~~SECRET~~

DECLASSIFIED

CLASS LOG NO
ARC 61-91

D6

SECOND PERIODIC REVIEW

ORBIT RELIABILITY OF THE SAMOS F-2 SYSTEM

[VEHICLE NUMBER 2301; CONFIGURATION III]

31 JANUARY 1961

Pro 102

Declassification IAW
EO 13526
by the Air Force Declassification Office
Date: 6-29-16 Reviewer# 125

Prepared under Contract IDA-50-3

ARINC RESEARCH CORPORATION

A SUBSIDIARY OF AERONAUTICAL RADIO, INC.

PUBLICATION NO. 149-8-214

DS 61-1082-B1

610222

DECLASSIFIED

~~SECRET~~

DECLASSIFIED

Second Periodic Review

ORBIT RELIABILITY OF THE SAMOS F-2 SYSTEM [VEHICLE NUMBER 2301, CONFIGURATION III]

31 January 1961

a report prepared by

C. L. Noelcke and J. M. Alderman
ARINC Research Corporation

in coordination with

Dr. Vasily D. Prian
Lockheed Aircraft Corporation
Missiles and Space Division

for the Advanced Research Projects Agency
(ARINC Contract IDA-50-3)

Carl L Noelcke
Carl L. Noelcke
for ARINC Research Corporation

Vasily D. Prian
Vasily D. Prian
for Lockheed Missile and Space Division
of Lockheed Aircraft Corporation

~~This document contains information affecting the national defense of the United States within the meaining of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.~~

Declassification IAW
EO 13526
by the Air Force Declassification Office
Date: 6-29-16 Reviewer# 125

Publication No. 149-8-214

ARINC Research Corporation
a subsidiary of Aeronautical Radio, Inc.
1700 K Street, N. W.
Washington 6, D. C.

DECLASSIFIED
~~SECRET~~

FOREWORD

The report presented herewith summarizes the results of the second periodic review of the orbit reliability of the F-2 SAMOS configuration. This review has been performed by ARINC Research Corporation for the Advanced Research Projects Agency under the authority of Contract IDA-50-3, issued by the Institute for Defense Analysis on 18 May 1959, and amended 2 June 1960. It has been conducted in coordination with the Missiles and Space Division of Lockheed Aircraft Corporation. The first periodic review on the project was issued 5 August 1960. The information contained in that report has been updated and applicable portions are incorporated in this document.

For the most part, the information employed in this investigation has been made available through the cooperation of the Lockheed Missiles and Space Division and the Ballistic Missile Division of the Air Research and Development Command. The assistance of these agencies is greatly appreciated.

▶ NOTE ◀

As this report was going into production, the following information was received from Lockheed:

According to LMSD instructions from the Air Force (CCN - 41 MSN - BMC - 61 MSN - 2771) against Contract AF 04(647)-563, SAMOS F-2 Configuration III will have a new booster. It should therefore be emphasized that the analysis presented in this report is based upon use of the Atlas Agena booster system, which differs in several important respects from the Thor Agena booster that will be used in the future with this configuration. A major reason for the change was the unavailability of Atlas boosters and pads and the availability of Thor boosters.

Because the performance of the Thor is lower than that of the Atlas booster, it has been necessary to make a number of equipment changes, involving a reduction in the complexity of the configuration and replacement of certain components that presented reliability hazards with more dependable components. These changes result in a reliability benefit, purchased at the price of decreased orbit life and altitude. Examples of the changes are:

1. Removal of all solar cell arrays and associated equipment.
2. Operation on the batteries alone.
3. Replacement of LODAP with the Interim Programmer.
4. Redesign of the Communications and Control Subsystem to resemble that now employed in the Discoverer program.

A complete reliability analysis will be performed as soon as the present configuration is fully crystallized.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

SUMMARY AND RECOMMENDATIONS

1. Purpose of Review

The SAMOS Program is directed toward development of several different types of satellite weapons systems, all having the general purpose of reconnaissance. Although each type of satellite uses a different method of reconnaissance, they are all considered part of the same program, because the Lockheed AGENA satellite vehicle and auxiliary equipment are common to the various payloads. This report is concerned with the F-2 ECM (electronic countermeasures) reconnaissance system, which has as its object the detection and measurement of parameters of pulsed electronic emissions.

The ultimate design reliability goal for the F-2 ECM configuration is a mean time-to-failure of one year in orbit, although an interim goal of 20 days in orbit has been established for the current test series.

Amendment Number 2 to Contract IDA-50-3, dated 2 June 1960, was issued to ARINC Research Corporation for a study of reliability in the SAMOS program. This report describes the results of the second review of the orbit reliability of the system as presently conceived (Vehicle 2301, Configuration III), and discusses some of the major problem areas affecting the present design. Through the cooperation of Lockheed Missiles and Space Division (LMSD), the ARINC analysis is accompanied by an LMSD review and commentary.

2. Description of the System

The SAMOS F-2 satellite, as currently conceived, consists of a number of subsystems, all vital to the mission success of the system. These subsystems are as follows:

Subsystem A -- the vehicle airframe, including the hardware used to mate the AGENA airframe to the booster.

Subsystem B -- the propulsion components, including motor and fuel system.

Subsystem C -- the solar battery array and controls, a secondary battery bank, DC to AC inverters, -28 VDC power supply, + 28 VDC voltage regulator, and synchronous power amplifiers.

Subsystem D -- the vehicle attitude-stabilization equipment, including gyros, an inertia wheel, gas reaction jets, and the necessary control electronics.

Subsystem F-2 -- the antenna systems, dual scanning receivers for each of two frequency bands, a digital data analyzer, and a tape recorder for data storage.

Subsystem H -- command receivers, decoder-programmers data and telemetry multiplexers, and data link transmitters.

The complexity of the over-all satellite equipment may be judged from the fact that the vehicle and payload contain approximately 15,000 electronic parts, including 1670 transistors. Only primary equipment necessary for fulfillment of the reconnaissance mission is included in this part count, which does not take into consideration redundant components (such as the standby-data processor of Subsystem F-2) which are in the system solely for the purpose of improving reliability.

The predictions of mean life and reliability that are presented in this report cover only the orbital phase of the mission -- i.e., the assumption is made that the vehicle has survived boost and orbital injection without damage or degradation. For this reason, Subsystems A and B will not be considered in this report, inasmuch as they are not included in the operation of the system once the satellite has achieved orbit.

3. Reliability Evaluation Procedure

As will be shown in the following section of this summary, the ARINC prediction for the mean time-to-failure of the system is much lower than the LMSD prediction. The fundamental difference between the ARINC estimates and the LMSD estimates lies in the part failure rates employed in the calculations.

Part failure rates provide the basis for the predictions of component reliability, subsystem reliability, and finally system reliability. A failure rate is assigned to each transistor, diode, capacitor, resistor, etc., in the system. The probabilities of survival of individual parts are summed by means of a mathematical model of the system, which takes into account such items as simple redundant units and specific failure criteria.

A number of simplifying assumptions are involved in generation of the model. Briefly, these assumptions are:

a) Parts are applied in a reasonable environment.

b) There can be system (tolerance) failures, even though there are no technical part failures.

c) In-orbit maintenance is not possible.

d) Alternate modes of operation are equivalent in reliability.

e) Failure rates are constant with time.

f) Failures are mutually independent.

g) Except where noted, mode switching devices are failure-free.

h) Parts do not deteriorate during "off" periods.

i) Several part types have been excluded from the analysis.

j) All parts are considered essential for success.

Additional details on the general assumptions may be found in Appendix B.

ARINC and LMSD are in agreement on the basic mathematical model, but differ with respect to the failure rates employed. The difference in failure rates reflects differences in points of view. LMSD uses failure rate information obtained from other equipment manufacturers, and these failure rates reflect the substantial improvements in part reliability in recent years. LMSD also points out that satellite environment is favorable to long life, and that satellite parts are specially selected for stability.

ARINC agrees that rates consistent with those used by LMSD are employed in the industry, but these are usually derived from data which have been censored to eliminate all failures attributable to equipment design deficiencies, equipment manufacturing defects, and field operational deficiencies. Use of such rates is an expression of LMSD's conviction that failures of these types can be eliminated from the operational SAMOS satellites to be put in orbit within the next few years.

ARINC is unable to share LMSD's confidence in the ability of the equipment manufacturers to achieve such a design and manufacturing level at the present stage of SAMOS System development. It has been ARINC's experience that, in order to assure such low "catastrophic" failure rates, it is necessary to have a long standing part standardization program, a rigorous specification program requiring larger life-test samples than are provided for in present MIL specifications, and an adequate period of field experience to eliminate design and manufacturing deficiencies. ARINC has therefore used, for prediction purposes, failure rates derived from field data on new systems in the early years of operational usage. ARINC believes that these failure rates, based on data that include <ins>all</ins> types of failures, are realistic for a satellite system in the early operational stage. However, inclusion of these additional factors causes the ARINC prediction to be more pessimistic than LMSD's. This failure-rate conflict is typical of one existing throughout the industry and originating in the differing viewpoints of equipment manufacturers and equipment users.

4. Prediction Results [Vehicle 2301, - Configuration III]

The expected mean times-to-failure for the SAMOS F-2 system and the four subsystems, as predicted by ARINC and LMSD, are shown in Table 1. The predictions are based on the subsystem and system reliability functions presented in Figures 1 and 2.

Table 1 shows the previous mean time-to-failure predictions as well as those made in the current analysis. The 20-percent decrease in the ARINC estimate of system MTF was caused by two factors: increased complexity due to the addition of parts to many units within Subsystem C, and a change in the mathematical model for Subsystem D which was made after a careful review of present system requirements. Frequently, as systems mature toward actual hardware, performance is found inadequate and parts are added in order to obtain the necessary improvement in performance.

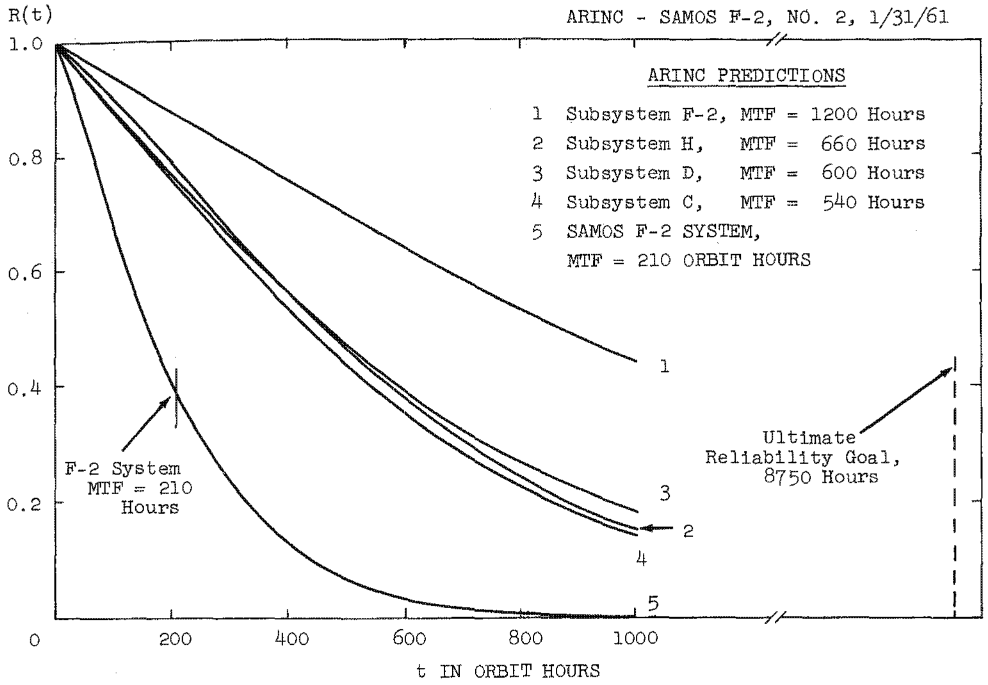


FIGURE 1

ARINC: PREDICTED RELIABILITY FUNCTIONS FOR SAMOS F-2 SYSTEM AND SUBSYSTEMS

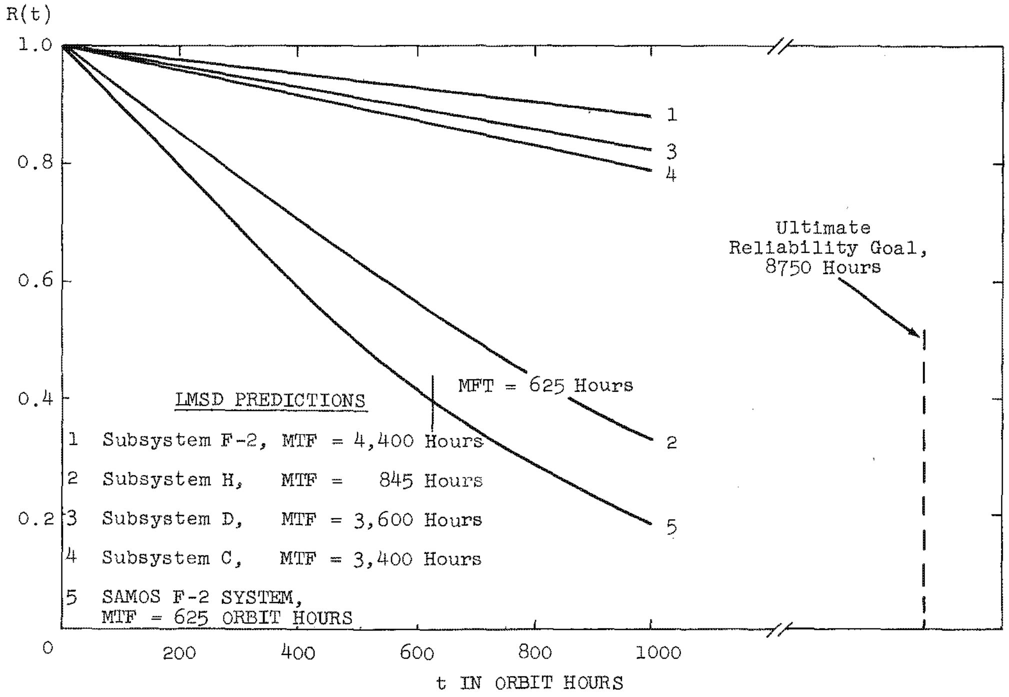


FIGURE 2

LMSD: PREDICTED RELIABILITY FUNCTION FOR SAMOS F-2 SYSTEM

TABLE 1

COMPARATIVE MEAN LIFE PREDICTIONS, PREVIOUS AND PRESENT, FOR SAMOS F-2 SYSTEM AND SUBSYSTEMS

Items	Mean Life, in Hours in Orbit			
	Previous Prediction		Present Prediction	
	ARINC	LMSD	ARINC	LMSD
F-2 System	275	485	210	625
Subsystems:				
C	700	3,038	540	3,400
D	1,150	1,750	600	3,600
F-2	1,050	1,190	1,200	4,400
H	520	800	660	845

Both LMSD and ARINC have re-evaluated their assigned part failure rates since the previous reliability review of this system. The re-evaluation resulted in the assignment of failure rates that were, in general, lower than those used previously. The effects of increased complexity overrode the effects of reduced failure rates in the ARINC calculations, while the reduced failure rates so outweighed the increased complexity in the LMSD calculations that the current LMSD estimate for system MTF is approximately 30 percent higher than the previous estimate.

5. Recommendations for Reliability Improvement

Three of the four subsystems -- Subsystem C, D, and H -- are all major contributors to the unreliability of the SAMOS F-2 System, and should be improved to improve the orbital reliability of the system.

Subsystem C -- It is recommended that an effort be made to reduce the complexity of Subsystem C by reducing the number of units necessary for the payload. It may be possible to do this by rearrangement of the loads -- i.e., separation of payload items from non-essential items, such as non-operational telemetry power supplies, so that a smaller number of power-supply units would be vital to successful payload operation.

A critical examination should be made of power consumed by non-essential loads, to appraise the possibility of employing dissipative (series type) regulators directly off the 28-volt battery without relying on the 2000-cycle inverter. It is possible that 28-volts DC may not be the optimum battery voltage. Results of a study of this kind would be useful in the design of later vehicle configurations.

Additional life-tests of power-supply units should be expedited in order to uncover potential sources of unreliability in design and manufacturing techniques, so that the highest level of design maturity may be achieved in a minimum of time.

Subsystem D -- The principal sources of unreliability in the D Subsystem are apparently the series elements that constitue the common portion of the horizon sensor and the gas channel electronics. It is suggested that the gas channel electronics be examined with a view to eliminating at least one modulator and one demodulator from each channel. Zero drift in these elements may be expected. A life-test of Subsystem D is indicated to permit identification and elimination of as many modes of failure as possible, as soon as possible in the development cycle.

Subsystem H -- Probably the two most fruitful areas for a concentrated reliability-improvement effort are the LODAP and the narrow-band data link transmitter. It is recommended that an investigation be made of the possibility of replacing the LODAP with the MIDAS orbital programmer. The orbital programmer's independence of stored program commands offers considerable potential for reliability improvement.

The UHF narrow-band data link transmitter employs a magnetron and a relatively complex power supply to obtain the necessary frequency stability. There is an almost universal reliability problem in UHF narrow-band techniques -- a problem involving the trade-off of RF-circuitry reliability against power-supply reliability. The current state of the art indicates that VHF transmitters can be made with mean times-to-failure which are an order of magnitude greater than those that can be obtained with UHF transmitters. An auxiliary VHF transmitter has been included as a second back-up for the UHF transmitters in the vehicles under consideration. In the interim before development of later configurations, the UHF transmitters should be subjected to a rigorous life-test program, in order to obtain mature design at the earliest possible date.

I. INTRODUCTION

1.1 Purpose and Scope of Report

This report presents the results of the second reliability study performed by ARINC Research Corporation (ARINC) on the current SAMOS F-2 satellite design, under Amendment Number 2 to Contract IDA-50-3, dated 2 June 1960, as amended. The report presents predictions by both ARINC and the Lockheed Missiles and Space Division of the reliability of the SAMOS F-2 System in the orbit phase, and discusses the major differences between the two estimates. It is expected that, in general, these differences will be resolved as the SAMOS F-2 program progresses.

The report contains an assessment of the reliability that appears feasible on the basis of the current state of the art, and a description of the major problem areas which appear to be the limiting factors in the effort to achieve the desired goals. The mathematical theory, computations, and assumptions involved in the prediction of component and system reliability, along with other supporting data, have been placed in the appendices.

1.2 SAMOS F-2 Design Objectives

The design objective of the SAMOS F-2 System is to provide a satellite reconnaissance capability for the detection and measurement of parameters of pulsed electronic emissions on certain frequency bands. This information will be used to locate areas of possible military activity, as well as to provide data for the design and operation of electronic countermeasure equipment. Data will be collected, analyzed, reduced to digital form, and recorded while the vehicle is over an area of interest. Read-out of the recorded data will be performed while the vehicle is within communications range of one of several ground readout stations. On the ground, additional equipment, not considered in this report, will further process the data and display it in forms usable by the several interested authorities.

1.3 SAMOS F-2 System - Spaceborne Equipment

The satellite portion of the SAMOS system will consist of satellites placed in orbit as required at an altitude of approximately 260 nautical miles. The primary payload of each satellite is the reconnaissance information-gathering and data-transmission equipment. Additional equipment, the proper operation of which is vital for mission success, consists of the flight control and guidance system, electrical power supply and command receiver, and decoder and programmer equipment.

The AGENA, which is the vehicle for the SAMOS system, is launched with an Atlas missile as booster. On Atlas burnout, the AGENA is separated from the booster and coasts up to orbital altitude, meanwhile reorienting itself so that the vehicle longitudinal axis is horizontal. On reaching the programmed altitude, the Bell engine in the AGENA is fired for a period of time sufficient for the attainment of orbital velocity, then cut off, and the vehicle is reoriented to a nose-down position for operation. The attitude control subsystem must then establish a constant pitch-down rate sufficient to maintain the vehicle in accurate orientation with respect to the local vertical at all times during orbit.

Attitude control in orbit will be achieved by a combination of vehicle mass distribution, a rotating pitch wheel, two gyros, and a cold-gas reaction system. It is intended that the gyros and pitch wheel will provide most of the attitude control necessary, and that the gas reaction system will be brought into operation only for the correction of gross attitude errors.

Electrical power for the vehicle equipment will be provided by a solar array in conjunction with a secondary battery bank. The solar array will be extended from the vehicle after orbit is achieved, and will be capable of orientation to achieve the optimum exposure to solar radiation. The DC power provided by the solar array and the battery bank will be converted to AC and DC power at various voltages and frequencies by several static inverters and voltage regulators.

For convenient reference, the vehicle equipment has been classified into several subsystems. Those which will be considered in this report are defined as follows:

Subsystem C:	Electrical Power Generation and Conversion
Subsystem D:	Vehicle Guidance and Attitude Control
Subsystem F-2:	Reconnaissance Payload
Subsystem H:	Data Link and Command Equipment.

1.4 General Basis for Reliability Prediction

A prediction of system reliability can be made during the early development phase of the system if adequate information is available concerning design concepts, circuit configurations, parts to be used, use conditions, system tolerances, and design margins. The reliability prediction is then based on a knowledge of the relationship which can be expected between system failure and part behavior. Parts can fail without producing system failures, and system failures can occur without part failures. In the evaluation of a particular system, it is necessary to estimate the relationship between basic failure rates of the different part classes and the failure rate of the system due to the behavior of these parts. Assumption of a 1-to-1 relationship can lead to optimistic estimates that cannot be matched in practice. Realistic values for the factors relating basic part failure rates to system failure rates for a particular system are therefore important.

In the early phases of system development, before accumulation of adequate reliability test data from which to determine these factors, it is necessary to draw on past experience with other systems. The method employed by ARINC in the prediction of SAMOS F-2 orbit reliability utilizes ARINC studies of airborne, shipborne, and ground-based systems, in which weighted failure rates for parts have been derived from the results of controlled field tests of systems in current production. These weighted failure rates have been used with good accuracy in predictions of the reliability of new airborne system designs, as subsequently verified during reliability bench tests and field operations. The weighted failure rates include allowance for system tolerance and deterioration failures, interactions among parts and components which produce system failure, relative importance of parts to system success, and the basic part failure rate under specified use conditions. A table of part failure rates as used in the current SAMOS F-2 evaluation is presented in Appendix A.

1.5 Prediction Method

In a preliminary prediction of system reliability for use in estimating feasible reliability during the early design stage, a reliability block diagram of the system is first developed. The block diagram orients components within the system, in series and series-parallel combinations, for each system function that is being evaluated, to reflect design provision for redundancy and switching devices -- and, to the extent practicable, to show interdependencies among components. A parts count is made, by part class, within each component of the block diagram. Component failure rates are estimated by adding failure rates of the parts within each component. Component failure rates are then combined, taking into account duty cycle and redundancy, to develop the estimated failure rate for the system function.

A summary of the general assumptions underlying ARINC's prediction method is presented in Appendix B.

II. EVALUATION OF SAMOS F-2 RELIABILITY

This section presents an evaluation of SAMOS orbit reliability, based on predictions of component and subsystem reliabilities. Two independent sets of predictions are given -- one by ARINC and one by LMSD. Detailed analyses of the individual components and other supporting data are included in the appendices.

2.1 Reliability Block Diagram for the SAMOS F-2 Orbital System

A simplified reliability block diagram for the SAMOS F-2 orbital system is shown in Figure 3. Subsystems F-2, C, and H perform the functions of acquiring reconnaissance data, encoding it, and transmitting it to the ground readout stations. Subsystem D provides attitude stabilization for the AGENA vehicle, which carries the payload.

ARINC - SAMOS F-2, NO. 2, 1/31/61

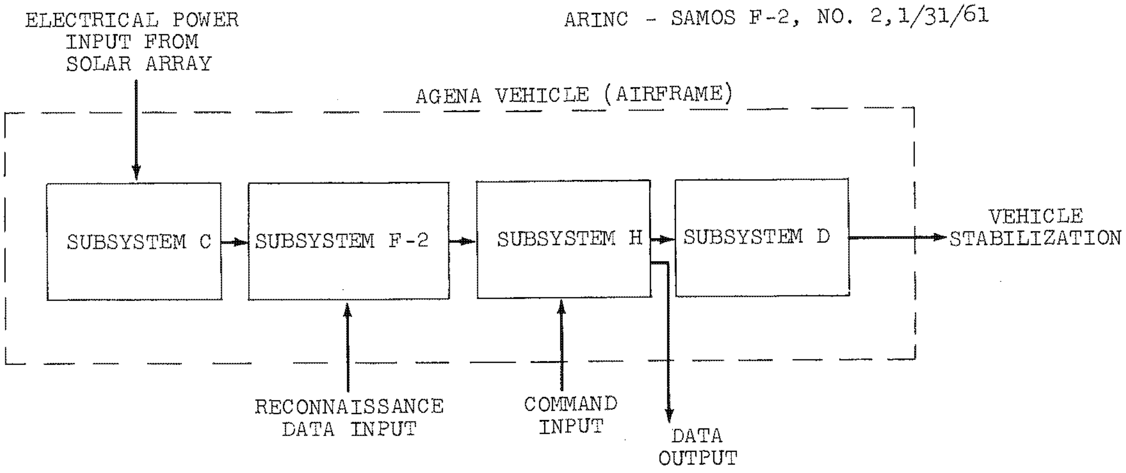


FIGURE 3

SAMOS F-2 SYSTEM, ORBITAL PHASE: RELIABILITY BLOCK DIAGRAM

These subsystems are all considered equally important to system success, although partial failures within some of the subsystems, producing varying degrees of system-performance degradation, can be tolerated to some extent. It is assumed, for example, that a failure of one of the two gyros in Subsystem D will prolong the time required for vehicle restabilization following a perturbation, but will not otherwise affect system success. No attempt has been made to estimate the operational effectiveness of partially degraded systems.

The block diagram implies an assumption of independence among subsystems. This assumption is adopted for the sake of ease in combining reliabilities to estimate the reliability of the system as a whole. While it is known that the assumption is seldom entirely valid in relation to complex systems, the error thus induced is usually small and on the optimistic side.

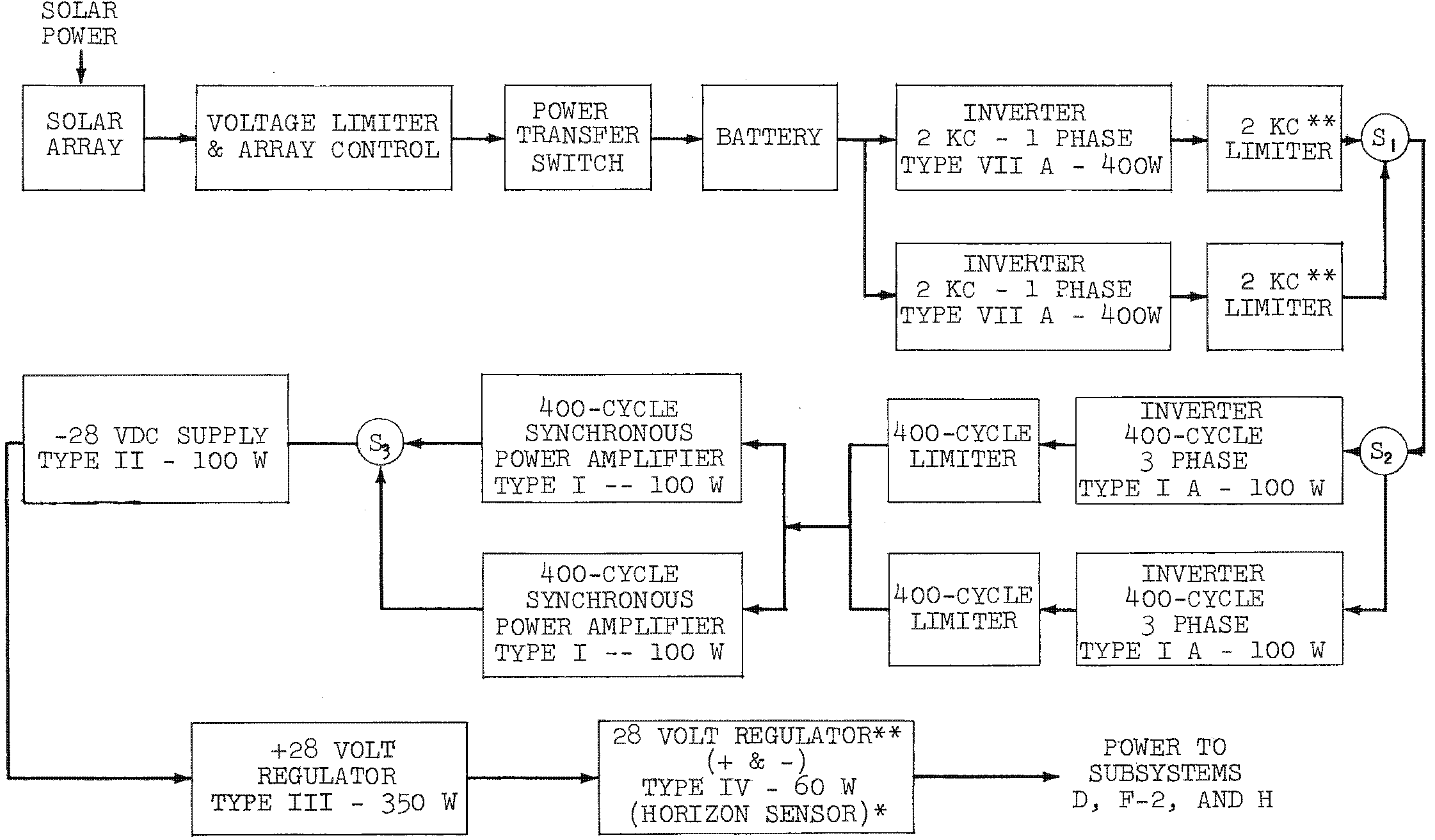
An exponential distribution of the times-to-failure of non-redundant components within individual subsystems is assumed, except as otherwise noted in the analysis. Past observations indicate that this assumption is valid for complex components. Redundant component configurations are treated at discrete time intervals in order to permit the application of the product-rule at these time intervals in the combination of redundant and non-redundant reliabilities.

2.2 Reliability Evaluation of Subsystem C

2.2.1 Reliability Block Diagram

The reliability block diagram for Subsystem C is presented in Figure 4. Except for the (+ and -) 28-volt regulator for the horizon sensor, the components shown in the figure are those currently planned for the F-2 configuration. The horizon-sensor power supply will actually be a Type VII instead of a Type IV; but since plans on the Type VII power supply are not readily available, it has been assumed that the two components are equivalent for reliability prediction purposes.

ARINC - SAMOS F-2, NO. 2, 1/31/61



* The horizon sensor actually employs a Type VII power supply. Due to the lack of immediate information on the Type VII, it is assumed that Type IV and Type III are equivalent for reliability prediction purposes.

** Units added since first periodic review.

FIGURE 4

SUBSYSTEM C: RELIABILITY BLOCK DIAGRAM

The individual elements making up Subsystem C have increased in complexity during the interim since publication of the first interim report. This increase in complexity can be noted in the increased parts counts for equivalent elements. The parts counts previously employed are shown in parentheses in Table 2.

Spare components in the redundant configurations are on a standby basis and are energized by a relay if a failure is detected in the primary component. All components not in the standby state have a 100-percent duty cycle. It is assumed that failure of any non-redundant component or total failure of a redundant combination will result in system failure. The reliabilities of the solar-cell array and the secondary battery were not included in the prediction computations, owing to lack of valid failure-rate data on these items. The input power switch and pins, connectors, plugs, and similar types of parts were also excluded, since these items operate only once or are not subjected to stress after orbit is achieved. Owing to lack of design information, the array control also was omitted from the analysis. These elements will be taken into account in the future, by both LMSD and ARINC, as data become available.

The failure rate of each component was predicted by adding the estimated failure rates of its constituent parts. Because of the extensive redundancy employed, the failure rate of the subsystem is not constant, but instead increases with time. The prediction will therefore be shown in the form of a reliability function, and the mean life will be estimated by integrating the reliability function over the complete time interval $(0, \infty)$.

2.2.2 Analysis of Switching Circuits

Reliability evaluation of the redundant components of the subsystem requires a detailed analysis of the switching circuit. There are generally three switching states involved:

(1) normal operation

(2) premature operation (switching when not required)

(3) operational failure (failure to switch when required -- i.e., a dud).

TABLE 2

SUBSYSTEM C: PART FAILURE RATES AND NUMBER OF PARTS, BY COMPONENTS

Type of Part	Part Failure Rate x 10^{-6}		Number of Parts in Each Component								
	ARINC	LMSD	Inverter 2 KC Type VIIA (EM424D-2)	Inverter 400-Cycle Type IA (EM417A)‡	# Limiter 2 KC	Limiter 400-Cycle	Power Amplifier Type I (EM428D)	-28VDC Supply Type II (EM422A)	+28 VDC Regulator Type III (EM761)	28 VDC# Regulator (+&-) Type IV (EM807)	Voltage Limiter
Power Transistor	40.0	4.0	10 (8)	18 (6)			5 (2)	4	5 (2)	4	1*
Signal Transistor	6.0	0.8	5 (7)	17 (27)			(3)		3	8	(1)
Power Diode	3.5	1.0	5	4			3	3 (4)	2	4	
Signal Diode	1.7	0.3	3 (6)	31 (30)			10 (12)	2 (1)	10	18	
Zener Diode	2.2	0.5	6 (4)	5 (4)			3 (4)	(2)	7	8	5 (5)
Potentiometer	15.0	1.5	1	2	1		1	1	2	2	
Resistor, Fixed	0.5	0.2	30 (27)	105 (99)		2 (2)	14 (15)	13 (5)	20 (2)	24	1 (1)
Capacitor (> 1 MFD)	5.0	1.0	18 (26)	33 (48)			16 (12)	6 (4)	4 (5)	14	
Capacitor ($\leq$ 1 MFD)	0.6	0.1	7	26			2	6	5	13	
Choke	7.5	2.5	3 (6)	5 (6)	1	1	3 (5)	1 (1)	5 (1)	4	
Choke, Light Duty	2.0	0.5	3	1			2	1 (1)	1	2	
Transformer, Power	12.0	3.5	4 (8)	8 (11)			3 (5)	1 (1)	1 (1)	2	
Transformer, Light Duty	4.0	1.0	4	3			2				
Mag.-Amp.	16.3	5.0	1 (1)	2 (2)		(2)	1 (1)		1 (1)		
Solenoid**	36.0	20.0	2 (2)	2 (2)			2 (2)				
Relay	20.0	4.0									1 (1)
Crystal, Quartz	2.0	0.4		1 (1)							
Failure Rate x 10^{-6}	ARINC		770.8	1442.9		8.5	496.1	250.5	388.2	448.0	34.9†
	LMSD		111.1	215.4	4.0	2.9	74.0	36.8	63.9	76.9	7.7

* A failure rate of 1.7 x 10^{-6} was used for this transistor since it is only used as a switch.

** Solenoids shown are not part of these inverters, but are in the associated inverter change-over units. These rates were used in calculating the reliability of the inverters with their change-over units.

† Failure of a Voltage Limiter will result in some system degradation, but not system failure. A failure rate of 1.5 (one relay contact) was used in computing the system reliability.

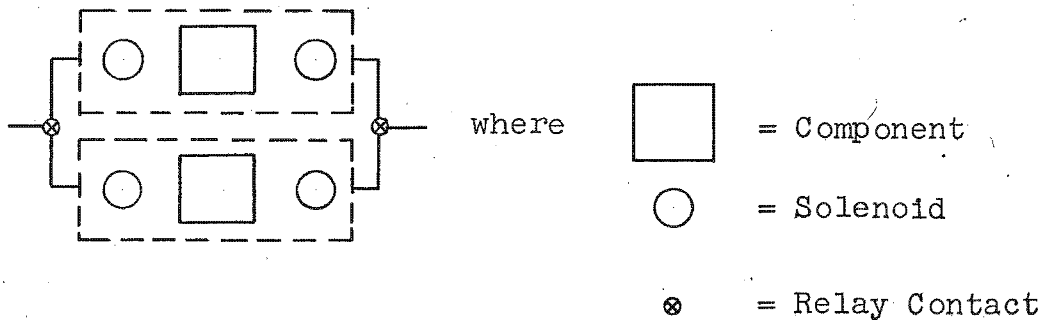
‡ A Type IB 400-cycle inverter, similar to Type IA and Limiter is now planned. Details are not currently available.

( ) Parts count from previous analysis.

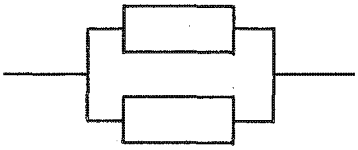
\# Indicates units added since first periodic review.

TOP

Also involved is the ability of the switch to make and maintain a good contact (contact reliability). A dud failure will always result in component failure, whereas premature switching will reduce the effectiveness of the redundancy application. The switching devices in Subsystem C are relay networks in which the contacts are controlled by either of two pairs of solenoids, the second pair being energized if the primary component fails. Since the various switching failure probabilities are unknown, and since many combinations of events are possible, it was decided to simplify the prediction calculation by limiting consideration to the effect of premature switching due to solenoid failure. Under the assumptions that contact reliability is 1.0 and the probability of a dud is zero, the block diagram for a redundant unit in Subsystem C can be drawn as follows:



This configuration can be converted to the simpler form



which, for the standby case, has the reliability function for identical components

$$R(t) = e^{-\lambda t}(1 + \lambda t),$$

where λ is the total failure rate of two solenoids and one component.

2.2.3 Calculation of Subsystem Reliability

Table 2 lists the number of parts within each component, by part type, and gives the part failure rates employed in the prediction. Using the estimated component failure rates shown in the table, the reliability function computed for Subsystem C is equal to:

$$R(t) = e^{-At} e^{-Bt}(1 + Bt)\, e^{-Ct}(1 + Ct)\, e^{-Dt}(1 + Dt)$$

where

A = sum of the failure rates of the non-redundant components

B = sum of the failure rates of the 2-KC inverter and the 2-KC limiter

C = sum of the failure rates of the 400-cycle inverter and the 400-cycle limiter

D = failure rate of the 400-cycle synchronous power amplifier.

The equation can be further simplified to:

$$R(t) = e^{-a_1 t}\left[1 + a_2 t + a_3 t^2 + a_4 t^3\right]$$

where

$a_1 = A + B + C + D$

$a_2 = B + C + D$

$a_3 = BC + BD + CD$

$a_4 = BCD.$

The subsystem mean time-to-failure (MTF) can be shown to be equal to the following:

$$MTF = \frac{1}{a_1} + \frac{a_2}{a_1^2} + \frac{2a_3}{a_1^3} + \frac{6a_4}{a_1^4} \quad .$$

Using the above equations and the ARINC component failure rates shown in Table 2, we have:

$$R(t) = e^{-0.003852}\left[1 + 0.002741t + 0.000002265t^2 + 0.000000000571t^3\right]$$

and the estimated reliability for Subsystem C is

ARINC Estimated MTF = 540 hours	LMSD Estimated MTF = 3400 hours

The predicted reliability functions are shown graphically in Figure 5.

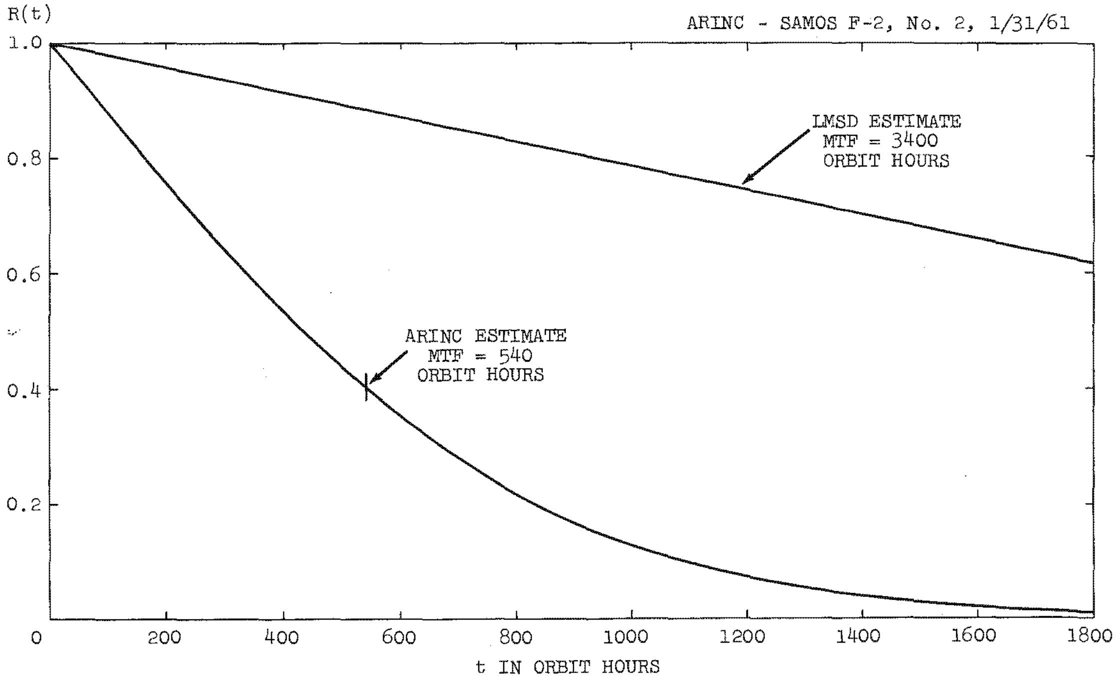


FIGURE 5

SUBSYSTEM C: PREDICTED RELIABILITY FUNCTIONS

2.2.4 Comparison of Present Prediction of Subsystem C Reliability with Previous Prediction in First Periodic Review

As shown above, the present ARINC estimate of the mean time-to-failure for Subsystem C is 540 hours, as compared to a corresponding estimate of 700 hours in the first periodic review. The decrease of 160 hours in the MTF estimate is attributable chiefly to the addition of (1) the 2-KC limiter, (2) the 28-volt DC regulator (+ and -), and (3) greater complexity in the Type III 28-volt DC regulator. The parts counts for the present and previous analyses are compared in Table 2.

2.3 Reliability Evaluation of Subsystem D

Subsystem D maintains the attitude of the AGENA vehicle during the engine-operating, coast, and orbital phases of operations. The attitude-sensing element, during the engine-operating and coast phases, is an inertial reference platform (IRP). During the orbital phase, a horizon scanner provides the pitch sense signal while the control-moment gyros (CMG's) provide yaw and roll sense signals.

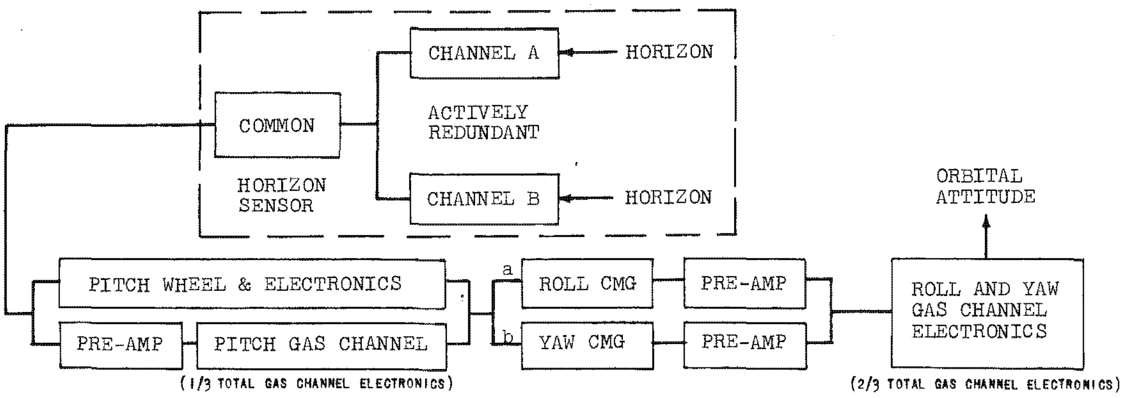
Attitude changes are accomplished by gimbaling the engine for pitch and yaw control and by using a cold-gas jet-roll control during engine operation. During coast, the attitude is changed by six cold gas jets. In orbit, a system providing fine and coarse attitude control is employed. The cold-gas jet system is used when attitude corrections larger than four degrees are required. Vernier pitch control is provided by a pitch wheel which is speeded up or slowed down to generate the required stabilization. When the pitch wheel nears maximum speed in either direction, the cold-gas system is employed to counteract its momentum so that the wheel does not become saturated. The yaw and roll control-moment gyros are constant speed gyros with their rotational moment vectors along the pitch axis and their respective gimbal axes along the roll and yaw axes. These are single-degree-of-freedom rate gyros with viscous damping. The gyros provide a restoring torque when the axes of the rotors are not perpendicular to the plane of the orbit. When the four-degree limit is exceeded, a signal is picked off the gimbal to actuate the gas jet system.

2.3.1 Reliability Block Diagram and Functional Diagram

Figure 6 presents both a reliability block diagram and a functional diagram of the attitude control subsystem. Several modes of in-orbit operation of this subsystem are possible, depending on the perturbations encountered. In principle, the roll and yaw control-moment gyros, given enough time, would stabilize the AGENA about these two axes, thus permitting recovery from reasonable perturbations. The roll and yaw gas jets will handle large attitude perturbations during orbit more rapidly. The

ARINC - SAMOS F-2, No. 2, 1/31/61

RELIABILITY BLOCK DIAGRAM



FUNCTIONAL DIAGRAM

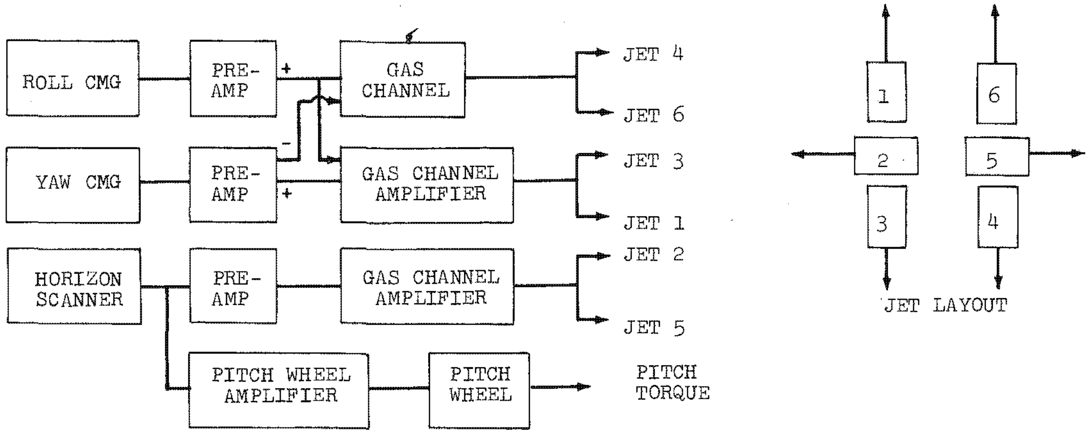


FIGURE 6

SUBSYSTEM D: RELIABILITY BLOCK DIAGRAM AND FUNCTIONAL DIAGRAM roll and yaw control-moment gyros are essential to operation of the D subsystem because they provide both a sensing element and at least part of the control function; but for purposes of this analysis, it is assumed that only one is required.

Table 3, together with the attached notes, shows the limitations placed on the attitude control subsystem when various portions of the subsystem fail. The one indispensable unit is the horizon scanner.

The cold-gas system is considered essential in handling the initial task of orbital orientation and establishment of pitch rate. Once the initial orientation phase of orbital flight has been accomplished, the cold-gas system should remain relatively inactive.

2.3.2 Calculation of Subsystem Reliability

Table 4 shows the parts count by block in the reliability diagram. The following reliability mathematical model was developed, with all indicated redundancy counted as active:

$$R_D = R_A \cdot R_B \cdot R_C \cdot R_E \cdot R_F$$

where

R_A = redundant portion of horizon scanner.

R_B = non-redundant portion of horizon scanner.

R_C = pitch wheel electronics in parallel with pre-amplifier and pitch gas channel electronics.

R_D = roll CMG multiplied by pre-amplifier, in parallel with yaw CMG multiplied by pre-amplifier

R_F = roll and yaw gas channel electronics.

The estimated mean time-to-failure for the subsystem is as follows:

ARINC Estimated MTF = 600 hours	LMSD Estimated MTF = 3600 hours

TABLE 3

LIMITATIONS IMPOSED ON ATTITUDE CONTROL SUBSYSTEM BY FAILURE OF VARIOUS PORTIONS OF THE SUBSYSTEM

Element	Mode of Operation						
	1	2	3	4	5	6	7
Horizon Scanner	X	X	X	X	X	X	X
Pitch Gas Channel	X		X	X	X	X	
Pitch Wheel & Electronics	X	X		X	X	X	X
Roll CMG	X	X	X		X	X	X or X
Yaw CMG	X	X	X	X		X	
Roll & Yaw Gas Channel Electronics	X	X	X	X (Yaw)	X (Roll)		
Gas Supply	X	X	X	X	X	X	

Limitations by Mode

1. Entire subsystem operable.
2. Pitch wheel does not over speed.
3. Reduced pitch accuracy and rapid depletion of cold gas.
4. If pitch wheel is operating at relatively high speed, it will tend to correct for roll without damping, thus resulting in yaw perturbation. Yaw CMG will furnish damping for the system. No roll-sensing element is available; hence, no roll cold gas correction is available.
5. Same as Note 4 with roll and yaw statements reversed.
6. If either gas channel amplifier fails, a roll (or yaw) correction will result in a yaw (or roll) reaction as well.
7. Unless a relatively large perturbation in attitude is introduced, these elements are sufficient to maintain system attitude. The failure of any reaction-correction devices in other subsystems can introduce perturbation which will require a relatively long time for the gyros alone to correct. The limited speed of the pitch wheel must be remembered. Solar array reorientation is not possible.

TABLE 4

SUBSYSTEM D: PART FAILURE RATE AND NUMBER OF PARTS, BY COMPONENTS

Type of Part	Part Failure Rate x 10^{-6}		Horizon Sensor			Pitch Wheel Amplifier	Gas Channel Amplifier	Pre Amplifier
	ARINC	IMSD	Per Channel	Series Circuitry	Roll** Error Signals			
Capacitors, Gen.	0.6	0.1	10 (9)	4	(5)	8 (8)	23 (16)	1
Capacitors, Tant.	5.0	1.0	45	6	5	4	6	1
Diodes, Signal	1.7	0.3	38(22)	56	6 (13)	5 } (20)	40 (40)	8
Diodes, Zener	2.2	0.5	18	16	14	1 }	30	1
Gyro, Control Moment	91							
Motors, AC	88.0	10.0	1					
Relays, Gen.	20.0	4.0				3 (1)	16* (1)	
Resistors	0.5	0.2	129(38)	67	20 (22)	20 (34)	198 (68)	7
Potentiometers	15.0	1.5	9 (1)	9	5 (1)	(1)	3 (3)	2
Transformers	4.0	1.0	5 (4)		(2)	9 (3)	9 (7)	2
Chokes (Light)	2.0	0.5				2		
Transistors, Sig.	6.0	0.8	36(12)	39	5 (7)	4 } (11)	31 (21)	3
Transistors, Pow.	40.0	4.0				8 }		
IR Cells	2.0	0.1	1					
Pitch Wheel	88.0	45.1				1		
Total Failure Rate x 10^{-6}	ARINC		860.7	565.3	181.0	577.5	863.8	80.9
	LMSD		154.3	84.3		113.2	113.2	12.8

* Relays de-energized during orbital operation, required for ascent.

** Required to furnish Roll Signal to Subsystem F-2 Attitude Converter not part of control function Subsystem D.

( ) Indicates part count in first periodic review.

The two largest (and approximately equal) contributors to Subsystem D unreliability are the series horizon scanner element and the roll and yaw gas channel amplifiers. The gas channel amplifiers contain several conversions from AC signals to DC signals, and vice versa, to form a series of analog computer operational amplifiers. The function of these channels is to accept a phase-selective AC signal from the inertial reference platform or control-moment gyros and furnish a DC signal to operate gas jet solenoids. A dead band is necessary for small corrective signals (less than four degrees). Also necessary are a region of proportional control, including a time constant, and a saturation region for unduly large correction signals. All of the required performance except the time constant can be achieved on the signal in AC form. It is suggested that LMSD study this approach to determine whether a reduction in complexity can be achieved. As an alternative, a scheme might be devised to turn the gas channel amplifiers on and off, either on real time command or at infrequent periodic intervals, in order to reduce the duty cycle of the amplifiers.

The effects of the gas channel amplifiers and the non-redundant portion of the horizon sensor on the reliability of the subsystem are so severe that reduction of the failure rates of these components by a factor of two would improve the subsystem mean life by a factor of two. Figure 7, which presents the LMSD and ARINC predicted reliability functions for the entire D Subsystem, also shows the ARINC functions for the non-redundant elements (series horizon scanner and roll and yaw gas channel amplifiers) and for the redundant elements (equivalent to the subsystem minus the two high-failure-rate items).

2.3.3 Comparison of Present Prediction of Subsystem D Reliability with Previous Prediction in First Periodic Review

The estimated reliability of Subsystem D has been affected by a change in the mathematical model and changes in the part counts of the individual circuit elements. The ARINC MTF estimate has decreased to one half of that given previously (600 hours currently, as compared to 1150 hours previously), because the more favorable part failure rates did not compensate for the effect of the more accurate model.

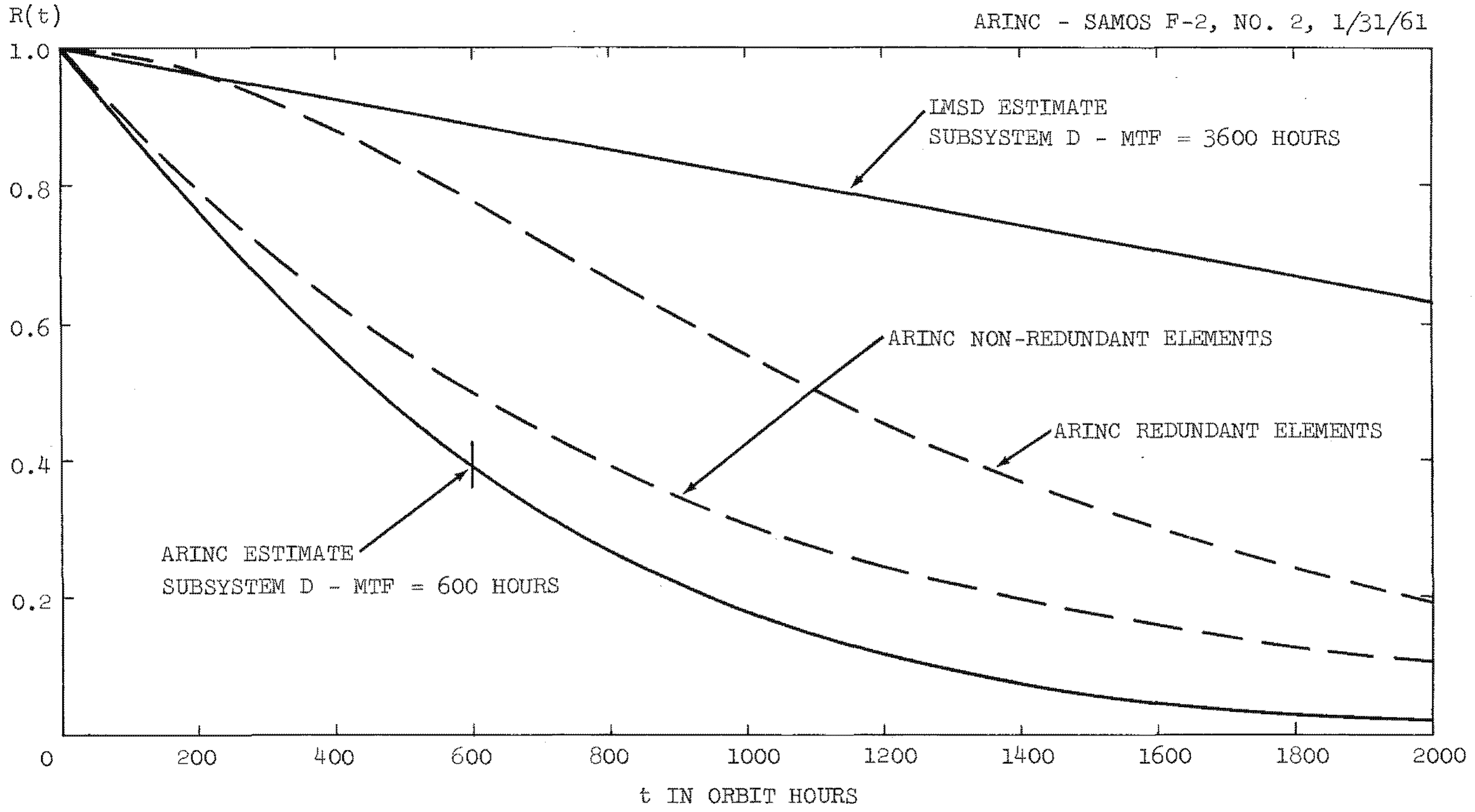


FIGURE 7

SUBSYSTEM D: PREDICTED RELIABILITY FUNCTIONS

The LMSD estimate of the subsystem MTF increased from 1810 hours to 3600 hours, with the same models as those used by ARINC. The changes in part failure rates between the first and second evaluations caused this apparent contradiction. The models are sensitive to the relative failure-rate changes for the various part types.

2.4 Reliability Evaluation of Subsystem F-2

2.4.1 Configuration and Reliability Block Diagram

ARINC's previous reliability analysis of the F-2 Subsystem was based on the configuration to be employed in Flights 1 and 2. These units, which are to remain unchanged, are now under construction for early delivery. The advances in configuration and in development of improved circuitry which have taken place in the interval since the analysis of the Flight 1 and 2 version are presently being incorporated into equipment to be built for Flights 3 and 4. Table 5 shows the functional capabilities of the two versions of the subsystem.

TABLE 5

FUNCTIONAL CAPABILITIES OF TWO VERSIONS OF SUBSYSTEM F-2

	Flights 1 and 2	Flights 3 and 4
Frequency Bands	1 - 2500 to 3200 MC 2 - 9000 to 10,000 MC	1 - 2500 to 3200 MC 3b - 130 to 290 MC 3c - 290 to 650 MC
Parameters of Intercepted Signal Measured	(a) PRF - 1 (b) PRF - 2 (c) Pulse Width	(a) PRF - 1 (b) PRF - 2 (c) Pulse Width (d) Pulse Amplitude (e) Pulse Amplitude Difference (f) Non-Uniform PRF (g) Sequential Pulse Detection
Bit Word/ Intercept	50 Bits	69 Bits

Figure 8 is a reliability block diagram of the Subsystem F-2 configuration for Flights 3 and 4. The heavily outlined items with grey background are those which were not part of the configuration for Flights 1 and 2 -- except for the ± 12-volt power supply, which was part of the Flight 1 and 2 equipment but was omitted from the previous analysis.

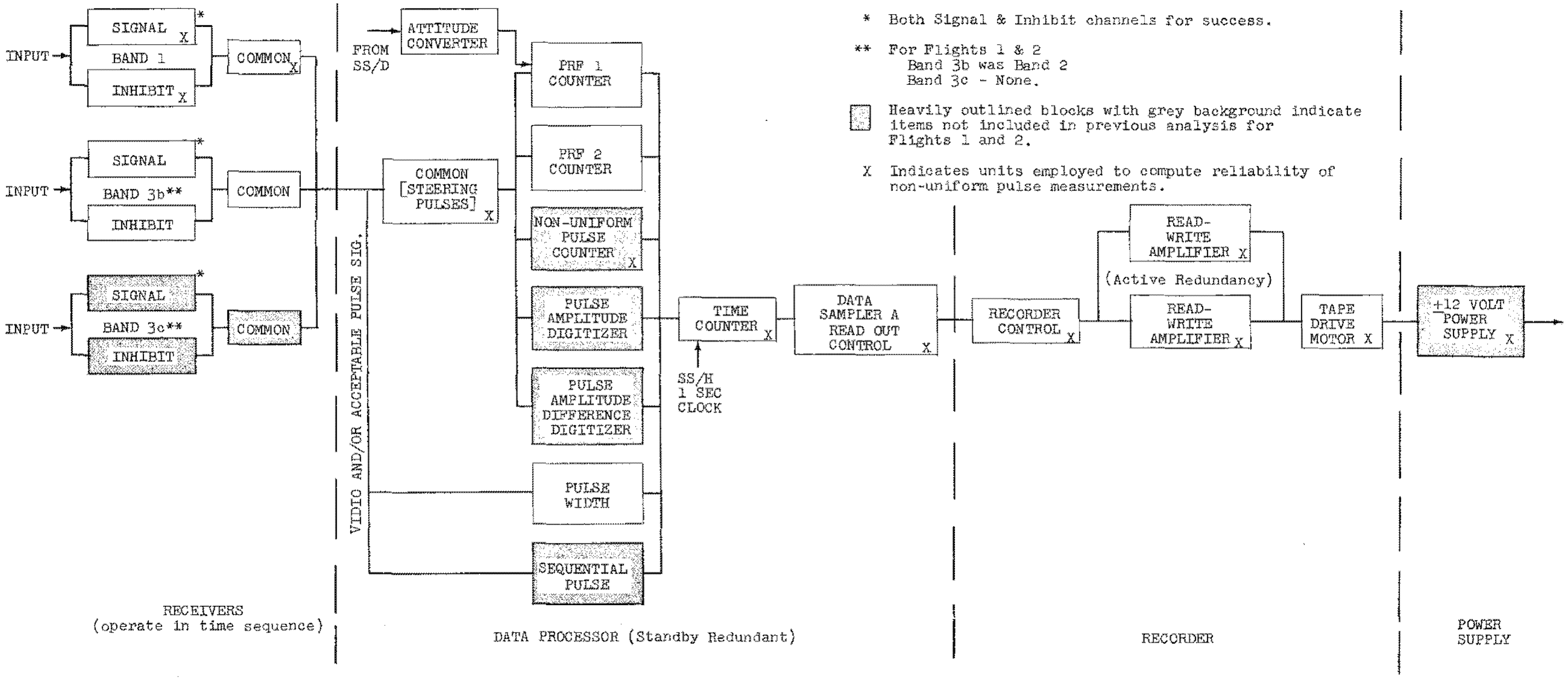
Each frequency band has two receivers and a common local oscillator. The receivers cover their frequency range in approximately seven seconds. The bands are covered in sequence. The antenna on the signal channel is highly directional, while the antenna on the inhibit channel has a broader directional pattern. The sensitivity of each receiver is adjusted so that an on-axis signal produces a higher output from the signal receiver. A signal from a source that is off the antenna axis by more than approximately 30 degrees will produce a stronger signal from the inhibit channel than it will from the signal channel. An amplitude comparator starts the data processor when the output of the signal receiver is greater than the output of the inhibit receiver.

The data processor converts the output of the amplitude comparator into a digital word which is stored in a start-stop tape recorder. Time and vehicle attitude are entered on the tape. A read-out of the tape is executed upon receipt of a real time command from Subsystem H. The digital data are transmitted to a ground station through the narrow-band data-link transmitter of Subsystem H.

Auxiliary functions such as calibration and telemetry circuitry have been omitted from the F-2 analysis.

2.4.2 Calculation of Subsystem Reliability

In computing the reliability of the F-2 payload package in the first evaluation of SAMOS F-2 reliability, notice was taken of the steps which Airborne Instruments Laboratory (the Subsystem F-2 subcontractor) was taking to ensure the reliability of the equipment. These steps included rigid design specifications covering component derating and a design review program in which all audio



* Both Signal & Inhibit channels for success.

** For Flights 1 & 2
Band 3b was Band 2
Band 3c - None.

▨ Heavily outlined blocks with grey background indicate items not included in previous analysis for Flights 1 and 2.

X Indicates units employed to compute reliability of non-uniform pulse measurements.

FIGURE 8

SUBSYSTEM F-2 (FLIGHTS 3 & 4): RELIABILITY BLOCK DIAGRAM and digital circuits were checked with all possible combinations of high and low limit parts. For this reason, the predicted failure rates of all parts in analog applications were reduced by an arbitrary factor of three in the F-2 package only. In the current analysis of the over-all SAMOS system, more recent failure-rate data have been used, and it has been noted that most contractors are now implementing reliability programs similar to that used by AIL. For this reason, the analog part failure rates for semiconductor devices have been substantially reduced from those used in the previous analysis, and the reduced rates have been applied for the entire SAMOS system. Therefore, the special correction is no longer being applied to the payload alone.

The reliability function forSubsystem F-2 is, of course, dependent on the definition of subsystem failure. At this time, no information is available on the amount of degradation that can be tolerated in the receiver portion, nor is information available regarding the effect on subsystem performance if a particular analyzer or combination of analyzers fails. Because "importance factors" for these components cannot be assigned at the present time, it was decided to make the prediction on the basis of a 100-percent information-return requirement. Therefore, the results will be pessimistic if it proves possible to lose some components and still have what can be considered a "successful" system.

Defining success for a system such as the SAMOS F-2 presents a problem. For example, frequency of intercept and time of intercept are required to obtain position, and so are necessary for the success of the mission. If a PRF measurement is missing, the effectiveness of the system will be limited but some degree of success may still be possible. A similar situation exists with respect to other individual measurements shown in Table 7. All measurements shown for Flights 1 and 2 are considered necessary for success. A later section of this report shows that the probability of success in obtaining any one measurement is so heavily weighted by the serial equipment that the unreliability of individual measurement devices has a relatively small effect on the overall system reliability.

For a 100-percent-successful subsystem, after applying the product rule for series elements and the appropriate formulas for the redundant configurations, we have

$$R(t) = e^{-(\lambda_1 + \lambda_2)t}(1 + \lambda_2 t)\left[2e^{-\lambda_3 t} - e^{-2\lambda_3 t}\right]^3$$

where

λ_1 = sum of the failure rates of all receiver components.

λ_2 = sum of the failure rates of all data-processor components.

λ_3 = sum of the failure rates of the read and write channels.

The failure rates for the data-read and synch-read channels are the same; similarly, the data-write and synch-write channels have the same failure rates.

Using the ARINC component failure rates given in Tables 6-A and 6-B (pages 34 and 35) for only the equipment employed in the Flight 1 and 2 version of the configuration,

$$R(t) = e^{-0.001330t}\,(1 + 0.000821\,t)\cdot$$
$$(2e^{-0.000094\,t} - e^{-0.000188\,t})^2,$$

and the ARINC prediction for subsystem mean life, as shown below with the LMSD prediction, is approximately 1200 orbital hours.

ARINC Estimate MTF = 1200 orbital hrs.	LMSD Estimate MTF = 4400 orbital hrs.

The reliability functions predicted for Subsystem F-2 are shown in Figure 9.

2.4.3 Comparison of Present Prediction of Subsystem F-2 Reliability with Previous Prediction in First Periodic Review

In the previous review of this subsystem, ARINC predicted a mean life of 1025 hours. The dashed line in Figure 9 shows the effect of including the ± 12-volt power supply in the estimate.

Since the Flight 3 and 4 configuration adds complexity to the subsystem by increasing its functions, an analysis was made to determine the effect of the increased complexity. This analysis was based on a series path including one receiver and the appropriate components in the data processor on a standby redundant basis, the recorder

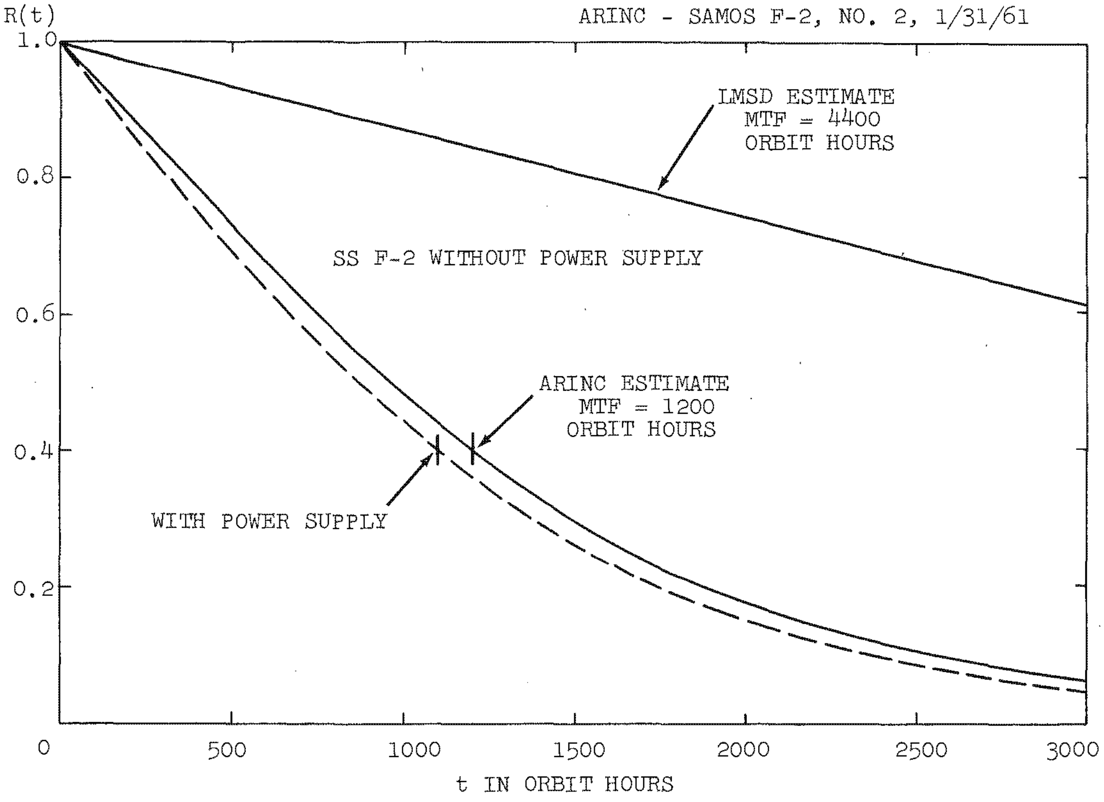


FIGURE 9

SUBSYSTEM F-2: PREDICTED RELIABILITY FUNCTIONS

TABLE 6-A

SUBSYSTEM F-2; RECEIVERS, RECORDER AND POWER SUPPLY, (FLIGHTS 3 & 4):
COMPONENT AND PART FAILURE RATES: NUMBER OF PARTS BY COMPONENT

Type of Part	Part Failure Rate x 10^{-6}		Receivers, Amplitude-Comparator and Control				Recorder		Tape Drive†	Power Supply ±12 Volts
	ARINC	LMSD	Band 1†	Band 3b†	Band 3c	Common per Band†	Recorder Control*†	Read & Write Amplifier (redundant)†		
Capacitor:										
General <1.0 µfd	0.6	0.1		23	13	87	36	5		
Tantalum >1.0 µfd	5.0	1.0					15	8		8
Coil, Inductanceq	2.0	0.5		25	11	57				1
Diodes:										
Signal <1.0 w	1.7	0.3	4	4	4	51	54	2		
Power >1.0 w	3.5	1.0							2	4
Zeners	2.2	0.5								4
Klystron	23.9	23.9	1							
Motors, AC	88.0	20.0				1				
Motor Drive 400 cps - 3 Phase	88.0	20.0							1	
Relays, General	20.0	4.0				4	2		5	
Resistors:	0.5	0.2		3	2	192	113	34	9	21
Transformer:										
Power/Pulse	4.0	1.0				1		1		1
RF or IF	4.0	1.0		4	4					
Transistor, Analog: <1.0 w	6.0	0.8		1		40				
Transistor, Digital:										
Signal <1.0 w	1.7	0.8					24	4	1	4
Power >1.0 w	40.0	4.0						6	2	4
Trans. Tube	23.9	23.9			1	1				
Shaft Encoder**	1.0	1.0				1				
Over-all Failure Rate x 10^{-6}	ARINC		30.7	94.1	77.5	785.8	325.7	314.2	281.2	246.1
	LMSD		25.1	21.4	36.3	184.8	84.6	44.1	52.6	38.9
30% Duty Cycle	ARINC		9.2	28.2	23.3	235.7	97.7	94.3	84.4	73.8
	LMSD		7.5	6.4	10.9	55.4	25.4	13.2	15.8	11.7

* 4FF & 4EF or I Circuits & 1 Delay Line part count estimated as 12 transistors, 12 diodes, 32 resistors and capacitors.

** Based on loss random digits only and redundant band switching circuitry (timers).

† Units employed in Flight (1 & 2) Configuration. (Band 1 & 2 were considered.)

TABLE 6-B

SUBSYSTEM F-2 DATA PROCESSOR, (FLIGHTS 3 & 4): COMPONENT AND PART FAILURE RATES: NUMBER OF PARTS BY COMPONENT

Type of Part	Part Failure Rate x 10^{-6}		Common Clock 10 KC†	PRF Counter 1†	PRF Counter 2†	PW. Shaping & Selection†	Non-uniform PRF	PA Digitizer	PA Difference Digitizer	Sequential Pulse	Time Counter†	Data Sampler & Read-out Control†	Attitude Converter
	ARINC	LMSD											
Capacitor:													
General <1.0 µfd	0.6	0.1	29	40	53	16	74	61	41	20	64	92	14
Tantalum >1.0 µfd	5.0	1.0	18		4	12	5	12	20	2	4	10	
Coil, Inductance	2.0	0.5				1							
Crystal, Quartz	2.0	0.4	1					1					
Delay Line	4.0	2.0				3		1	2				
Diode: Signal <1.0 w	1.7	0.3	82	66	106	30	289	101	76	3	109	108	8
Resistor	0.5	0.2	101	70	132	72	238	177	148	55	163	246	42
Transformer: Power/Pulse	4.0	1.0	1		3			5	3				2
Transistor Digital <1.0 w	1.7	0.8	24	20	33	29	54	54	46	14	37	70	14
Over-all Failure Rate x 10^{-6}	ARINC		345.1	205.2	366.1	219.9	771.5	474.6	426.0	78.4	388.1	530.8	74.8
	LMSD		86.3	53.8	96.9	67.7	189.9	134.4	120.3	27.1	105.3	156.8	25.4
30% Duty Cycle	ARINC		103.5	61.6	109.8	66.0	231.5	142.4	127.8	23.5	116.4	159.2	22.4
	LMSD		25.9	16.1	29.1	20.3	57.0	40.3	36.1	8.1	31.6	47.0	7.6

†Units employed in Flight (1 & 2) Configuration. (Band 1 & 2 were considered.)

circuitry, and the power supply. (Components considered for the non-uniform PRF path are indicated with an "X" in Figure 7.) The results of these computations were plotted and are shown in Figure 10. The individual reliability functions all fall in the small band indicated. The total failure rate of the serial equipment is so overwhelming that the failure rate of the measurement circuits, whether taken in series (as was done in the estimate above) or as separate functions (as was done here) does not significantly affect the outcome.

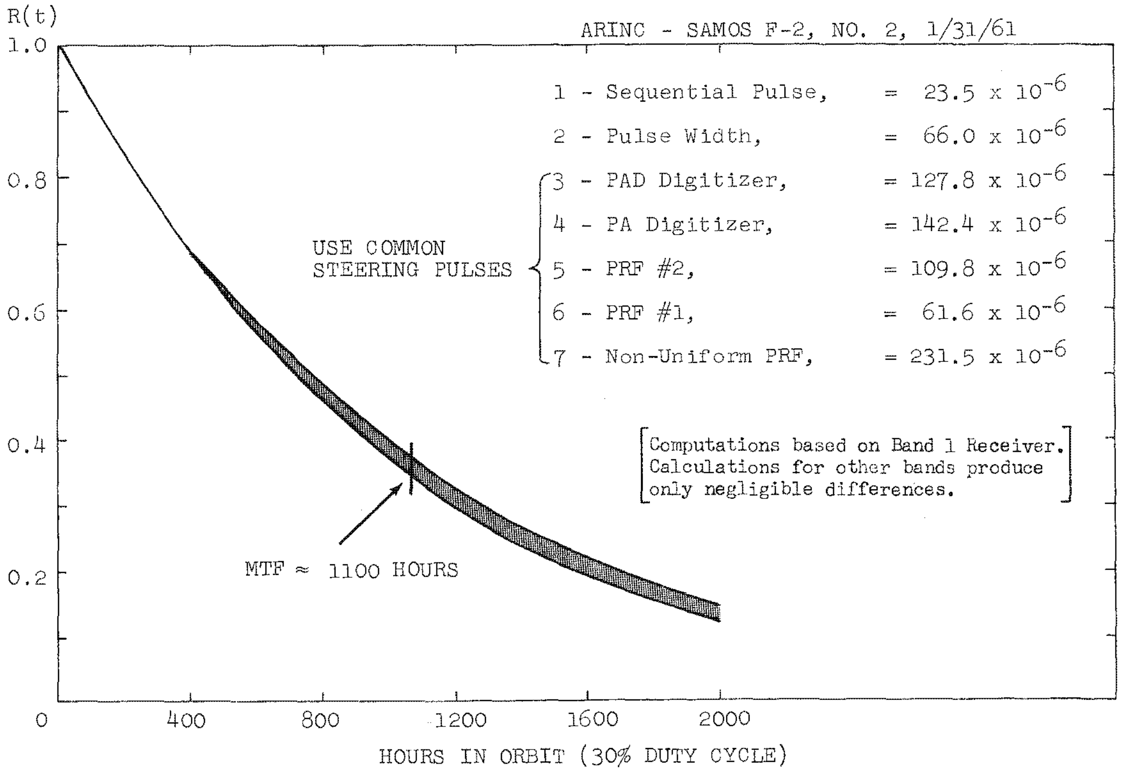


FIGURE 10

SUBSYSTEM F-2: PREDICTED RELIABILITY FUNCTIONS
FOR SPECIFIC MEASUREMENTS

To illustrate this point, the probability of survival associated with the non-uniform PRF circuitry is shown in Table 7. Each point on the line in Figure 10 was obtained by multiplying the probability of serial-equipment survival by the probability of survival of the redundant non-uniform PRF.

The reliability improvements that will most affect the system reliability will be those associated with the serial equipment. An examination of the failure rates of individual elements does not indicate a wide variation; therefore, further improvement in reliability must be based either on elimination of serial equipment or on improvement in many individual elements. This analysis is optimistic, in that the individual series elements in the data processor were considered individually redundant.

TABLE 7

PROBABILITY OF SURVIVAL ASSOCIATED WITH PRF CIRCUITRY
(ARINC ESTIMATES)

Time - in Orbit Hours	Probability of Survival		
	Total Serial Equipment	Non-Redundant Non-Uniform PRF Equipment	Redundant Non-Uniform PRF Equipment
0	1.000	1.000	1.000
200	.832	.935	.998
400	.691	.875	.992
600	.573	.818	.982
800	.475	.765	.970
1000	.393	.715	.955
1200	.325	.669	.938
1400	.268	.626	.919
1600	.221	.585	.899
1800	.182	.547	.877
2000	.150	.512	.855

2.5 Reliability Evaluation of Subsystem H

The analysis of Subsystem H reliability presented in this section of the report is essentially ARINC's, although some commentary on the LMSD analysis is included. The complete LMSD analysis of this subsystem (which is referred to, in the most recent LMSD documents, as the C & C -- command and communications -- subsystem) is available in Appendix C.

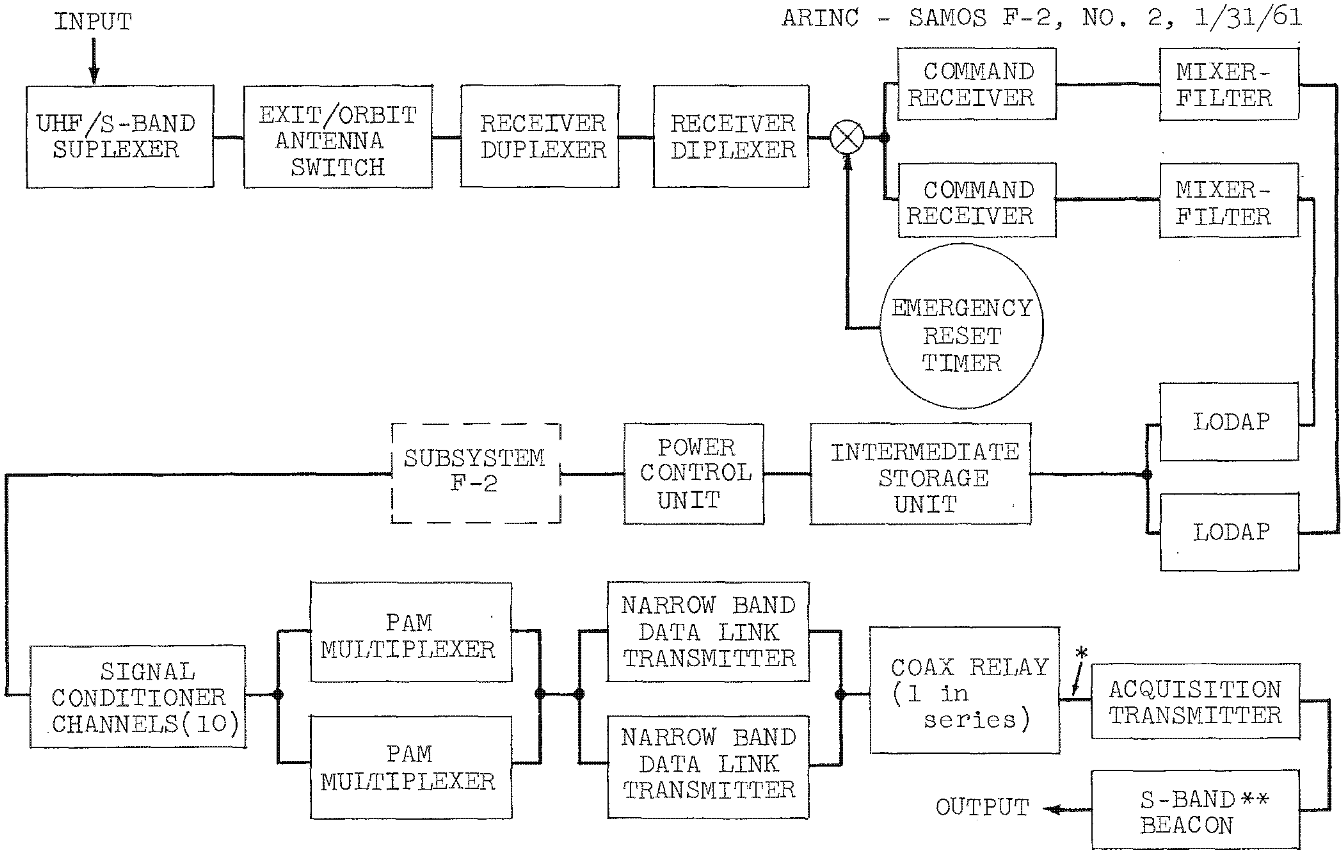
LMSD's analysis of Subsystem H was not completed in sufficient time to permit reconciliation of differences between LMSD and ARINC with respect to the reliability models employed and the parts counts for individual units. Many of these differences are recognized as resulting from differences in a few of the basic assumptions made by the two organizations. Examples are given below, in the discussion of the reliability block diagram for the subsystem. It is gratifying, however, that despite these differences, the two analyses lead to the same general conclusion as to the portion of the subsystem making an undue contribution to unreliability.

2.5.1 Reliability Block Diagram (ARINC)

The functions of the equipment comprising Subsystem H are the transmission of data from the vehicle to the ground, and the decoding and execution of command signals from the ground to control the vehicle electronic equipment. The reliability block diagram of this subsystem is shown in Figure 11.

Data Transmission: Operational data from the payload are transmitted in two forms: the digital signal read-out from the tape recorder in the payload, and approximately 17 operational telemetry channels used in adjustment and trouble diagnosis of the receivers and data processor. The digital data are transmitted directly by a narrow-band data-link transmitter, with a spare transmitter provided as back-up. The operational telemetry channels, together with a number of other telemetry channels, are time division multiplexed by a 256-channel multiplexer, the output of which is also connected to the narrow-band (1 Mc) transmitter. In addition to the two narrow-band UHF transmitters, a VHF transmitter is also

ARINC - SAMOS F-2, NO. 2, 1/31/61



* LMSD calculations include a VHF transmitter, Recorder, and Recorder Programmer in series at this point. See text.

** LMSD calculations include a doppler beacon in parallel with the S-Band beacon. See text.

FIGURE 11

SUBSYSTEM H, F-2 VEHICLE CONFIGURATION: RELIABILITY BLOCK DIAGRAM provided for transmission of telemetry data only. There is also a standby multiplexer. Changeover to the standby transmitter and multiplexer is effected by ground command.

LMSD included more of the data-transmission equipment in its calculations than did ARINC. Specific instances are as follows:

1) In its reliability analysis, LMSD considered 60 percent of the available telemeter channels essential to success of the subsystem. While recognizing the usefulness of the vast number of channels employed for the retrieval of engineering data, ARINC does not regard them as essential to the primary reconnaissance mission. Hence, in its calculations, ARINC has restricted consideration of the telemeter channels to 10 specific channels of the PAM multiplexer. (It may be pointed out that, in either case, complexity -- and, therefore, reliability -- increases with the number of available channels. The timing circuit becomes more complicated, and must always be accounted for as a serial item in the analysis.)

2) Included in the LMSD analysis were a telemetered signal tape recorder, a recorder programmer, and a VHF transmitter. These items permit the recording of telemetry data while the vehicle is out of contact with the ground control stations, and subsequent read-out of the data while the vehicle is in communication with the ground control station. ARINC, considering this feature non-essential to the reconnaissance mission, has not included these items in its calculations of subsystem reliability.

For vehicle location and tracking, Subsystem H also includes a VHF acquisition transmitter and an S-band transponder beacon. A decoder has been added to the beacon, but was not included in the analysis. The decoder provides eight on-off real time command circuits. These eight channels will be employed for emergency-command switching power for diagnostic purposes in the event of a failure.

The various receivers and transmitters are connected to the appropriate antennas by a series of duplexers and coaxial relays. The duplexers have not been included in the reliability calculations, inasmuch as they consist of passive RF elements.

3) Another difference between the LMSD and ARINC analyses is in the parts counts for the PAM multiplexer signal conditioners. Depending on the signal level of the sensor, either of two separate varieties of signal conditioners is employed. For signal sources of five-volts maximum value or above, a passive scaling circuit composed of resistors and capacitors is employed as a signal conditioner. Low-output sensors (less than five-volts maximum amplitude), such as thermocouples, resistance thermometers, strain gauges, etc., require an active amplifier circuit between the sensors and PAM multiplexer input. ARINC, in checking through the telemeter channels it had selected as essential, found that amplifiers were not necessary. LMSD, as explained above, included a greater number of TM channels, and many of these included active amplifiers.

Commands: Control of the vehicle and payload equipment is exercised through a system of command receivers, filter-mixers, and command decoder-programmers. The command decoder-programmers are referred to as LODAP [(Lockheed Decoder and Programmer)]. In the normal mode of operation, signals from one command receiver are passed through a filter-mixer, in which filters extract the control tone pulses from the composite signal. The resultant pulse train is applied to the input of the operating LODAP, which is essentially a digital decoder and memory device. The LODAP circuitry decodes the digital work formed by each pulse train, checks it for the correct address, and determines from the word whether the command is to be executed on receipt (real time command) or performed at some later time (stored program command). The stored program commands are read into the LODAP memory for execution at a time determined by the time label in the command word.

The outputs of the LODAP are the contacts of 21 DPDT relays for real time commands (RTC) and 13 DPDT relays for stored program commands (SPC). These outputs are applied to the intermediate storage unit, in which relay logic matrices provide a capability of 40 RTC's and 24 SPC's. In addition, the intermediate storage unit contains latching relay circuitry which responds to one particular RTC from either LODAP and keeps all of the output functions connected to the LODAP from which it received the last real time command switch pulse. The latter feature permits switching to a standby LODAP to replace a failed unit.

As mentioned previously, the normal mode of operation consists of one command receiver driving one LODAP through an associated mixer-filter unit. SPC's from the LODAP in use will turn the command receiver and the LODAP's own decoder equipment on and off at appropriate times, and will also command the various vehicle and payload functions. Failure of the selected command receiver to come on may thus be due either to failure of the receiver itself or to failure of the LODAP circuitry which is supposed to turn the receiver on.

An emergency reset timer monitors both the main and the standby command receivers. If neither of these receivers has received a signal for a pre-set interval, the timer activates an emergency circuit, applying power to both receiver-mixer-LODAP chains. Each LODAP has a different address. By sending a succession of RTC's to the vehicle, using the two addresses alternately, and observing from the transmitted data whether or not the commands are being performed in the vehicle, it is possible to determine which receiver-mixer-LODAP chain has failed. When the fault has been thus localized, the surviving receiver-mixer-LODAP chain may be used to switch the alternate equipment off and resume the normal mode of operation.

2.5.2 Calculation of Subsystem Reliability

Table 8 gives the parts count and part failure rates of Subsystem H components. Except in the case of the emergency reset timer, it was assumed that redundant switching is failure-free. Because the LODAP, a relatively unreliable component, is used to perform switching through real time commands, this assumption leads to optimistic results with respect to the reliability improvement obtained through redundancy. The commands exercised through the beacon-decoder can be employed to provide some redundancy.

TABLE 8

SUBSYSTEM H: COMPONENT AND PART FAILURE RATES[1]; NUMBER OF PARTS BY COMPONENTS (F-2 CONFIGURATION)

Type of Part	Part Failure Rate x 10^{-6}		Number of Parts in Each Components (ARINC)											
	ARINC	LMSD	Command Receiver (R-5)	Mixer Filter	LODAP[2]	Int. Storage Unit	Emergency Reset Timer	Power Control Unit	Coax Relays	Signal Control Channels	PAM[3] Multiplexer	N.B.D.L. Tx.	Acq. Transmitter	S-Band Beacon
Signal Transistor Analog	6.0	See Appendix D for LMSD Failure Rates and Part Count	17	4						20		34	4	5
Signal Transistor Digital	1.7				547	48	50				104			13
Power Transistor	40.0		1	2	2							6		5
Signal Diode	1.7		11		882	235	77				210	36	1	15
Power Diode	3.5				7							9		4
Zener Diode	2.2		2								13	30		3
Resistors	0.5		53	12	1206	162	113				264	208	5	85
Potentiometer	15.0										46	7		5
Capacitor Tantalum >1µfd	5.0		7								8	57		7
Capacitor < 1µfd	0.6		86	10	325	63	29				38	93	11	56
Transformer Power-Pulse	12.0				1							6		2
Transformer Signal or IF	4.0		4		241	1	26					11		4
Coil	2.0		40	6								30	8	6
Mag Amp.	16.3											2		
Choke, Iron Core	7.5				20		2					10		2
Relay, Gen.	20.0							25				2		
Relay, Spec.	2.3				26	75	2							
Relay, Coax.	125.0								1					
Register Core	4.0				108									
Crystal	2.0		1									1	1	
Tube												1[4]		2[5]
Duty Cycle			10%	10%	100%	16%	100%	16%	10%	10%	10%	10%	100%	10%
Failure Rate Corrected for Duty Cycle x 10^{-6}	ARINC		37.6	12.8	2120	124.2	413.4	80	12.5	12	144.7	313.8	52.8	117.2
	LMSD		15	5.0	1588	148.7	65	33.0		50	70	70	18.1	30

[1] The following components are not included in the prediction: UHF/S-Band Duplexer, Receiver Duplexer, Receiver Duplexer, and UHF Diplexer.

[2] Part count based on thirteen (13) real time and thirteen (13) stored time commands. Three thousand (3,000) cores are excluded.

[3] Ten (10) of two hundred and fifty-six (256) channels; and, three (3) of eight (8) flip-flops are considered in the part count.

[4] One (1) magnetron at 1660 x 10^{-6}.

[5] One (1) 6771 at 309 x 10^{-6}; one (1) M-471 at 309 x 10^{-6}.

The components that are energized only for real time commands and read-out have an estimated 10-percent duty cycle. This estimate is based on the fact that the vehicle is in range of a read-out station approximately 9 percent of the orbital time; an additional 1.0 percent was assumed for equipment warm-up. For components that are also energized by stored program commands, 6.0 percent was added to the duty cycle.

Some ambiguity seems to exist with respect to the position which the VHF data-link transmitter should occupy on the reliability block diagram. At first appearance, it would seem that the VHF transmitter acts as a spare for the two UHF data-link transmitters. However, the information available at this time indicates that the VHF transmitter will handle the digital data output only; it will not handle the operational telemetry channels necessary to perform receiver adjustments to obtain the data. Since, at the time of the earlier analysis, it was not known whether the VHF transmitter would be required in the operational system, ARINC calculated the predicted reliability function twice, first including the VHF transmitter as a series element and then omitting it entirely. The reliability function for the subsystem as a whole was not seriously affected by either the inclusion or the omission of this transmitter. For the present estimate, the VHF transmitter was excluded from the analysis.

The predicted reliability function for Subsystem H obtained by use of the ARINC failure rates is shown graphically in Figure 12. The ARINC estimate of the mean life of the subsystem is approximately 560 hours. Figure 12 also shows the subsystem reliability functions predicted by LMSD. Derivation of these functions is explained in Appendix D.

2.5.3 Comparison of Present Prediction of Subsystem H Reliability with Previous Prediction in First Periodic Review

During the interval since the previous analysis of this subsystem, its estimated mean life, as predicted by ARINC, has increased from 540 to 560 orbital hours. The change is due partly to the lower failure rates employed in this analysis and partly to changes in parts counts.

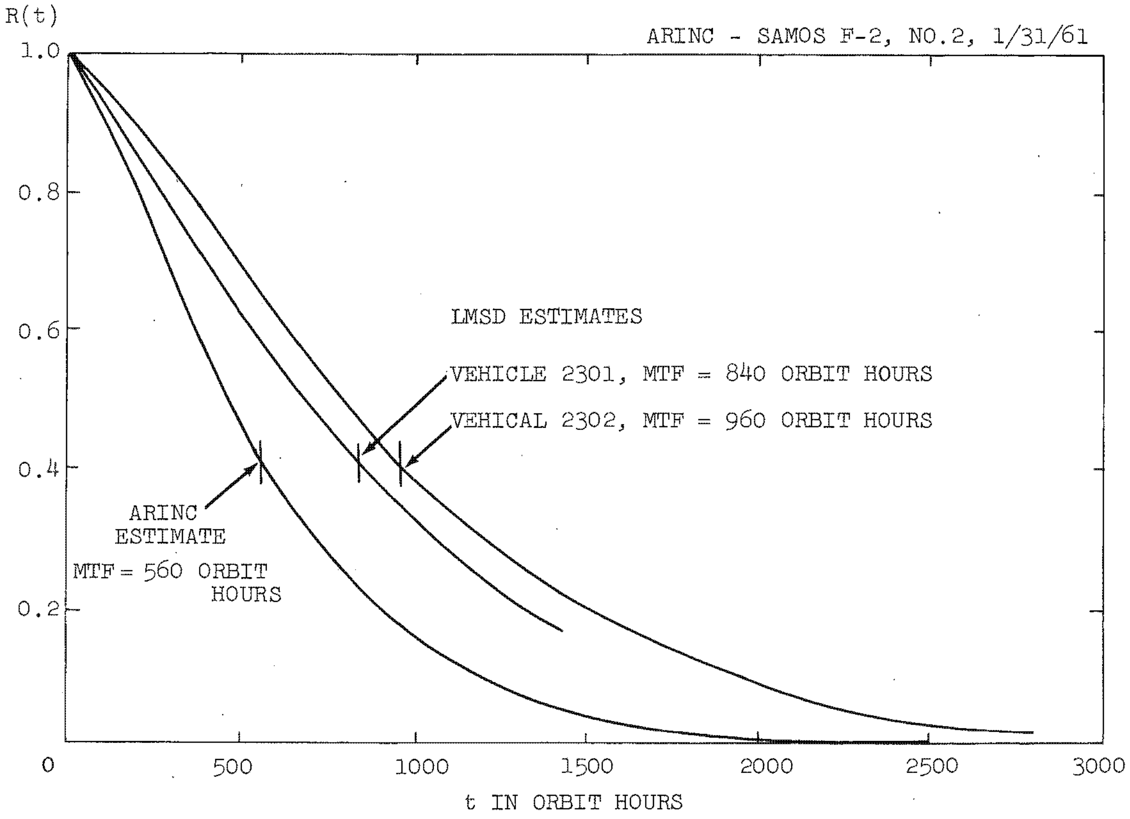


FIGURE 12

SUBSYSTEM H: PREDICTED RELIABILITY FUNCTIONS

The LODAP is responsible for most of the unreliability associated with Subsystem H. A failure in the LODAP units results in loss of command of the vehicle. One feature of the LODAP contributing to its unreliability is the relatively large amount of serial equipment necessary to the operation of the unit. An orbital programmer which has been designed for use on the MIDAS Satellite features very little serial equipment, and can be made highly reliable. The difference, from the reliability viewpoint, consists in the fact that a malfunction in the LODAP is likely to affect all commands, while a malfunction in the orbital programmer affects only one specific command. The present capability of the orbital programmer is 32 real time commands and 7 stored program commands, while the LODAP provides 21 real time commands and 13 stored program commands. If the SAMOS F-2 requirement cannot be reduced to the present capabilities of the orbital programmer, the orbital programmer could be increased in capacity to 32 real time commands and 15 stored program commands by the addition of another digit in the channel address.

A failure-rate analysis indicates that most of the LODAP's failure rate of 2120 x 10^{-6} per hour is due to the serial equipment. The orbital programmer has a failure rate of 251 x 10^{-6} per real time command unit (32 commands) and 417 x 10^{-6} per stored program command. Approximately 50 x 10^{-6} in each of these two failure rates is due to the failure rate of the serially connected clock in the programmer. The stored program commands are employed chiefly to turn on the F-2 system over enemy territory. If one independent command channel is lost, the intelligence of that pass is lost; and that stored-program-command channel is not employed in future operation, thus causing a slight increase in the frequency with which it is necessary to transmit commands to the vehicle. On the other hand, in the LODAP, since most of the equipment is serial, all capabilities are lost if one is lost.

Analysis indicates that the situation with respect to real time commands is similar to that just described for stored program commands. In addition, it is interesting to note that the failure rate of the over-all beacon-decoder with a 10-percent duty cycle is 1615 x 10^{-6} per hour, or 161.5 x 10^{-6} when considered in terms of ortibal hours. It is reasonable to expect that the eight real time commands associated with the beacon-decoder will be available for the life of the payload.

ARINC is in complete accord with LMSD's conclusion that the complexity of Subsystem H must be reduced in order to achieve the one-year reliability goal for the system (see Appendix C, Section VIII, Paragraph 1). ARINC would favor an approach that would completely separate the command and telemetry channels used for reconnaissance from those used to obtain strictly engineering information, so that the reconnaissance system operational requirements only would contribute to the complexity of the hardware being developed for ultimate use. This approach would lead to the earliest maturity date for the final hardware.

2.6 Orbit Reliability of the SAMOS F-2 System

2.6.1 Calculation of System Reliability

The ARINC and LMSD predicted reliability functions for the SAMOS F-2 Satellite System are presented in Figures 13 and 14, respectively. As indicated in Figure 13, the ARINC prediction for the mean time-to-failure of the F-2 configuration is approximately 210 hours in orbit.* In making this prediction, it was assumed that any failure in the F-2 subsystem would be considered as a complete failure of the system. If partial operation of Subsystem F-2 can be tolerated, the system mean time-to-failure will be slightly higher. As Figure 13 shows, the payload is far from the major contributor to system unreliability, even when the first failure in the payload is used as a criterion of system failure.

When the present prediction of 210 hours in orbit is compared with the current interim goal of 480 hours in orbit, it is evident that the goal is not unreasonable. The predicted mean life of the system does, however, indicate the magnitude of the design and test effort which must be expended if the mean time-to-failure of the F-2 vehicle configurations is to be extended to the contractually required length of one year.

2.6.2 Comparison of Present Prediction of SAMOS F-2 System Reliability with Previous Prediction in First Periodic Review

Table 9 shows the estimated mean times-to-failure for each of the subsystems and for the system as a whole, as predicted previously and as currently predicted. It is evident that the largest gains in reliability can be achieved by improving the reliabilities of Subsystems C, D, and H.

---

* For a method of applying this mean time-to-failure figure to logistic planning, see A General Method for Determining Logistic Requirements for a Satellite System, by E.L. Welker and C.E. Bradley, ARINC Research Corporation Publication No. 4222-172, 17 February 1960.

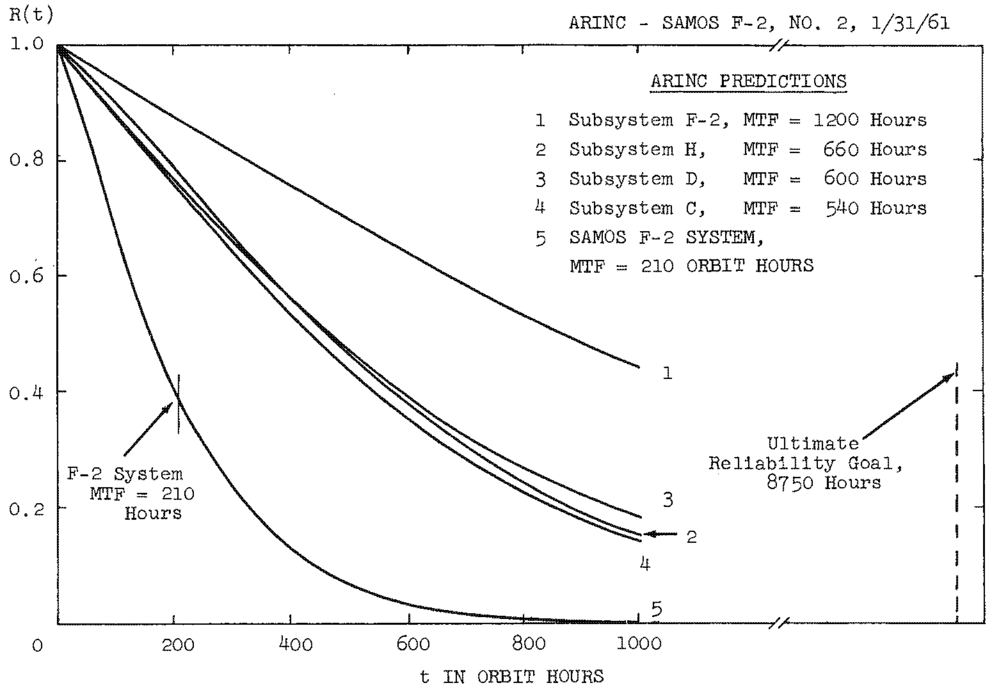


FIGURE 13

ARINC: PREDICTED RELIABILITY FUNCTIONS FOR SAMOS F-2 SYSTEM AND SUBSYSTEMS

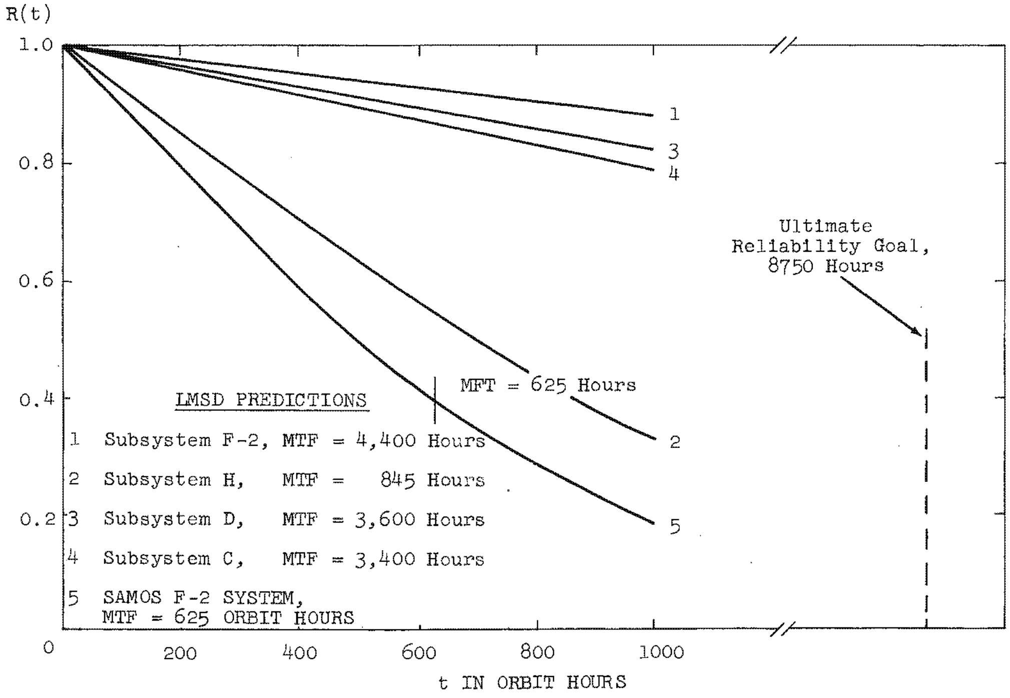


FIGURE 14

LMSD: PREDICTED RELIABILITY FUNCTION FOR SAMOS F-2 SYSTEM

TABLE 9

COMPARATIVE MEAN LIFE PREDICTIONS, PREVIOUS AND PRESENT, FOR SAMOS F-2 SYSTEM AND SUBSYSTEMS

Items	Mean Life, in Hours in Orbit			
	Previous Prediction		Present Prediction	
	ARINC	LMSD	ARINC	LMSD
F-2 System	275	485	210	625
Subsystems:				
C	700	3,038	540	3,400
D	1,150	1,750	600	3,600
F-2	1,050	1,190	1,200	4,400
H	520	800	660	845

In comparing the current estimates of SAMOS F-2 System reliability with past estimates, it can be seen that the ARINC prediction of system mean time-to-failure decreased by about 20 percent while the LMSD prediction increased by about 30 percent. The difference between the present and past estimates is due to the opposed tendencies of two factors: namely, an increase in complexity and a decrease in the values of the part failure rates employed by both ARINC and LMSD. In the case of the LMSD prediction, the magnitude of the decrease in failure rates overwhelmed the effect of the increase in complexity; in the ARINC prediction, the decreased failure rates did not wholly compensate for the increased complexity of the system.

APPENDIX A

SOURCE OF FAILURE DATA

1. Part Failure Data for Reliability Prediction

Of the several sources of part failure data available for the prediction of system reliability, the two principle sources are part life-tests and system life-tests.

1.1 Part Life-Tests

Life-test data on parts are compiled from specification life-tests conducted by the part manufacturer in conformance with military or industrial specifications, and from laboratory life-tests conducted by the user of the parts. When the stress levels for the life-tests are representative of a wide range of use conditions, a family of reliability "trade-offs" can be developed to show the relationships between basic part failure rate and "use" stresses. These data generally represent the "inoperative" or "random" failure rates of parts, and often do not include tolerance or deterioration failures.

For successful use of basic part failure rates for the prediction of system reliability, it is necessary to determine the relationship between part failure rate and system failure rate due to each part class. This relationship, often popularly expressed as a "K-factor," must be developed for each particular circuit function in each of several use environments for the particular preventive maintenance and marginal test procedure contemplated during the operational life of the system. These K-factors for a particular system design can best be developed through extensive component and system life-tests. Where the newly designed system is to be a long-life system, the values for K can no longer be assumed to remain constant over the operating period, because failure rate due to deterioration instability generally follows a Gaussian pattern -- i.e., has an increasing failure rate. This axiom dictates that life-tests for the development of realistic values for K must extend over a period of time sufficient to take into account the likelihood of an increasing failure rate due to deterioration and detrimental interaction among parts and components.

1.2 System Test Data

System test data, gathered through controlled life-tests of components and systems in the development, production, and field phases of system evolution, provide a measure of the relationship between system failure rate and the behavior of parts within the system, over extended periods of operating time. The result is an expression of system failure rate due to the parts making up the system. These so-called "part failure rates" are, therefore, actually the complex combination of basic part failure rates and the weighting factors (K's) discussed above, into single-valued estimates of the contribution of individual parts to system failure. These weighted part failure rates are also adjustable according to use conditions and preventive maintenance provisions.

In the early design phase of a new system, it is practical to use weighted failure rates of the kind discussed above for preliminary prediction of system reliability, with the purpose of pointing out the major problem areas within the system and obtaining a realistic estimate of the status of design reliability with respect to program goals. On the basis of the preliminary estimate, reliability assurance program plans can be adjusted to conform with the size of the reliability problem early in the design phase.

2. ARINC Prediction Data

In the prediction of system reliability, ARINC uses part failure data derived from controlled production tests and field tests conducted for the military services on airborne, shipborne, and ground-based systems. The systems that have been employed in the tests have ranged in complexity and function from communication receivers to digital computers. Within the past six months, an extensive study on the part failure rates observed and the rates employed for prediction purposes has been conducted for the Air Force under Contract AF 33(600)-40259.* The failure rates used in previous MIDAS predictions have been brought up to date and now reflect the latest observed rates.

---

* Reliability Study of Microwave and Transmitting Tubes, Semiconductors, Relays, and Other Parts, ARINC Publication No. 123-6-189, 30 September 1960.

If failure rates for prediction purposes are to be realistic, care must be exercised to avoid including favorable effects more than once and also to avoid failure rates based on highly censored failure data. Most of the failure rates currently used by ARINC have been observed in equipment types employing stress derating. Therefore, the application of reduction factors based on reduced stress would lead to optimistic equipment predictions. The second pitfall, failure censoring, is frequently encountered in data obtained from equipment manufacturers. Usually, the failures associated with design, operational, and production errors, or with poor procedures, have been eliminated from such data; consequently, the failure rates reflect the situation that would exist if the components were not associated with a circuit and subject to such hazards. (It should be pointed out that debugging-test data are not included -- and, in any event, failures of these types do not necessarily show up in the short-term debugging tests.)

The upper half of Figure 15 is a graphical summary of the most recent compilation of observed failure-rate data on transistors used in computer equipment. The lower half of the figure shows the failure rates employed by equipment manufacturers in making predictions; these rates tend to be about one order of magnitude less than the observed failure rates. It would appear from Figure 15 that equipment manufacturers are somewhat optimistic about their design and manufacturing processes. Still, three ground digital computers did display transistor failure rates in the range from 0.2×10^{-6} to 0.3×10^{-6} per hour (assuming that censoring was not a major factor in computing these rates). This suggests that it is possible to design and produce equipment in which transistors will have failure rates within this low range. To assure such low failure rates, however, it will be necessary for transistor specifications to provide for relatively large life-test samples. The failure rates for other part types follow a pattern similar to that of transistors.

LMSD uses part-failure rates obtained from other equipment manufacturers. In general, these rates reflect substantial improvements in part reliability, particularly in recent years, due to state-of-the-art advances and reliability improvement programs. It is LMSD's contention that the favorable environment of satellite operation and the special selection of satellite parts will offset any possible tendency toward optimism in these failure rates.

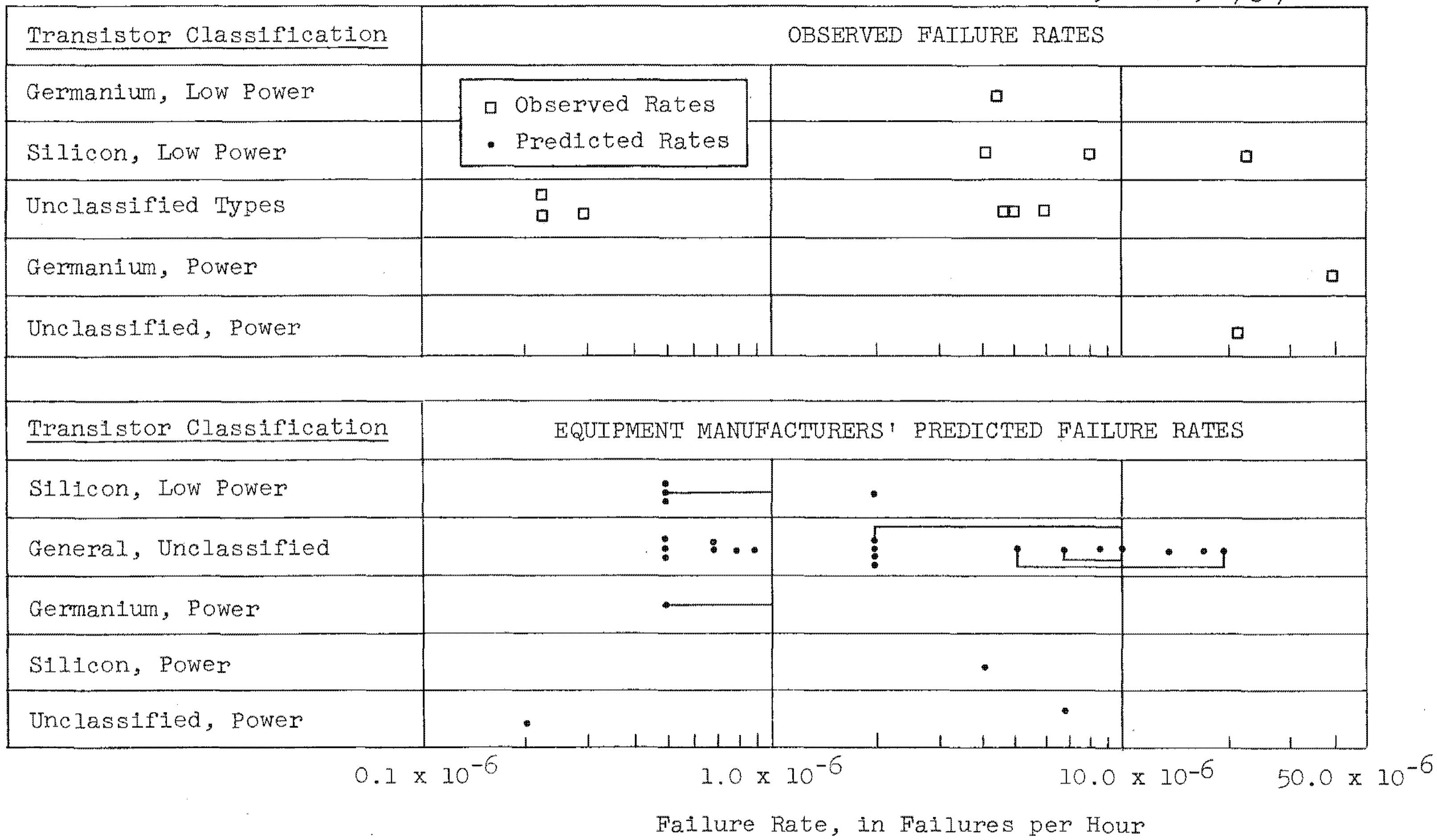


FIGURE 15

TRANSISTOR FAILURE RATES: OBSERVED RATES VS. RATES USED BY EQUIPMENT MANUFACTURERS FOR PREDICTION PURPOSES

TABLE 10

PART FAILURE-RATE DATA USED IN RELIABILITY PREDICTIONS

Part Type	Failure Rate (in Failures per Hour)		Part Type	Failure Rate (in Failures per Hour)	
	ARINC	LMSD		ARINC	LMSD
Capacitors, General	0.6×10^{-6}	0.1×10^{-6}	Motors, A-C	$88. \times 10^{-6}$	20.0×10^{-6}
Capacitors, Tantalum	5.0	1.0	Pitch Wheels	88	45.0
Chokes, Filter	7.5	2.5	Potentiometers	15.0	1.5
Chokes, R.F.	3.0	0.5	Relays: Coaxial	125.	100.
Cores, Magnetic	1.0	.01	LODAP	2.3	0.4
Coils, RF	2.0	0.5	General	20.	4.0
Crystals, Quartz	2.0	0.4	Power (Samos)	-	20.0
Diodes: Signal, $P < 1$ W	1.7	0.3	Resistors at 25%	0.5	0.2
Power, $P > 1$ W	3.5	1.0	Switches or Commutators	1.5	1.5
Zener	2.2	0.5	Transformers: Power	12.	3.5
Gyros, Control Moment	91.0	83.0	IF, Signal, Light Duty	4.0	1.0
IRP's (Gyros)	-	100.0	Transistors: Digital, $P < 1$ W	1.7	0.8
IR Cells	0.2	0.2	Signal, $P < 1$ W	6.	0.8
Heaters	3.0	3.0	Power, $P > 1$ W	40.	4.0
Magnetic Amplifiers	16.0	5.0	Slip Rings or Brushes	3.0	1.5

ARINC believes that the equipment manufacturers' failure rates are based on only the basic catastrophic failures observed under optimum conditions, and are therefore conducive to optimistic predictions. ARINC employs failure rates which reflect good design and manufacturing practices, but which include consideration of failures due to environmental or operational stresses, as well as catastrophic failures. These failure rates have been shown to be applicable to the early stages of field operation in many equipments, and ARINC believes they are realistic for prediction of satellite reliability. (The ultimate or intrinsic failure rate attributable solely to catastrophic failures of parts is usually reached only after field experience and equipment modification. Furthermore, unless special specifications with the requisite provisions for life-test assurance are employed, the catastrophic failure rate for a part lot or lots can increase by several orders of magnitude. Normal MIL Specifications for parts are not, in general, adequate to support failure rates below approximately 50×10^{-6} per hour.)

Table 10 presents a comparison of the failure rates employed by LMSD and ARINC in predicting MIDAS reliability.

APPENDIX B

SUMMARY OF GENERAL ASSUMPTIONS

1. Assumptions Pertaining to Probability of Part Failure

For purposes of the ARINC predictions, the following assumptions were made in relation to the probability of part failure:

(1) All parts are used within electrical ratings -- resistors and capacitors at 25 percent of rating.

(2) Design margins are compatible with the initial variability of part parameters.

(3) Provision for in-flight preventive maintenance is non-existent.

(4) All parts operate in ambient temperatures in the range from 0°C to 50°C, although, as is realized, current specifications describe a range of ambient temperatures from -35°C to +80°C.

(5) During early life (the first few thousand hours), the part failure rate is constant.

(6) Where applicable, part failure rates are corrected for duty cycle.

2. Assumptions Pertaining to the Prediction Method

Assumptions made with respect to the prediction method are listed below.

The concept of "system failures due to parts" as a criterion of the types of part failures considered in calculating part failure rates (see Appendix A) is the basis for the assumptions that:

(1) Except where redundancy exists, all parts considered are necessary for successful system performance.

(2) Part failures are independent of each other.

Where redundancy exists, the following assumptions are made:

(3) All redundant modes of operation are equally "effective."

(4) Standby elements cannot fail if de-energized, although it is known that "shelf" or storage life can be a serious problem with certain parts.

(5) Active elements in parallel are not dependent in a load-sharing sense -- i.e., failure of one of the parallel elements will not increase the failure rate of the surviving element.

(6) Except where noted, malfunction-sensing and switching devices are failure-free.

The first assumption, adopted to simplify the preliminary prediction, tends to yield pessimistic results. This pessimism is more than offset by the optimism produced by the remaining assumptions.

APPENDIX C

This appendix consists of a reproduction of a report (Classification: ~~Confidential~~) prepared by Lockheed Missiles and Space Division.

DECLASSIFIED

LOCKHEED AIRCRAFT CORPORATION
MISSILE SYSTEMS DIVISION

REPORT LMSD 380122/64-34

APPENDIX C

ANALYSIS OF INHERENT RELIABILITY

C & C SUBSYSTEM

SAMOS 2301-2302

By

L. E. Dostert, Jr.

15 January 1961

Approved by:

Edward McKaba
E. McKaba, Manager
SETD Support (Reliability)
Satellite Systems

DECLASSIFIED
~~SECRET~~

~~SECRET~~

DECLASSIFIED

ABSTRACT

This report analyzes the reliability of the Communications & Control Subsystem of the Samos 2301-02 series vehicles. Success for 2301 is defined as payload/vehicle command <u>and</u> payload reconnaissance data transmission and payload/vehicle status-failure telemetry and acquisition/tracking data transmission. For 2302, the requirement for status-failure telemetry is eliminated from the definition of success. It is estimated (through use of simplified parts failure rate analysis techniques) that the probabilities of successful operation of the C & C Subsystem in the flight series are, respectively:

	2301	2302
10 days	.84	.88
20 days	.65	.71
30 days	.48	.54
40 days	.34	.40
50 days	.24	.30
60 days	.16	.21

The approximate mean-time-to-failure of the 2301 Subsystem ($R(t) \approx 0.4$) is 840 hours, and of the 2302 subsystem is 960 hours.

DECLASSIFIED

~~SECRET~~

I. GENERAL ASSUMPTIONS AND CONSIDERATIONS APPLICABLE TO C & C RELIABILITY ANALYSIS

A. General Assumptions

1. Component function failures occur as a result of independent random catastrophic part failures.

2. The catastrophic failure of any part will cause catastrophic failure of the component which contains it, and hence failure of a system containing the component, unless there is a spare component.

3. Unless otherwise noted, failure sensing and switching between redundant components and groups is assumed to be failure-free.

4. The probability of component failure is a direct function of operating time; cycling or reduction of operating time by duty-cycling does not increase the probability of failure.

5. Average part derating is assumed to be 0.4 unless otherwise noted.

6. Ambient temperature at which parts operate is 70°C.

7. System input-output interface reliabilities are taken as unity.

8. None of the components which share a common power supply can fail the supply.

9. Reliability estimation techniques which approach validity for design-matured equipments are also applicable to early production equipments for purposes of obtaining first order reliability approximations.

10. In components subject to wearout failure, the probability of survival follows an exponential distribution to the time region of onset of wearout failure (which is defined as -3σ from the mean of the wearout failure density function).

General Considerations

1. The assumption concerning maturity of equipment is of critical importance in any application of the findings of this type of estimation technique. It should be kept in mind that the model of a Poisson equipment failure distribution is an approximation that becomes increasingly valid as design, system operations, and production deficiencies are identified and corrected. The early life failures of complex equipments may be an order of magnitude greater than the constant rate achievement of a completely debugged system. The engineering judgment to assess the degree of optimism inherent in the assumption rests on an evaluation of the capabilities and training of the production process and the results of design and environmental testing performed. A significant source of documentary evidence of the ability of a total

production screening process to release adequately debugged equipments may be found by examining the performance of equipment during the design proofing or qualification test. If the qualification test meets the criteria:

(a) Representative equipment using the identical personnel, processes and checkout equipment and procedures as on regular production versions;

(b) Properly designed test, with adequate regard for selection of production model, random sequencing of order of environment testing and statistical adequacy of samples tested;

(c) A high positive correlation of design environmental parameters with real environments;

then the confidence in the reliability estimates provided can more closely be assessed. As it is, the variables associated with even a refined reliability estimate (considering the application and thermal stress on each individual part) are such that the error in prediction is indeterminate, and is especially significant in the early production effort. The estimation technique is useful to determine whether a given design is "in the ball park" for its longevity requirements, but extreme caution should be exercised in using the information with respect to decision-making affecting equipment changes in a given R & D system configuration.

II. SPECIFIC ASSUMPTIONS AND CONSIDERATIONS APPLICABLE TO THE C & C SUBSYSTEM OF SAMOS 2301-2302

A. Specific Assumptions

1. For Samos 2301, success is defined as payload/vehicle command, and payload reconnaissance data transmission and payload/vehicle status-failure telemetry and acquisition-tracking data transmission.

2. For Samos 2302, success is defined as payload/vehicle command and payload reconnaissance data transmission and acquisition-tracking data transmission.

3. No components operate to the time region of deterioration failure within the time interval considered in this analysis (defined as -3σ from the mean of the gaussian density function assumed to describe wearout phenomena).

B. Specific Considerations

1. While an S-Band Beacon and Decoder are included in the subsystem design to provide an auxiliary real time command capability, adequate command back-up for the functions of the LODAP's are not provided. Failure of the Stored Program function of the LODAP(s) would preclude operation of the payload as intended within the framework of mission objectives.

III. SUBSYSTEM OPERATION

A. Command Signals are received from the ground by the Command Receiver in the appropriate link (selected by command), amplified, detected and sent through the filter section of the Filter-Mixer to the Command Decoder and Sequence Programmer (LODAP). The LODAP decodes the command signal, and determines whether the command is to be executed in Real Time (when received) or Stored Time (later, or out of contact with the ground station). At the time of command (or later, as appropriate), the LODAP initiates closure of a relay, and through the Intermediate Storage Unit, a relay closure in the Power Control Unit. The primary function of the ISU is doubling of the available real and stored time commands by addition of a bank of relays to the LODAP command channels. Thus, for each real and stored time command channel, there is a "so-called "E" operation and an "F" operation.

B. Reconnaissance data (in digital form) is read out, by command, from the payload through one of the redundant mixer-UHF Narrow Band Data Link Transmitter links.

C. Status/failure telemetry data from the payload and vehicle is PAM time-multiplexed by one of the redundant PAM multiplexers (selected by command) and either read out in real time through the same Mixer-UHF Narrow Band Data Link Transmitter link as (B) above, or when our of station contact, stored on the Tape Recorder for later readout during a station contact. The recorded data is read out through a separate VHF transmitter.

D. Acquisition signal transmission is supplied by either the Acquisition Transmitter or the Dual Frequency Doppler Transmitter. Tracking information for ephemeris determination is obtained from range plus angle data through the S-Band Beacon Transponder or doppler plus angle data through the Dual-Frequency Doppler Transmitter.

IV. COMPONENT PARTS LIST, FAILURE RATES, AND DUTY CYCLES

A. Command Receiver

	Quantity	λ (x 10^{-6}/hr.)	λ_p(x 10^{-6}/hr.)
Transistor	19	0.5	9.5
Diode	11	0.5	5.5
Resistor	50	0.5	25.0
Capacitor	105	0.7	73.5
Transformer	41	0.5	20.5
Crystal	1	0.2	0.2

$\sum \lambda_p$ = 134.2 x 10^{-6}/hr.

At 10% Duty Cycle, $\sum_{o} \lambda_p \approx$ 15 x 10^{-6}/hr.

B. Filter (1/2 of Filter Mixer)

	Quantity	$(x\ 10^{-6}/hr.)$	$(x\ 10^{-6}/hr.)$
Transistor	27	0.5	13.5
Diode	24	0.5	12.0
Resistor	94	0.5	47.0
Capacitor	44	0.5	7.0

$\sum \lambda_p$ = 110.3 x 10^{-6}/hr.

x 1/2 $\sum \lambda_p$ = 55.1 x 10^{-6}/hr.

at 10% Duty Cycle, $\sum_s \lambda_p \approx$ 5 x 10^{-6}/hr.

C. Sequence Programmer (LODAP)

Transistors	480	0.5	240.0
Diodes	791	0.5	395.5
Capacitors	324	0.7	226.8
Inductors	50	0.1	5.0
Power Transformers	3	6.0	18.0
Memory Cores	3177	0.01	31.8
Register Cores	163	0.50	81.50
Relay (Latching)	42	0.4	16.80
Resistors	1099	0.5	549.5
Power Transistors	21	1.0	21.0
Power Diodes	7	1.0	7.0

$\sum \lambda_p$ = 1588.1 x 10^{-6}/hr.

(Duty Cycle 100%)

D. Intermediate Storage Unit

Resistors	63	0.5	31.5
Capacitors	27	0.7	18.9
Transistors	20	0.5	10.0
Diode	129	0.5	64.5
Transformers	2	0.5	1.0
Relays	57	0.4	22.8

(100% Duty Cycle) $\sum \lambda_p$ = 148.7

E. Power Control Unit

Relays	42	0.4	16.8
Diodes	29	0.5	14.5
Resistors	4	0.5	2.0

(Duty Cycle 100%) $\sum \lambda_p$ = 33.0 x 10^{-6}/hr.

F. Mixer (1/2 Filter Mixer)

(See Para. III-B)

G. Narrow-Band Data Link Transmitter

	Quantity	(x 10^{-6}/hr.)	(x 10^{-6}/hr.)
Resistors	160	0.5	80.0
Capacitors	113	0.7	79.1
Diodes	101	0.5	50.5
Transistors	49	0.5	24.5
Signal Inductive Devices	35	0.1	3.5
Power " "	9	6.0	54.0
Crystals	1	0.2	0.2
Magnetrons	1	400.0	400.0

$\sum \lambda_p$ = 691.8 x 10^{-6}/hr.

At 10% Duty Cycle, $\sum_{D} \lambda_p \approx$ 70 x 10^{-6}/hr.

H. Signal Conditioner

Transistors	180	0.5	90.0
Resistors	990	0.5	495.0
Capacitors	360	0.7	252.0

$\sum \lambda_p$ = 837.0 x 10^{-6}/hr.

Defining success as 60% of all channels

$\sum \lambda_p$ = 502.2 x 10^{-6}/hr.

At 10% Duty Cycle, $\sum_{D} \lambda_p \approx$ 50 x 10^{-6}/hr.

I. PAM Multiplexer Type F

Resistors	1125	0.5	562.5
Capacitors	110	0.7	17.0
Transistors	434	0.5	217.0
Diodes	646	0.5	323.0

$\sum \lambda_p$ = 1179.5 x 10^{-6}/hr.

Defining success as 60% of all channels

$\sum \lambda_p$ = 707.4 x 10^{-6}/hr.

At 10% Duty Cycle, $\sum_{D} \lambda_p \approx$ 70 x 10^{-6}/hr.

J. Tape Recorder Programmer III B

	Quantity	(x 10^{-6}/hr.)	(x 10^{-6}/hr.)
Transistors	35	0.5	17.5
Diodes	61	0.5	30.5
Resistors	149	0.5	74.5
Capacitors	45	0.7	31.5
Signal Inductors	3	0.1	0.3
Relays	1	4.0	4.0

$\sum \lambda_p$ = 158.3 x 10^{-6}/hr.

(Duty Cycle 100%)

K. Tape Recorder (AMR-110)

Resistors	60	0.2	12.0
Capacitors			
(Gen)	22	0.1	2.2
(Ta)	17	1.0	17.0
Diodes	30	0.3	9.0
Transistors	15	0.8	12.0
Signal Transformers	2	1.0	2.0
Relays (Gen)	5	4.0	20.0
Coils	6	0.5	3.0
Motors	1	20.0	20.0

$\sum \lambda_p$ = 97.2 x 10^{-6}/hr.

At 10% Duty Cycle, $\sum_o \lambda_p \cong$ 10.0 x 10^{-6}/hr.

L. VHF Transmitter UED

Resistors	41	0.5	20.5
Capacitors	54	0.7	37.8
Transistors	13	0.5	6.5
Diodes	11	0.5	5.5
Receiving Tubes	4	17.5	70.0
Transmitting Tubes	1	100.0	100.0
Signal Transformers	17	0.5	8.5
Power "	1	6.0	6.0
Quartz Crystals	1	0.2	0.2

$\sum \lambda_p$ = 255.0 x 10^{-6}/hr.

At 10% Duty Cycle, $\sum_o \lambda_p \cong$ 25 x 10^{-6}/hr.

	Quantity	(x 10^{-6}/hr.)	(x 10^{-6}/hr.)
M. Acquisition Transmitter			
Resistors	6	0.5	3.0
Capacitors	12	0.7	8.4
Transistors	4	0.5	2.0
Diodes	1	0.5	.5
Signal Transformers	8	0.5	4.0
Quartz Crystal	1	0.2	0.2

(Duty Cycle 100%) $\sum \lambda_p$ = 18.1 x 10^{-6}/hr.

N. S-Band Beacon Transponder			
Diodes	18	0.5	9.0
Transistors	25	0.5	12.5
Resistors	105	0.5	52.5
Capacitors	62	0.7	43.4
Inductors	8	0.5	4.0
Relays	1	4.0	4.0
Transmitting Tubes	2	100.0	200.0

$\sum \lambda_p$ = 325.4 x 10^{-6}/hr.

At 10% Duty Cycle, $\sum, \lambda_p \approx 30 \times 10^{-6}$/hr.

O. Dual Frequency Doppler

(No data available; estimated equal to Acquisition Transmitter)

(Duty Cycle 100%) $\sum \lambda_p \approx 20 \times 10^{-6}$/hr.

V. RELIABILITY BLOCK DIAGRAM, MATHEMATICAL MODELS AND PROBABILITIES OF SURVIVAL

(See Figures 1 through 3.)

VI. DISCUSSION

A. The mission life objective defined by the Samos Project Office for this series of flights is a vehicle mean-time-to-failure (R(t) 0.4 of 30 days for 2301 and 120 days for 2302, within which objective the C & C Subsystem is required to exhibit a 0.8 probability of survival. Under the definition of success applicable to the 2301 C & C Subsystem, the 30 day probability of survival is .48. Under the definition of success applicable to 2302, the 120 day probability of survival is .04. The probability that at least one of the two flights will operate through the mission life objective is ~.50.

B. The Emergency Reset Timer (ERT) is here considered as a failure sensing/switching device. In the event of failure of the LODAP in use to open its Command Receiver prior to an active pass (thus not permitting reset of the timer) after a preset period of time has elapsed the ERT will open both command links, permitting re-entry to the vehicle. There are two ways such a system can succeed to time $\underline{t}$: The first link will operate from t_o to t_1 or it will fail at some time $t_1 < \underline{t}$; the ERT will operate from t_o to t_1, enabling switchover to the operating link which will operate from t_1 to $\underline{t}$. For further discussion of the derivation of the analytic expression, see Ronald O. Anderson, "Analysis for Space Vehicle Control System Redundancy."

C. The failure rates applied to the piece parts represent those approved by SETD Reliability for use in interim reliability analyses. These failure rates assume an average part derating of 0.4 and a part ambient temperature of 70°C. In some instances, where available information indicates that such failure rates are inapplicable (by virtue of derating, or piece parts of a known higher than average quality level) different failure rates were used. In all cases, the failure rates used in arriving at a component failure rate are shown.

VII. CONCLUSIONS

A. The Samos 2301-02 C & C Subsystem configuration exhibits an inherent reliability which yields an operating life ($R(t) \geqslant 0.8$) of approximately 288 hours under the 2301 definition, is approximately 840 hours, and under the 2302 definition, 960 hours.

B. The most serious reliability problem areas are, together with their failure rates:

LODAP	1590×10^{-6}/hr.
Int. Storage Unit	148×10^{-6}/hr.
Tape Recorder Programmer	160×10^{-6}/hr.

In all three cases, the requirement for a 100% duty cycle plus the component complexities yield low probabilities of survival for any length of time.

VIII. RECOMMENDATIONS

If the C & C Subsystem for the F-2 mission is to meet the ultimate operational objective of $R(t) \geqslant 0.8$ for $t = 8760$ hours, the following modifications in the program are mandatory:

1. Reduction of C & C Subsystem performance requirements by at least an order of magnitude. The subsystem is required to perform too many functions with too great an accuracy for there to be any hope of the Subsystem meeting the stated reliability objectives within the state-of-the-electronic-art.

2. Fabrication of all subsystem components from high reliability Minuteman-type piece parts.

3. Substitution of redundant Command Programmers, fabricated as in (2) on the preceding page for the LODAP. This will permit elimination also of the Intermediate Storage Unit and, perhaps, the Tape Recorder Programmer.

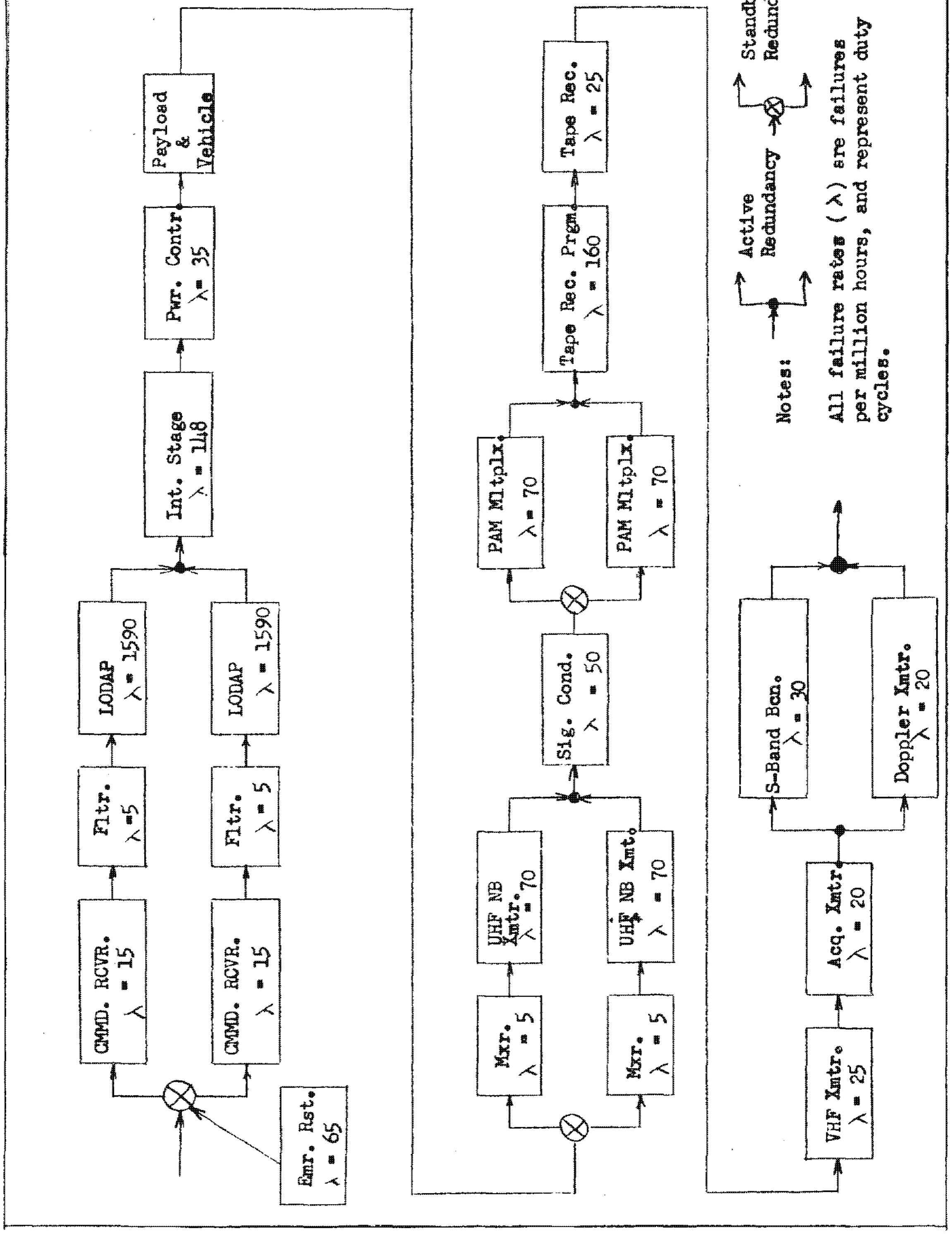
4. An extraordinary effort to be carried out to mature the design and fabrication processes of the Subsystem.

~~SECRET~~

DECLASSIFIED

	NAME	DATE	LOCKHEED AIRCRAFT CORPORATION MISSILES and SPACE DIVISION	TEMP.	PERM.
Prepared	L. E. Dostert, Jr.			Page	
Checked			TITLE RELIABILITY BLOCK DIAGRAM C & C SUBSYSTEM SAMOS 2301-2302	Model	
Approved				Report No.	

FIG. 1



Notes:

All failure rates (λ) are failures per million hours, and represent duty cycles.

DECLASSIFIED

~~SECRET~~

~~SECRET~~

DECLASSIFIED

74

	NAME	DATE	**LOCKHEED AIRCRAFT CORPORATION** MISSILES and SPACE DIVISION	TEMP.	PERM.
Prepared	L.E. Dostert, Jr.		TITLE Mathematical Reliability Model	Page	
Checked			C & C Subsystem	Model	
Approved			Samos 2301-2302	Report No.	

FIG. 2

FOR 2301 C & C SUBSYSTEM, THE PROBABILITY OF SURVIVAL AS A FUNCTION OF TIME IS DEFINED BY:

$$R(t) = \left[1 + 24.5(1 - e^{-.0000065t})\right]\left[(1 + .000075t)(1 + .000070t)\right]\left[e^{-.002238t} + e^{-.002248t} - e^{-.002268t}\right]$$

FOR 2302:

$$R(t) = \left[1 + 24.5(1 - e^{-.0000065t})\right]\left[1 + .000075t\right]\left[e^{-.001908t} + e^{-.001918t} - e^{-.001938t}\right]$$

WHERE $R(t)$ = RELIABILITY AS A FUNCTION OF TIME

(t) = TIME, IN HOURS

e = THE BASE OF THE NATURAL LOGARITHMS, 2.718…

WHICH YIELD THE FOLLOWING PROBABILITIES:

TIME (DAYS)	2301	2302
10	.84	.88
20	.65	.71
30	.48 (MLO)	.54
40	.34	.40
50	.24	.30
60	.16	.21
120		.02 (MLO)

THE PROBABILITY THAT AT LEAST ONE OF THE TWO FLIGHTS WILL HAVE AN OPERABLE C & C SUBSYSTEM AT THE MISSION LIFE OBJECTIVE TIME (MLO) IS:

$$P(R) = 1 - (1 - .48)(1 - .02)$$

$$= .50$$

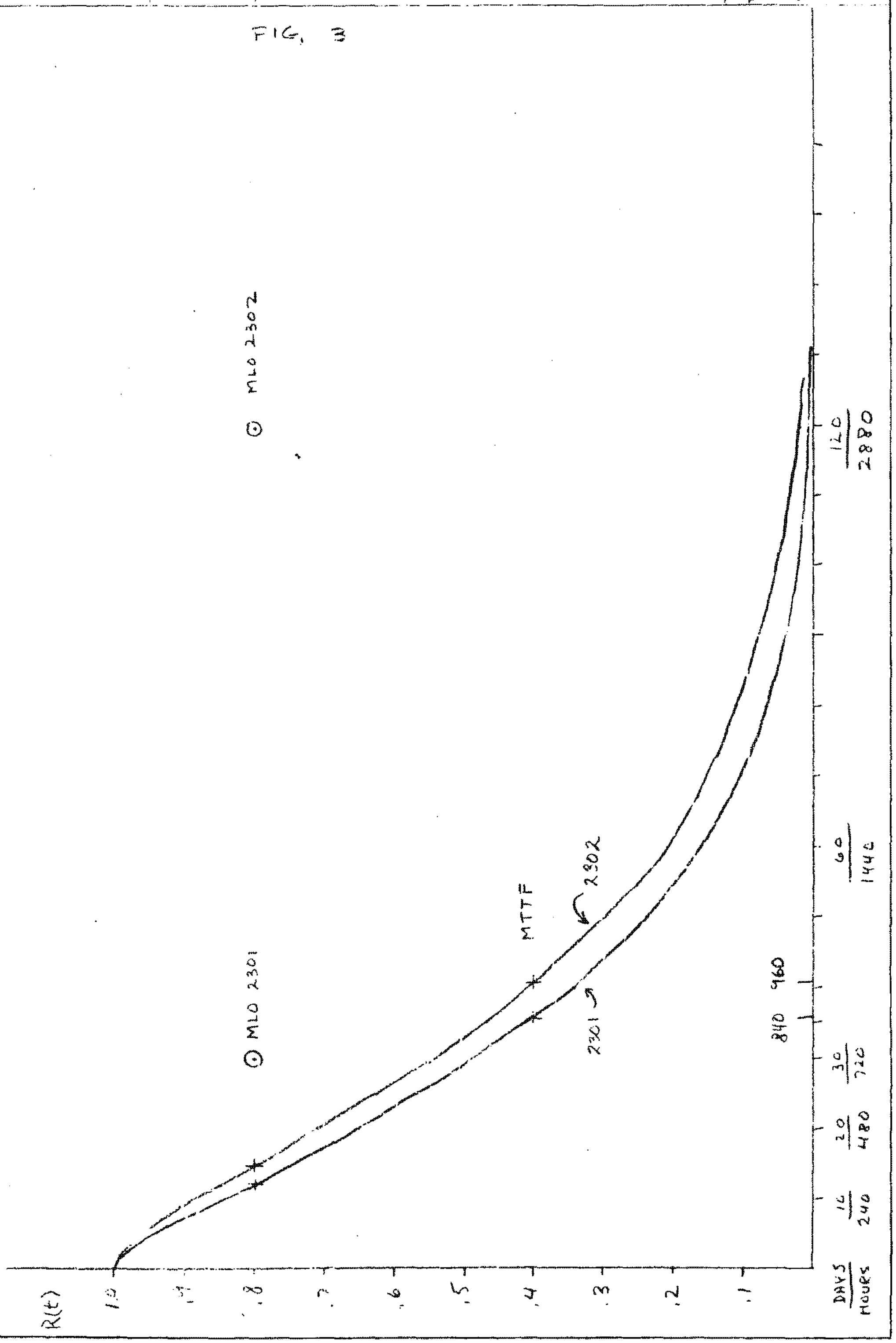
DECLASSIFIED

~~SECRET~~

DECLASSIFIED

	NAME	DATE	**LOCKHEED AIRCRAFT CORPORATION** MISSILES and SPACE DIVISION	TEMP	PERM
Prepared	R. C. DOSTERT, JR		TITLE RELIABILITY DISTRIBUTION FUNKTION	Page	
Checked			PLOT: C & C SUBSYSTEM	Model	
Approved			SAMOS 2301-2302	Report No.	

FIG. 3



DECLASSIFIED

~~SECRET~~

APPENDIX D

LIST OF TABLES AND FIGURES