such that the complexity of the phenomena involved would seem to limit the predictability of spacecraft behavior.

The first of these problem areas concerns the possibility of oscillation in the magnetic amplifier bistables. This problem was previously mentioned in PRC letter C68-5710, dated 1 May 1968. A separate

¹ Subsequent information indicates that the recommended course of action was implemented.

meeting was held on May 7 during the course of the critique to discuss the problem more fully. It was concluded, from all current evidence, that detailed knowledge of the dynamic behavior of these units is unavailable, and, therefore, assurance of their proper operation is constrained by the state of the art of magnetic amplifiers.

A similar situation exists in the second problem area in involving possible nonlinear interaction between the special purpose and wideband transmitters first noted on OGO V. This problem was discussed in PRC letter C68-5684, dated 5 April 1968. As indicated in that letter, certain undesired modes of operation of the varactor output stages are conceivable; however, to date, the existence of these modes has neither been proved nor disproved.

In both of these problem areas the substitution of empirical results for analytical understanding, while perhaps necessary, is not entirely satisfying. On the other hand, both problems have only appeared sporadically and, therefore, may not justify the expenditure of time and funds necessary to arrive at a more complete theoretical understanding.

E. Assessment of Operational Spacecraft

During the assessment period, two areas relative to the operational spacecraft were briefly investigated. These were (1) the transmitter anomaly noticed on OGO V and (2) observed random catastrophic piece-part failure rates on all OGO spacecraft. The results, previously transmitted via technical letters are summarized in the following two subsections.

1. Transmitter Anomaly, OGO V

Briefly, this anomaly involved the loss of the carrier from the special purpose transmitter and a concomitant drop in forward power and rise in reverse power of wideband transmitter A when both were transmitting over the directional antennas. Before the anomaly could be thoroughly investigated, it disappeared. Somewhat later, the forward power of wideband transmitter A dropped by a factor of 10.

The anomaly was investigated by PRC, primarily from the point of view of transmitter interaction. It was concluded that the effect of interaction in these transmitters would be to cause unusual modes of

operation due to parametric pumping in the varactor output stages. While the analysis of such action is exceedingly difficult, being described by nonlinear equations with time-varying parameters, it is evident that the coupling of energy between the output stages must be prevented to avoid undesired results. The varactor type of transmitter requires special treatment in that this design is more critical with respect to interaction between transmitters than more conventional designs. The interactions tend to make ground testing in nonanechoic surroundings difficult due to the effect of reflected energy. The incorporation of circulators or gyrators for transmitter isolation was suggested to alleviate this problem.

2. Observed OGO Orbital Failure Rates

In Reference 2, observed failure rates based on orbital flight data, as of 30 November 1967, of four OGO spacecraft were tabulated based on an upper 60-percent confidence level, for eight high-population generic part types. These rates were compared to the results found in Reference 3 on a part-by-part basis at both 60- and 95- percent confidence intervals. The results of Reference 3 are based on data, as of May 1966, from a wide variety of operational spacecraft. The comparison is tabulated in Exhibit 1.

The correspondence in part failure rates between the two sources is quite good implying that the results are reasonably indicative of the magnitude of piece-part failure rates to be expected in spacecraft designed and built prior to the 1965-1966 time period.

EXHIBIT 1 - GENERIC PART FAILURE RATES FROM ORBITAL SPACECRAFT (ALL FAILURE RATES GIVEN IN UNITS OF FAILURES/10⁹ HOURS)

Confidence Level		60 Percent		95 Percent	
Data Source		<u>Reference 2</u>	<u>Reference 3</u>	<u>Reference 2</u>	<u>Reference 3</u>
<u>Part Type</u>					
Transistors	7.6	5.4	18.1	13.0	
Diodes	1.45	5.5	4.77	10.0	
Resistors	1.25	1.8	4.06	4.2	
Capacitors	5.6	6.0	18.3	12.0	
Magnetics	16.0	--	52.9	--	
Relays	70.0	109.0	225.0	260.0	
Connections	0.229	--	0.74	--	
Connector Pins	1.05	--	3.26	--	

III. AN OVERVIEW OF ALL OGO INDEPENDENT RELIABILITY ASSESSMENTS

A. Introduction

It is the purpose of this section of the report to briefly summarize the efforts of Planning Research Corporation devoted to improving the reliability of the Orbiting Geophysical Observatories. These efforts are the result of eight independent reliability assessment studies conducted from October 1961 through June 1968. The primary objectives of these assessments are outlined in Reference 1 and Section I of this report. The elements of an independent reliability assessment which define the activities to be undertaken to meet these objectives are as follows:

1. Establish and allocate reliability goals for the system and major subsystems.
2. Construct a preliminary system reliability model.
3. Select generic component part failure rates.
4. Make a preliminary reliability prediction.
5. Identify potential reliability problem areas, using a failure mode, effect, and criticality analysis.
6. Construct more detailed reliability models for potential problem areas and exercise these models with more detailed component part failure rates.
7. Evolve and analyze competing designs for problem areas.
8. Conduct engineering design reviews.
9. Recommend design changes.
10. Periodically update reliability predictions and allocations (reflecting effect of design changes, etc.) and continue to perform detailed analyses of potential problem areas.
11. Review the development contractor's reliability programs and plans.
12. Review, in detail, the development contractor's reliability efforts.

13. Review independently the trouble and failure reports.
14. Observe tests and analyze and report on the test results.
15. Participate in the development contractor's design reviews.
16. Offer advice regarding noncompliance with specifications and contractual requirements.

Subsection III.B briefly summarizes the activity of each report period. General and specific benefits resulting from the independent assessments are outlined in subsection III.C.

B. Summary of Efforts

1. First Assessment Period (October 1961-February 1962)

This assessment period was devoted primarily to establishing the initial prediction and allocation of OGO spacecraft reliability. Two models were established to predict reliability--one based on the classical success/failure approach, and the second and preferred method, based on partial performance degradation in a continuous manner rather than the dichotomous treatment imposed by the classical approach. General assumptions with respect to the mission profile, operating procedures, environmental factors, etc., were established, and a set of piece-part failure rates for use in the model evaluation were designated based on the best available information.

Numerical values of reliability for the major subsystems and the spacecraft system were presented as a function of time using both modeling approaches. At the end of one year the preferred approach gave a reliability of 0.25, whereas the result of the classical approach was less than 0.01. The assigned goal was 0.70. This goal was apportioned to the major subsystems indicating strongly the necessity for upgrading the reliability of the Attitude Control and Stabilization (ACS) and Communication and Data Handling (CDH) Subsystems.

In addition, a detailed reliability analysis of the main commutator matrix in the CDH was performed, and a design tailored to the mission was recommended to replace the more general design. A determination was made of the average power generated by the solar cells under conditions of random tumbling of the OGO spacecraft. A critique of the

spacecraft contractor's concurrent reliability report was made designating differences in the modeling approach and the magnitude of assumed failure rates. Finally, an analysis was performed trading off weight reduction of the structures subsystem through redesign of the appendage deployment release mechanism against loss in reliability.

2. Second Assessment Period (February 1962-September 1962)

The effort in this period consisted primarily of a refinement of the prediction activities of the first assessment period, specifically, to bring more realism into the second assessment.

- a. A number of simplifying assumptions, that, of necessity, had been made in the preliminary assessment, were eliminated.
- b. Launch and POGO effects were brought into the assessment.
- c. Each individual subsystem assessment was more detailed and incorporated the latest design changes.
- d. Basic failure rates were revised based on new information.
- e. Both reliability models were reevaluated to reflect the greater depth of engineering analysis.

Compensating effects in the models resulted in no significant change in the predicted system reliability numerics.

An independent compilation of the OGO spacecraft parts complement was also completed during this assessment period.

3. Third Assessment Period (September 1962-April 1963)

The third assessment further refined and updated the results of the first two assessment periods. Primary emphasis was placed on increased engineering analysis at the subsystem level, guided by the basic objective of achieving a complete assessment of all aspects of the spacecraft. The mathematical models were revised to include subsystem interface considerations and applicable data arising from all available OGO spacecraft, and subsystem tests were incorporated into the

assessment. The numerical values of predicted spacecraft reliability resulting from the revisions were considerably lower than those derived in the previous assessments. The preferred method resulted in a value of 11 percent, whereas the classical approach yielded a value less than 0.1 percent.

The spacecraft reliability goal of 0.70 for 1 year's operation was reapportioned based on the updated information available during this assessment period. The ACS and CDH subsystems were reaffirmed as being the weakest links in the system. Numerous recommendations for the improvement of their inherent reliability were made.

A spacecraft weight prediction methodology was briefly investigated, and the prime contractor's approach to this problem was reviewed. The concurrent prime contractor's reliability assessments were also reviewed, and a subsystem-by-subsystem comparison was made with the PRC assessments. Finally, a detailed review of the OGO solar paddle vibration test results and a computerized analysis of the revised structural design was accomplished.

4. Fourth Assessment Period (April 1963-March 1964)

In this assessment period, attention was focused on particular problem areas rather than on spacecraft system reliability assessments. One problem treated in great detail was the discrepancy now manifest between the predictions of spacecraft reliability as reported by the prime contractor and PRC. All of the available prime contractor's reliability reports were reviewed and analyzed in detail, and a step-by-step comparative analysis was made with PRC's approach. Significant differences were found in the mathematical models (classical approach in both cases), parts complements, failure modes considered, subsystem descriptions, and failure rates. The effects of parameter drift screening on failure rates were evaluated and strongly recommended for use for transistors and diodes.

Three spacecraft elements and one experiment were singled out for detailed analysis. A method of optimizing the assignment of command functions to the OGO command relay matrix was derived that basically

minimized the effort of singular command system failures and that could be implemented with no hardware changes whatever. The horizon scanner in the OGO ACS subsystem was subjected to a detailed stress analysis focusing on the fatigue life (launch and orbital) of the flexure-pivot springs. The third spacecraft element analyzed was the Power Supply Subsystem and, in particular, the effect of certain switching circuit modifications made to this subsystem. In conjunction with this analysis, a review of available nickel-cadmium battery test reports was also conducted. The reliability of the radio astronomy experiment flown on the first EGO was analyzed in considerable detail. A number of recommendations for reliability improvement was made; however, it was concluded that the experiment reliability was consistent with the reliability of the spacecraft itself.

The final effort undertaken during this assessment period was an analysis and evaluation of the operational aspects of spacecraft system reliability to develop a practical means of assuring that the maximum "value" is obtained from an orbiting spacecraft and particularly to determine the remedial actions that can be taken in the face of spacecraft malfunction. Diagnostic routines and decision-action charts were generated for the CDH, ACS, Power Supply, and Thermal Control Subsystems.

5. Fifth Assessment Period (January 1964-August 1964)

This assessment continued the emphasis of the fourth assessment period by concentrating on engineering and reliability analyses of specific areas in an attempt to upgrade system reliability.

With respect to spacecraft hardware elements, a detailed analysis of the S-50 (POGO) Power Supply Subsystem was conducted including recommendations for a higher degree of redundancy, solar array requirements versus battery depth of discharge, and solar array capability. The POGO experiment programmer design was reviewed, and its impact on spacecraft and mission reliability was evaluated. Other changes similarly reviewed included the use of capacitive tachometers for the attitude control reaction wheels and changes in the universal wiring system and command receiver frequency.

Analyses of a more general nature included the determination of the potential worth of a parts burn-in program for OGO and an evaluation of the increased reliability that could be anticipated through the use of integrated circuits to replace discrete components in the OGO spacecraft. An investigation of the "purple plague" phenomena was also conducted. Finally, a recommendation for a single classical OGO reliability model was made to resolve the differences still outstanding between the spacecraft contractor and PRC.

Finally, the failure histories of units to be integrated in OGO A were reviewed to determine their potential flight reliability. Also reviewed were the OGO prototype thermal vacuum and spacecraft torsional vibration tests.

6. Sixth Reliability Assessment (January 1965-April 1966)

The analysis of various critical OGO hardware elements continued to play a central role in this assessment period. A rather lengthy and detailed analysis of the enable relay and driver circuit in the command system was made together with a number of suggested alternate configurations. It was firmly recommended that no changes be made. Due to the boom deployment failure of OGO I, an analysis of the boom deployment system was undertaken resulting in a number of design and testing recommendations. Also reviewed in some detail was the ACS nongated inverter. An alternate design approach utilizing a digital technique was proposed that would be more stable with respect to component tolerance build-up and parameter drift.

In this assessment period, increasing emphasis was placed on "manufacturing" reliability reflected in the establishment of the monthly System Index Report (SIR). The SIR was established to provide a continuous monitoring of hardware development, fabrication, and acceptance procedures as reflected in the development contractor's failure report summaries. Also, the failure histories of units to be integrated in OGO were reviewed to determine their potential flight reliability.

Finally, a more detailed study was undertaken to evaluate the potential reliability improvement to be anticipated for OGO through replacement of discrete components in the digital command decoder with

integrated circuits. A design approach was presented, including specific parts, which would reduce the decoder failure rate by a factor of one-third. An updating was also made of the S-49 EGO and S-50 POGO system reliability models and of the predictions reflecting design changes that had been implemented since the third assessment. The reliabilities improved only a negligible amount and are essentially equivalent for the two spacecraft.

7. Seventh Assessment Period (January 1966-December 1966)

Two major design changes were analyzed during this assessment period. The first of these involved a redesigned horizon scanner to overcome the "cold-cloud effect" noted subsequent to the launch of OGO II. The second is referred to as the Control Switching Assembly (CSA) designed to provide a spin-up capability for OGO in the event of loss of three-axis attitude control and stabilization. For the horizon scanner, the optical, mechanical, electrical, electronic, reliability, and system aspects of the redesign were assessed and compared to the previous wideband scanner design. The modified version was found to be superior on all counts. For the CSA, in addition to the usual failure mode and effects analysis, the effects of false commands were considered, and alternate circuits and command related improvements were suggested.

The SIR was continued during this assessment period, and an analysis of the failure histories, etc., of the units to be integrated in the OGO B spacecraft was evaluated.

During this assessment period, a completely revised and simplified spacecraft system reliability model was also formulated and evaluated incorporating all design changes, latest state of the art in reliability analysis, and the results of orbiting OGO spacecraft. In conjunction with this reassessment, and on a consistent basis with it, the operational reliability of OGO's I, II, and III was evaluated through August 1966.

8. Eighth Assessment Period (January 1967-June 1968)

a. Design Changes

During this period seven design changes were analyzed to determine their impact on subsystem and spacecraft reliability. These changes and the results of the analyses are as follows:

(1) Modified Attitude Control Subsystem (ACS)
for OGO's D, E, and F

A number of changes were incorporated into the ACS under this modification, all designed to preclude a failure similar to the roll channel magnetic amplifier failure of OGO III. The motor driver magnetic amplifiers were redesigned, time delay circuits were added to the roll and yaw reaction wheel, solar array control channels limiting and filtering components were added to the low-level and bi-stable circuits, new valve driver circuits were provided, and mechanical modifications of the solar array and OPEP drive mechanisms were incorporated.

The analysis of these modifications indicate that all were based on sound engineering principles and all had a positive impact on spacecraft reliability.

(2) Modified Power Supply Subsystem (PSS) for
OGO's D, E, and F

This modification is primarily designed to provide for the use of nickel-cadmium batteries for all missions, rather than utilizing silver-cadmium batteries for POGO missions, as was previously the case. In addition to the battery change, the series regulators, 125°F thermal switches, and cycle relay were eliminated from the previous design, and battery reconditioning circuits were added. Command capability was also augmented.

The analysis indicates that, with the possible exception of false command considerations, the new design is, in all respects, equal to or better than its predecessor.

(3) Modified Tape Recorder for OGO F

The unmodified tape recorder accepts data from the telemetry encoder at a rate of 4 kilobits per second (kbps) and stores these data on a magnetic tape traveling at a speed of 1.18 inches per second. The modified recorder accepts data at an 8-kbps rate and drives the tape at 2.36 inches per second.

When evaluated from the point of view of torque margins, bit dropout, and wearout, the modification appears not to present any new problems or to create noticeable additional hazard to the operation of the tape recorder over that exhibited by the unmodified units.

(4) Modified Command Distribution Unit (CDU) for OGO F

This modification provides for the elimination of CDU modules 6, 8, and 9 and their replacement with one, two, or three new modules, depending on the number of additional impulse commands desired.

The analysis indicates that the probability of the modified CDU failing in such a manner as to prevent the execution of an impulse command or cause the false execution of another impulse command is negligible.

(5) Data Switching Assembly (DSA) for OGO F

The purpose of the DSA is to reduce the total number of wires required to connect certain digital experiments, located in the appendages, to the spacecraft data handling subsystem. The DSA is an entirely new assembly for OGO F.

The results of the analysis are (1) that the probability of the DSA failing in such a manner as to lose any or all of the associated experiment data is essentially negligible, and (2) that the failure effects associated with the DSA are straightforward and do not extend beyond the DSA or even beyond an individual circuit within the DSA.

(6) Spin Precision Control Assembly for OGO's E and F, and SAI Switch for OGO E

Only a failure mode and effect analysis was performed for these two OGO spacecraft modifications. The failure effects are straightforward and do not extend beyond the units under consideration.

(7) Momentum Central Assembly (MCA) for OGO F

The purpose of this modification is to permit a greater degree of control flexibility than previously existed. The modifications are straightforward and present no reliability problems.

b. Other Activities

Attendance at the Failure Review Board meetings (FRBM's) and at various OGO spacecraft critiques during the report period revealed no problem areas that were not adequately dealt with in the framework of the meetings. No pattern could be found that would indicate a need for any systematic changes in the program for developing, fabricating, testing, or monitoring the OGO spacecraft hardware. This activity was substituted for the SIR of the previous two assessment periods to improve response time to problem areas, a number of which were reported in a technical letter during the course of the eighth assessment period.

The generalized spacecraft effectiveness prediction in use at the beginning of the report period was reevaluated and found not to have been significantly altered by the design changes considered during the period.

Revision and extension of the operational assessment methodology through September 1967 was also accomplished during this report period. The conclusions are that the initial operation of OGO's I, II, and III was worse than anticipated, whereas their long-range operation is better than was expected based on the predictive models.

C. Advantages of the OGO Independent Reliability Assessments

It is the purpose of this subsection to list some advantages, general and specific, felt to have accrued to the OGO program as a result of this series of eight assessment studies. Subsection III.C.1 lists general advantages, whereas subsection III.C.2 discusses specific benefits.

1. General Advantages of an Independent Reliability Assessment

- a. The assessment is system-oriented as contrasted with the development contractor's natural emphasis on the equipment or subsystem level.
- b. Assures the use of an objective (i.e., realistic) model.
- c. Objectively examines traditional or "pet" designs and procedures.
- d. Identifies potential problem areas before they become frozen designs.

- e. Separates political from technical implications.
- f. Provides detailed attention to the technical aspects of reliability by an experienced, well-balanced team.
- g. Provides an added incentive to the reliability efforts of the development contractor.
- h. Provides system effectiveness and mission decision inputs.
- i. Provides inputs to influence design decisions and program direction through rationally based optimization procedures.

2. Some Specific Benefits of the OGO Assessments

To identify specific benefits that have been derived from the OGO reliability assessments, it is helpful to consider the conclusions and recommendations that have been submitted. These are contained in the published reports (References 4 through 11) that document each assessment period. Not all of these will be cited here, but illustrative examples will be discussed to bring out the variety of advantages that can be associated with these studies.

The specific benefits listed below fall into four general categories. The first of these are recommendations that have been proposed by PRC in its technical advisory capacity and that have actually been implemented. The second category consists of recommendations that cannot be incorporated in current designs but clearly demand consideration in follow-on spacecraft or in second generation observatories. The third category of benefits are study conclusions that, although they do not lead directly design change recommendations, do open areas which merit additional study. The benefit derived in these cases is the identification of potential weaknesses and the justification of a searching review by the spacecraft contractor or the assessment team. The final category of benefits are those study results that indicate either the potential problem areas do not exist or that no recommended action is required.

Selected examples of specific benefits in each category are listed in the following subsections.

a. Implemented Recommendations

(1) The tone decoder within the Command Subsystem was critically examined in Reference 4 (page 102). Expanded capability of this device was recommended, and, as a consequence, the number of available tone commands was increased during the course of a redesign.

(2) The CDH subsystem employs funnel circuits which control the gating of both analog and digital data. The original design of these circuits gave unwarranted priority to the digital data and compromised the reliability of the analog data transmission. All aspects of this design were carefully analyzed in Reference 4 (page 106), and suggestions were presented for improvement. Subsequent drawing releases revealed that design changes were implemented, and the problem was alleviated.

(3) An analysis of the program failure reports, required for preparation of the OGO System Index Reports, revealed that the program was suffering from a possible decline in hardware quality. The results of this analysis were reported in the System Index Report (PRC D-1140), dated 25 November 1965. The analysis was based on all failure reports issued prior to 30 September 1965. The contractor has implemented a program to more closely control the total process of production, from receiving inspection to final testing.

(4) In the course of a detailed engineering and reliability study performed on the control switching assembly (Reference 10), it was recommended that a second set of relay contacts be placed in series with an existent set to provide additional protection against inadvertent entry into the yaw-spin mode of operations. This suggestion was accepted and implemented on both the OGO B and OGO D spacecraft.

(5) The modified power control unit for OGO's D, E, and F incorporated a number of recommendations resulting from the detailed analysis performed by PRC on this subsystem during the fifth assessment period. These recommendations were primarily aimed at achieving increased reliability through the provision of added switching capability for the purpose of redundancy (cross-strapping) and the elimination of certain nonessential piece parts, the failure of which could be

highly detrimental to the subsystem. The recommendations are documented in Reference 8, and the extent to which they were implemented is documented in Reference 11.

b. Open Recommendations

(1) In the course of the third assessment an analysis was made of the relative merits of the decoding schemes in use in the telemetry and command portion of the CDH (Reference 6, pp. III.A, 251-267). This analysis compares the failure effects of single-level gating and double-level gating in both command and telemetry applications. It is shown that the double-level scheme used in the command decoder is better applied to the commutation function in the telemetry system. Conversely, the command decoder, currently implemented with single-level gating, would be more reliable if double-level gating were used. The recommendation that these schemes be interchanged for the two applications could be incorporated in later OGO models.

(2) In performing the initial reliability assessments of the Command Subsystem, the question of optimal assignment of command functions to the intersections of the CDU command matrix was raised by the assessment team. The question was a natural one since a single failure in the CDU could, depending on the assignment used, cause complete loss of otherwise redundant functions or similar undesirable events. In response to this problem, a methodology was developed (Reference 7) that would, rather simply, yield near-optimal assignments in the type of Command Subsystem utilized in OGO. Since the methodology is related to the relative values of the actual command functions, optimization must be performed for each vehicle.

(3) In preparing the spacecraft critiques for OGO A, OGO B, and OGO C, PRC discovered certain problem areas (battery leaks, OPEP wrap-up fatigue, horizon scanner testing, boom deployment, etc.) that, while not correctable for the specific spacecraft concerned because of time considerations, were pertinent for later spacecraft. For example, it was suggested in the OGO C reliability critique that the horizon scanner

had not been tested under conditions approximating those it would face in flight. Since that flight, NASA has further tested scanner performance to demonstrate that a scanner modified to reduce the seriousness of cold clouds would quite probably overlook cold atmospheric masses and perform as intended.

(4) A number of recommendations with respect to the Command Distribution Unit modification were proposed by PRC in the eighth assessment period. These are documented in Reference 11 and relate to simplification of the ground selector circuits. Although their implementation is not critical from a probabilistic viewpoint, their implementation would effect a greater degree of simplicity and reliability.

c. Recommendations Suggesting Further Study

(1) During the fourth assessment period, PRC contributed to an effort to develop a practical means of ensuring that the maximum value, both scientific and engineering, would be obtained from operational orbiting spacecraft. This problem was termed the "quick-look" problem, and the PRC contribution is documented in Reference 7. Briefly, this effort consisted in verifying a rationale and providing flow diagrams and decision-action charts for the OGO subsystems, which would permit the isolation of malfunctions for which remedial action could be taken by ground command. Further development of the quick-look concept was continued by GSFC.

(2) Two separate studies were undertaken to investigate the feasibility of replacing discrete component part circuits in OGO with integrated circuits. The first was of a preliminary nature (Reference 8), while the second actually redesigned a small digital portion of the system (Reference 9). Both studies indicated the feasibility and increased reliability of the approach. The area considered in the redesign was so limited however, that a considerable number of discrete component parts were necessary to serve as an interface between the integrated circuits and the remainder of the system, thus reducing the force of the recommendation. A more advanced study would be required to determine the optimal mix of integrated circuits and discrete part circuits in the OGO satellites.

(3) As a result of the boom deployment failures noted on the first OGO launch, a detailed design critique of the OGO boom deployment system was performed. The results of this study are documented in Reference 9. A number of design changes were suggested for further study. Among these were the use of helical torsion springs to improve the positive torque margins, the use of subliming solids to control the boom deployment rate, and the use of flat electrical harnesses to reduce bending resistance and improve repeatability. In order to demonstrate the utility of any modification, a test program to determine if adequate positive torque margin exists at all deflection angles at an ambient temperature of -60°F before and after aging was suggested.

(4) In the control switching assembly study noted earlier (Reference 10), PRC questioned the necessity of the four-timer design of the gas inhibit logic function. It was pointed out that if only two of the timers were used, it might be possible to achieve the same operation with increased reliability. Further study is required to determine if two timers would truly provide the performance desired.

d. Recommendations for No Further Action

(1) In the process of assessing the Structures Subsystem, it was noted that the solar paddles appeared to be vulnerable to damage during the launch phase of the mission. This was indicated in Reference 5, and further study was recommended. Continued analysis took the form of a mathematical model of the structure and a computer program for exercising the model. The results were reported in Reference 12 and indicated that testing should be conducted to ensure that structural difficulties would not be encountered. Testing revealed that the problem was not of a serious magnitude; however, the value of the study is evident in the special emphasis that was placed on these tests and the improved scheduling for the tests.

(2) Detailed assessment efforts in the CDH area uncovered the fact that a large number of diodes were being carried in the spacecraft but not used in the circuitry. Because the quantity of such diodes was in excess of 1,000, a check on the weight, cost, and reliability penalty was made. These diodes are electrically unconnected parts in

standard welded circuit modules, and a brief study revealed that the trade-off involved in removing them did not warrant any action. This study was beneficial, however, in that it allayed any fears that the excess components were exacting a disproportionate penalty on the spacecraft. These findings were reported directly by letter (C63-282, dated 30 January 1963).

(3) In one attempt to upgrade OGO system reliability, the development contractor suggested a reconfiguration of the enable relay and driver circuit in the OGO Command Subsystem. Other configurations were suggested by NASA and PRC, since this circuit did appear to be a weak link in the subsystem. Detailed analysis by PRC revealed, however, that the unit was inherently quite reliable and that alternate configurations, while eliminating originally existent failure modes, only introduced others with equal or higher probabilities of occurrence and similar or more detrimental effects on the subsystem. Thus, it was recommended that no changes be made in the enable relay and driver configuration on the basis of improved reliability.

(4) As a part of the seventh assessment effort, PRC studied the design of the advanced OGO horizon scanner. This study included operating principles, system and circuit design, mechanical implementation, performance tests, and reliability. The details of these studies are documented in Reference 10. No major recommendations were offered since no major problems were discovered in any of the investigated areas. The benefit of studies such as this, aside from minor recommendations, is in the independent confirmation of the design quality of a critical item in the OGO Attitude Control and Stabilization Subsystem.

(5) The eighth assessment study of the seven modifications mentioned earlier (subsection III.B.8.a) resulted in no major recommendations for change; indeed, most of the modifications were judged to be a significant improvement over previous designs.

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