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EVALUATION OF METHODS FOR DETERMINING HARDWARE PROJECTED LIFE

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FOREWORD

This document is the result of a study to determine if there are accurate means to predict hardware life. The study was performed by Planning Research Corporation, Systems Services Company, Huntsville, Alabama, for the Central Systems Engineering Laboratory at Marshall Space Flight Center. The Technical Monitor was Mr. Bob Smith, S&E-CSE-V. The authors wish to express their appreciation for the cooperation of the many individuals and agencies who provided information.

ABSTRACT

This report summarizes an investigation of existing methods of predicting hardware life by reviewing previous programs having long life requirements, current research efforts on long life problems, and technical papers reporting previous work on life predicting techniques. The results indicate that there are no accurate quantitative means to predict hardware life on system level hardware. The effectiveness of test programs and the cause of hardware failures is presented. This information will be useful to program managers when addressing the long life problem.

OUTLINE

1.0 INTRODUCTION

1.1 OBJECTIVE

This study determined if means existed to predict, with any accuracy, the projected life of space hardware. Future space programs will orbit hardware for 10-20 years. This hardware must reliably operate for the full mission duration or repair, replace, and recycle plans must provide for continually operational systems. Achievement of such a goal requires well coordinated development activities between the design, verification and operational organization.

This study addressed those techniques and processes that are available to verify that hardware will remain operational for the required length of time. However, many findings relating to the design of hardware are presented herein. This data is useful to program management in seeing where the most significant shortcomings were on previous programs. As a secondary objective, the relative effectiveness of test programs were assessed.

1.2 SCOPE

The investigation reported herein was limited to a detail review of previous programs, research activities and technical work on the subject of long life hardware. The total effort expended on this review was eight (8) man months.

1.3 BACKGROUND

Future space programs will require operational hardware in orbit for 10 to 20 years. This hardware must be capable of lasting the full duration or have the capability of being repaired, replaced and recycled. In the past there have been many studies and activities addressing the problem of long life hardware. Some of the more significant efforts are summarized in figure 1-1.

Figure 1-1

STUDIES \ SUMMARY	OBJECTIVE	APPROACH	RESULTS
"Study of Accelerated Testing Techniques" By NASA-MSC, R. W. Bricker/SMD, Chairman	Determine existing acceleration test techniques and application to assuring long life hardware.	Survey industry & universities for successful application of acceleration testing.	Limited application of accelerated testing at the part/material level was identified.
"A Survey of Spacecraft Testing as Applied to Long-Duration Space Missions" By W. N. Douglas, NASA-MSC & G. W. Hewett, General Electric	Determine proper balance design, test, analysis to achieve reliable hardware extended missions.	Survey & evaluate existing & planned tests for long-duration space systems.	Identified limited application of accelerated life testing at part/material level & application to higher levels.
"Dormant Operating & Storage Effects on Electronic Equipment & Part Reliability" By Martin-Marietta Corp. for Rome Air Development Center	Develop quantitative data to define the reliability of electronic equipment & parts when subjected to dormant & storage stresses.	Survey industry for storage failure rate information.	Established criteria for new equipment to withstand long term storage.
"An Engineering Approach to Long-Life Complex Space Systems" By Dr. B. H. Caldwell, General Electric	Conduct studies to obtain quantitative data for program managers to use in allocating resources to programs.	Collect failure data on past programs & determine causes, identify sources of failures.	Design defects attributed to 50% of the failure causes.
"Study of Reliability Data from In-Flight Spacecraft" By Planning Research Corp. for General Electric	Update reliability data with operation experience gained on U. S. Space Programs.	Compile & analyze operational & historic data for 255 launches from 32 space programs.	Of assignable causes design defects attributed to 60% in-flight failures.
"Proceedings of the Symposium on Long Life Hardware for Space" By NASA-MSFC & Society for Quality Control Huntsville, Ala.	Present the best thoughts on the subject of long-life hardware.	Symposium presentation of technical papers on a variety of subjects.	Best collection of overall data available on long life hardware for space.

In general, the previous work indicated that there are many considerations when addressing the problems associated with meeting the mission objectives of long duration space programs.

1.4 STUDY APPROACH

The approach used for this study is depicted in figure 1-2. During the early stages of this study, it became evident that accurate methods of predicting hardware life at the subsystem and system level were not available. Therefore, the selected data included all aspects of the long life problem in an attempt to formulate a reasonable approach to finding a solution to the long life problem.

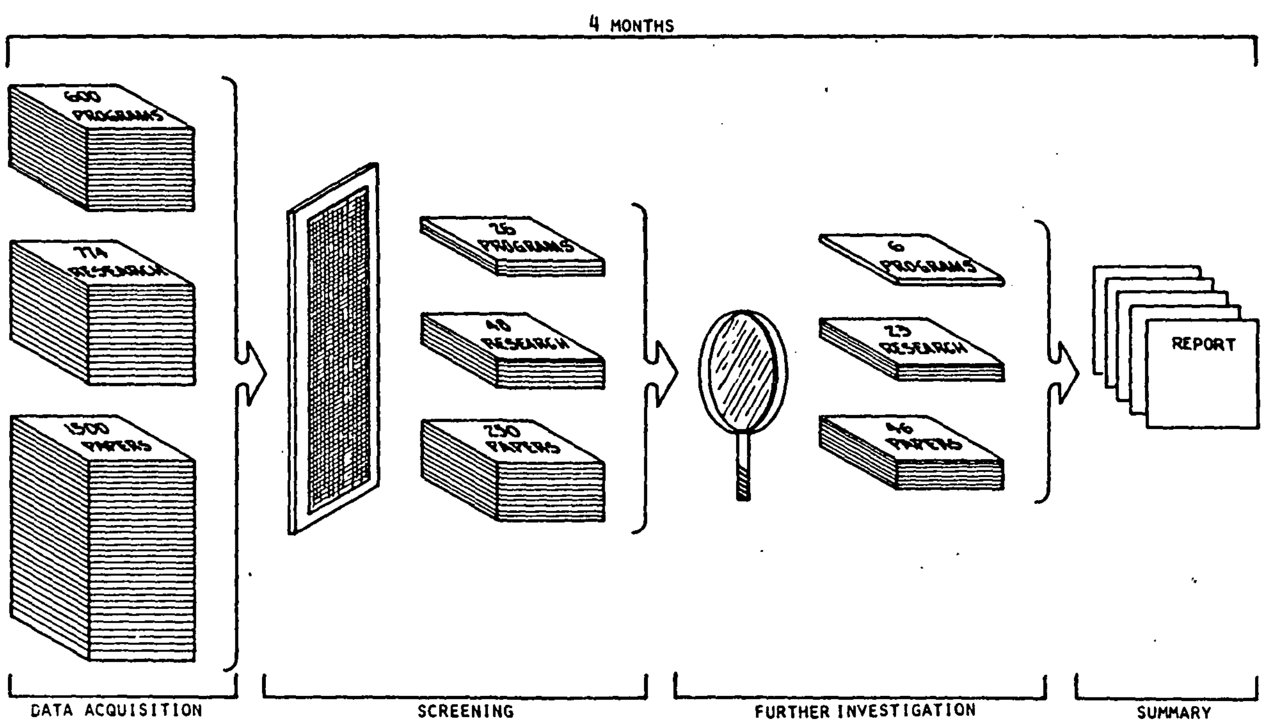


Figure 1-2

2.0 SUMMARY OF FINDINGS

The most significant findings of this study are:

- o Previous studies show that approximately 50% of flight failures are attributed to design inadequacy.
- o Quantitative techniques to determine hardware life have not been developed.
- o Accelerated life testing has been successfully applied at a part/component level.
- o Previous success on long life programs has been achieved by the following:
  - Utilizing a reliable design based on past experience
  - Utilizing only screened, high reliable parts
  - Providing redundancy
  - Providing multiple modes of operation
  - Conducting a well planned ground test program
- o Extensive and exhaustive testing programs will detect a large percent of the defects in design and manufacture.
- o There is no method or process available to continually, throughout a development program, validate the detail design requirements to assure consistency with mission and operational objectives.

The subsequent paragraphs present a summary of the findings from a review of previous programs, research effort, and technical papers.

2.1 REVIEW OF PREVIOUS PROGRAMS

An extensive review of previous programs having a long life requirement was conducted. The results of this review are:

- o The hardware design was based on past experience where reliability had been successfully demonstrated and proven.

- Extensive use was made of advanced research where new requirements were imposed or advancement in the state of the art was required.
- All programs employed extensive and exhaustive ground test programs to prove the hardware prior to flight.
- Only screened, highly reliable, and qualified parts were used.
- Extensive use of redundant components, circuits, subsystems, and systems to tolerate failures without total degradation of mission objectives was employed.
- The operational aspects of the systems provided alternate modes of operation such that mission objectives could be accomplished in the presence of failures.

The degree of success achieved by application of the above is illustrated in figure 2-1. In many cases the useful life exceeded the intended life indicating an overdesigned situation; or, on the other end of the spectrum, the useful life was significantly less than intended. In any event, it appears that accurate life prediction has not been easy to achieve.

Many studies have been conducted to determine the cause of flight failures. The most encompassing of these was a study conducted by Planning Research Corporation in 1967 covering data from 32 U. S. space programs. The significant finding of this study (shown in figure 2-2) is that of the 230 flight failures that had an assignable cause, nearly 60% of these could be contributed to inadequate design. Figure 2-3 delineates the specific design problems associated with these failures. Considering that these failures occurred after the hardware had undergone an extensive process of design reviews, development testing, qualification testing, in-process testing, acceptance testing, prelaunch testing, then it is safe to assume that the verification program did not accomplish the overall purpose of assuring that operational hardware, when deployed, will accomplish mission objectives.

Figure 2-1

SPACECRAFT LIFE VS INTENDED LIFE

SPACECRAFT	LAUNCH DATE	INTENDED LIFE (DAYS)	USEFUL LIFE (DAYS)	RATIO INTENDED/USEFUL
EXPLORER NO. XV	10-62	60	95	1.59
XVII	4-63	90	100	1.11
XII	8-61	365	112	.31
XXXVIII	7-68	365	180*	-
XXI	10-64	365	182	.50
ARIEL II	3-64	365	194	.53
XVIII	11-63	365	300	.82
XXXII	5-66	180	301	1.67
XIV	10-62	365	310	.85
ARIEL I	4-62	365	320	.88
XXXV	7-67	365	469*	-
XXXIV	5-67	365	585*	-
XXVIII	5-65	365	702*	-
XXVI	12-64	365	886	2.43
XXXIII	7-66	180	913*	-
OAO-I	4-66	365	0	0
NIMBUS-1	8-64	180	26	.14
OGO-5	3-68	365	302*	-
ATS-3	11-67	1095	421*	-
OGO-4	7-67	365	541*	-
OGO-2	10-65	365	719	1.97
ATS-1	12-66	1095	755*	-
NIMBUS-2	5-66	180	976	5.42
OGO-1	9-64	365	1578*	-

*SPACECRAFT CONTINUES TO OPERATE AS OF JANUARY 69.
DATA FROM:
"GODDARD SPACE FLIGHT CENTER TEST PHILOSOPHY AND RESULANT RECORD."

Figure 2-2

"STUDY OF RELIABILITY DATA FROM IN-FLIGHT SPACECRAFT"

PRC-R-948 MARCH 1967

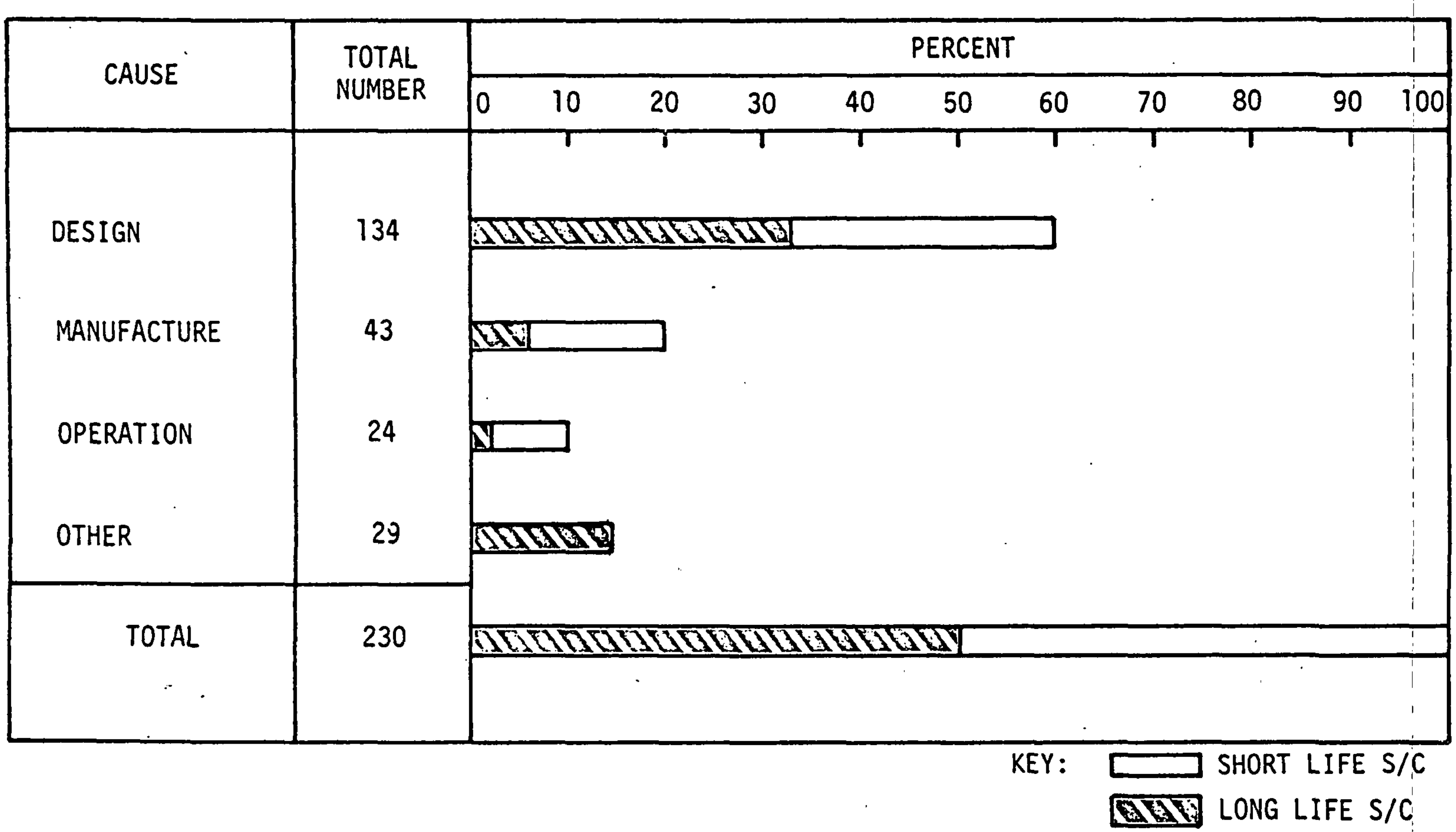
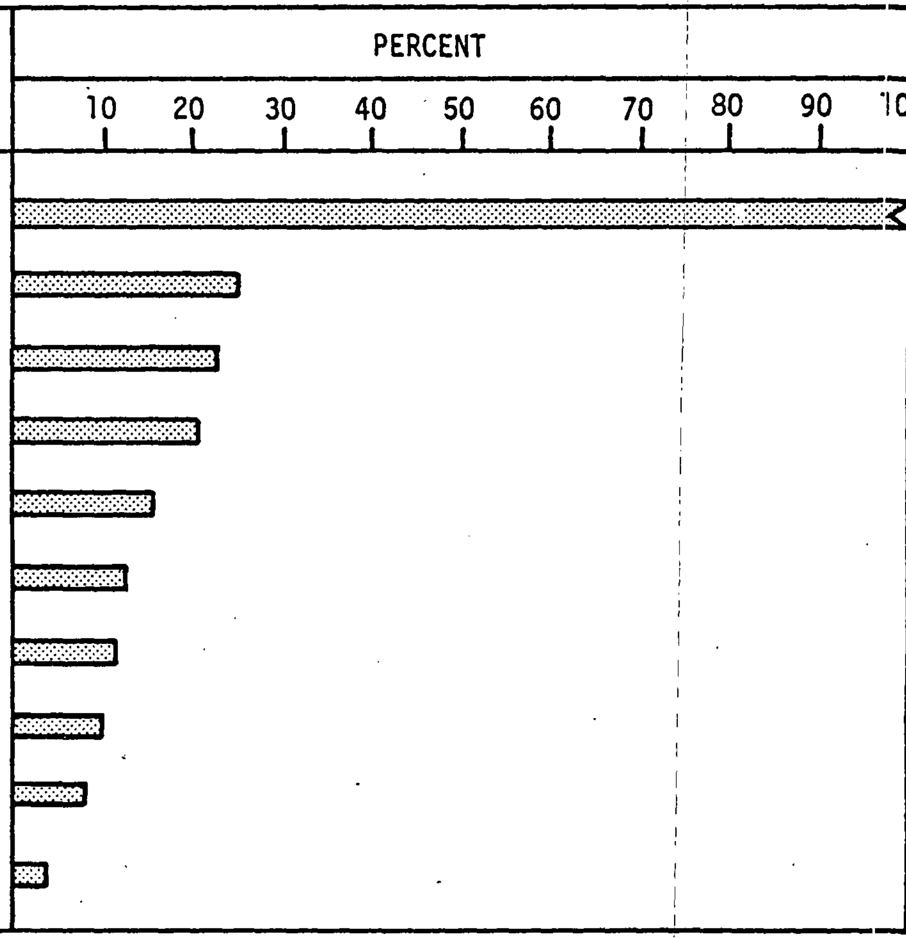


Figure 2-3

TYPES OF DESIGN PROBLEMS

CAUSE	NUMBER
DESIGN	134
RFI	26
SYSTEM	23
ELECT. COMP.	21
MECHANICAL	16
THERMAL	13
WEAR OUT OR DEGRADATION	12
RADIATION	10
LAUNCH VIBRATION AND SHOCK	9
ATMOSPHERIC CONDITIONS	4



2.2 SUMMARY OF CURRENT RESEARCH ACTIVITIES

This area of the investigation revealed the following.

- In nearly every case where a research activity was being conducted in a long life problem it was to extend the state of the art in a particular and specific area.
- In all cases, real-time testing was utilized to validate findings.
- A limited amount of research activity is being conducted on accelerated life testing on specific components and materials.
- All research activities addressing the long life requirements of subsystems and systems extensively utilize redundancy, alternate modes of operation, and high reliable parts in hardware composition.
- The only research associated with prediction techniques were addressing the problem of "failure prediction" not "life prediction."

In summary, our investigation of the research activity indicated that no effort is being expended on the methods to predict the life of system level hardware.

2.3 SUMMARY OF TECHNICAL PAPERS

The technical papers reviewed can be categorized as follows:

- Tests Methods
- Test Program Effectiveness
- Prediction Techniques

The findings from these technical papers are summarized below.

2.3.1 Test Methods

2.3.1.1 Accelerated Life Testing (ALT)

Accelerated Life Testing can be defined as follows.

> "Accelerated Life Test (ALT) is a test run (usually on a part) at operating/environmental conditions which provides a reduction in test cost over normal operating/environmental conditions and which provides an algorithm for extrapolating the reliability observed at the accelerated conditions to the reliability which will be obtained under normal life conditions."

The basic problem of any ALT is that the extrapolation algorithm is valid only if the mode of failure in the ALT is identical with the normal failure modes found in actual use. Acceleration is performed by increasing one or more of the stresses, applied singly or in combination, to force the failure mode. The most difficult part of ALT is the correlation of the failure data with the expected performance under actual use. Considerable effort is required to obtain valid correlation data. When considering black boxes or complex systems that have more than one failure mode, performing a valid ALT is difficult at best.

It is difficult to see any practical application of ALT to complex systems. Hundreds of such tests have been reported concerning simple electronics components. The use of ALT has contributed to many improvements in design and more uniform production of simple high-reliability electrical and electronic components; and applications at this level of complexity are practical and cost effective.

2.3.1.2 Dynamic Mission - Equivalent Testing

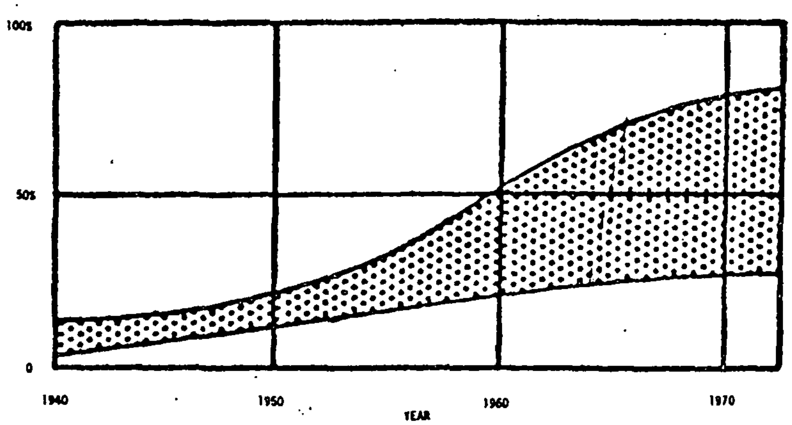
The Dynamic Mission-Equivalent (DME) concept compresses spacecraft test time in a manner similar to the ALT performed on simple assemblies and components. Studies of test and flight failures compared with the state of the equipment at the time of failure show that more failures occur when either the function or the environment is dynamic. Specifically, the number of failures during the power or mode switching, or when the temperature is changing rapidly, exceeds the number of failures that occur when the equipment is in a static state by a ratio of 5 to 1.

Dynamic Mission-Equivalent testing increases the efficiency of simulation by shortening the static or steady state periods of the mission life tests and concentrates the testing on the periods where the equipment is operated dynamically, and is exposed to changing environments. Additional severity is obtained by increasing the rate of change of one or more of the parameters. This technique, when applied to spacecraft-system level is very complex. However, certain mission critical functions can be tested with the DME process effectively.

2.3.2 TEST PROGRAM EFFECTIVENESS

During the past 30 years, the cost of testing on development programs has increased from a median of about 15 percent of the total development cost to over 50 percent. This is shown in figure 2-4.

(AS % OF TOTAL DEVELOPMENTAL COSTS)



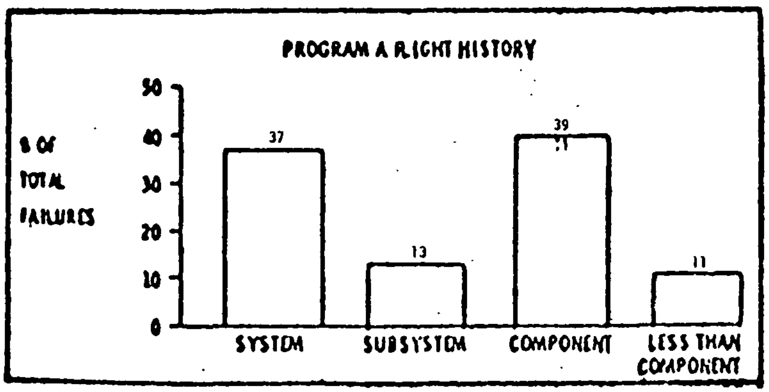
FROM AEROSPACE TECHNICAL FORECAST 1962-1972,
PUBLISHED BY AIA, PAGE 128

COSTS

Figure 2-4

In spite of these increased costs, the effectiveness of extensive and exhaustive ground test programs is frequently questioned by program planners and managers. The following data is presented to delineate the effectiveness of some typical past programs involving long life hardware.

Several studies have been conducted by various companies and organizations to identify the types, causes, and corrective action for previous flight failure. Figure 2-5 shows the flight failures from one typical program categorized by level of assembly.

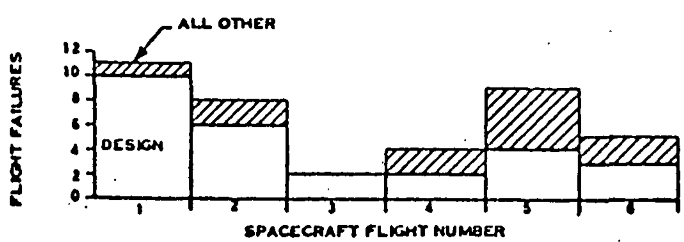


DEFECT OCCURRENCE VS LEVEL OF ASSEMBLY

Figure 2-5

When the same failures are categorized by cause of failure (see figure 2-6) it is obvious that the failures cannot be prevented by testing alone since the majority of failures are caused by problems associated with the design.

PROGRAM A

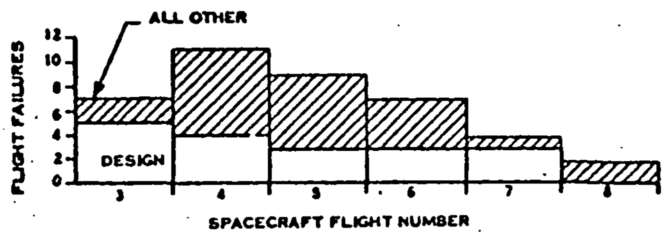


FLIGHT FAILURE HISTORY

Figure 2-6

To further illustrate this major problem, figure 2-7 delineates the flight failures from a second program categorized by cause.

PROGRAM B

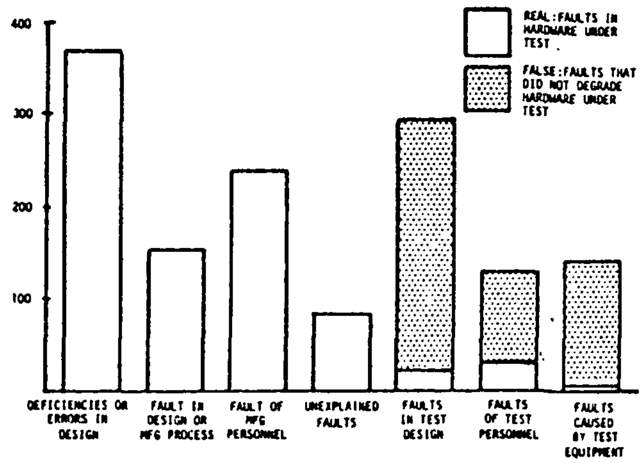


FLIGHT FAILURE HISTORY

Figure 2-7

This data also illustrates the benefits gained from experience and design maturity.

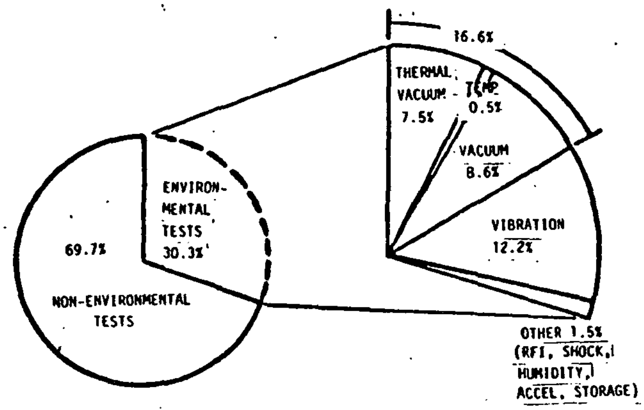
To illustrate the effectiveness of the various phases of a typical test program, the following data is present. This data, extracted from Appendix D, Section 3(a), summarizes 1400 documented problems encountered during qualification and acceptance testing at the component level and above plus failures encountered in flight of the operational Lunar Orbiter spacecraft. Figure 2-8 shows the cause of the problems categorized by organization in a typical program, i.e., design, manufacture, and test.



CAUSE OF FAILURES

Figure 2-8

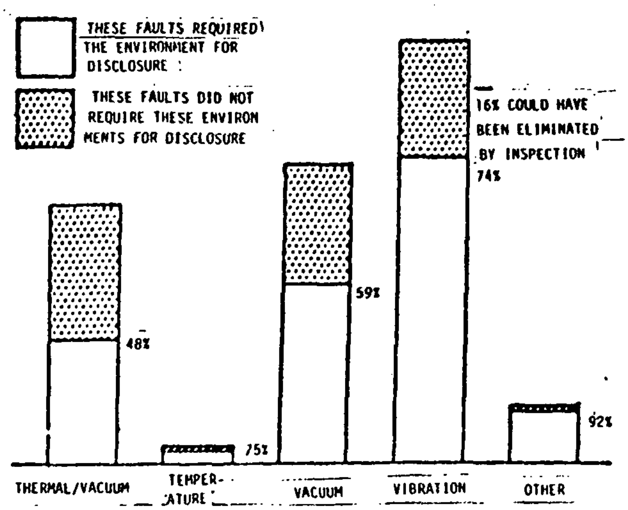
This data again illustrates the major problems associated with inadequate design. In addition, a significant number of problems are associated with faulty testing, both test design and conduction. Figure 2-9 delineates the breakout of type of test vs. number of hardware faults detected.



DISTRIBUTION OF HARDWARE FAULTS BY KIND OF TEST WHICH IDENTIFIED THEM

Figure 2-9

This chart shows that nearly 30 percent of the problems uncovered on the Lunar Orbiter test program were discovered during environmental testing. When the 30 percent are analyzed to determine if environmental testing was required to detect the failures, the results are shown in figure 2-10.



HARDWARE FAILURES DISTRIBUTED BY KIND OF ENVIRONMENTAL TEST

Figure 2-10

This data presents a fairly strong argument for adequate environmental tests on future programs.

Figure 2-11 shows the quantity of flight failures categorized by type of equipment. This data covers data from over 50% of the U. S. unmanned spacecraft programs prior to 1967.

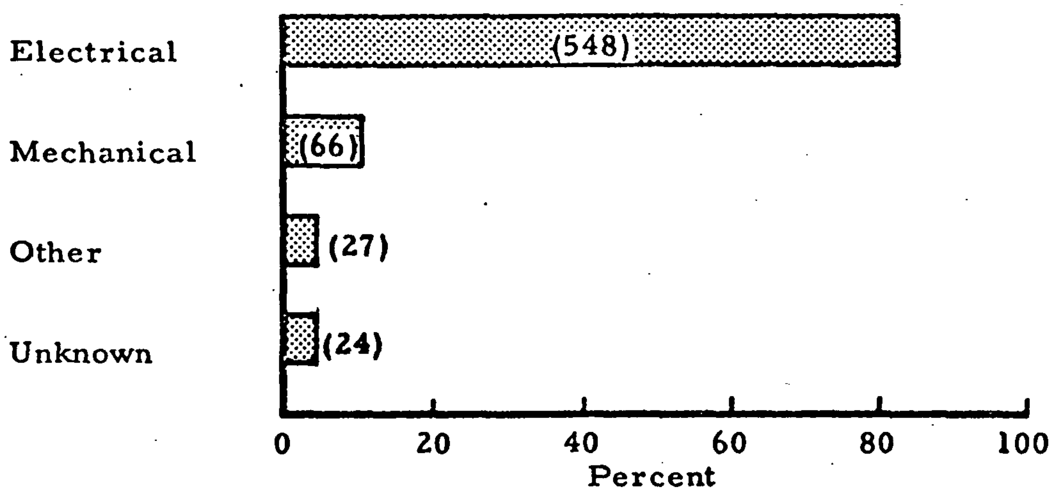
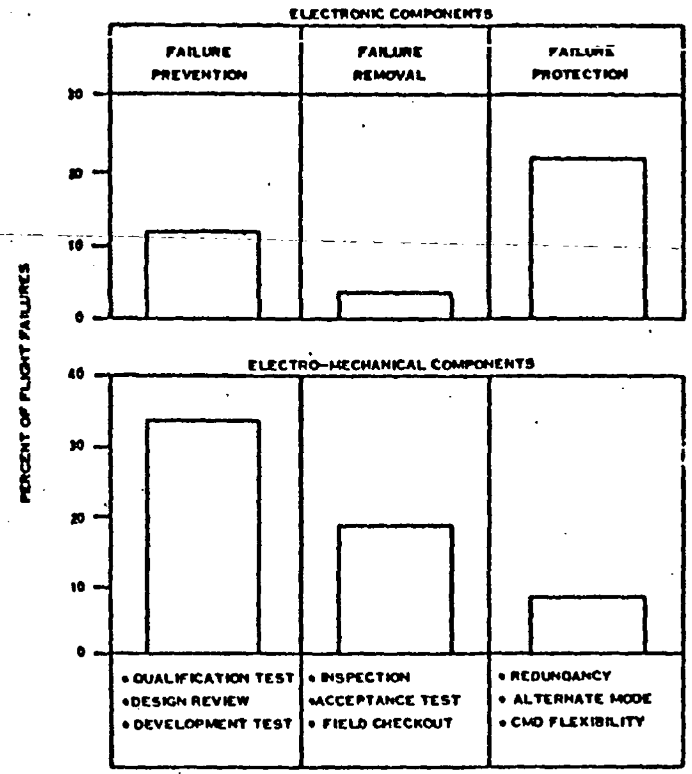


Figure 2-11

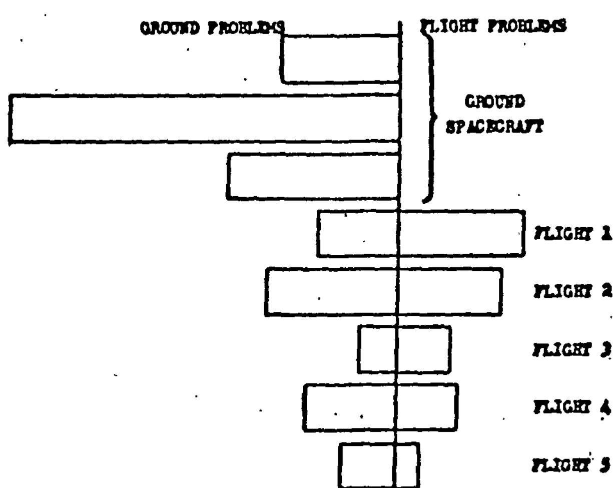
In figure 2-12 a comparison is made between electronic and electro-mechanical flight failures. The data shows that electro-mechanical components were responsible for 3/4 of the design caused failures. It is evident from the data that the majority of the electro-mechanical failures should have been eliminated in the design function.



Flight Failure Cause

Figure 2-12

Figure 2-13 is an indication of the overall effectiveness of the test program on Lunar Orbiter.



COMPARISON OF GROUND PROBLEMS WITH INFLIGHT PROBLEMS

Figure 2-13

From this it can be concluded that even though a large number of failures and faults are detected during an extensive and exhaustive test program, this in itself is not adequate to insure total mission success.

2.3.3 PREDICTION TECHNIQUES

During the review of technical papers several techniques for predicting hardware behavior were found. These can be categorized into:

- o Life Prediction
- o Failure Prediction

The techniques associated with life prediction involved components and materials. In no case did the prediction technique involve hardware at the subsystem or above level.

Failure prediction has received much more attention. During the review of technical papers, several methods and techniques were presented. Some of these are:

a. Fracture Mechanics
b. Signature Analysis
c. Feasibility Prediction
d. Methods of estimating life by:
   - o failure rates
   - o extrapolation

A summary of the quantitative prediction techniques are presented in figure 2-14.

Figure 2-14

QUANTITATIVE PREDICTION TECHNIQUES

TECHNIQUE	DESCRIPTION	APPLICATION
(1) Fracture Mechanics for Estimating Life Expectancies	o Describes several methods for using proof-test data to determine: o minimum life o maximum life o typical life expectancies o Based on critical sizes of cracks, flows, and growth rates	o Pressure vessels
(2) Fracture mechanics for determining turbine wheel design criterion.	o Buried flow analysis o Surface flow analysis o Apply critical stresses and plot against flow size to determine failure points	o Permits designer to determine that defect size which would cause a failure when specific stresses are applied. o Turbine wheel design
(3) Fracture mechanics for design and failure analysis.	o Describes foundations of linear elastic fracture mechanics and develops equations o Experimental determination of valid fracture toughness numbers	o Shows application to selection of materials o Identifies application to the following: pressure vessels, submarine hulls, ultra high strength all strength alloys, wrought and cast, composite materials, wood plastics, vistcoelastic materials and glass.

Figure 2-14 (Cont.)

QUANTITATIVE PREDICTION TECHNIQUES

TECHNIQUE	DESCRIPTION	APPLICATION
(4) Signature Analysis	o Predict pending failures of hardware o Limited to imminent failures as opposed to distant failures o Requires some experience of degradation	o Black Boxes o Intermittent motor devices o Simple rotating devices o Tape Recorders
(5) Signature Analysis using acoustic and vibration signals.	o Identify specific failure modes and times o Applied to machines which generate repetitive signatures o Diagnosis moving parts in machinery	o Useful in predicting life performance o Predict life of bearings, gears and associated moving parts machines
(6) Predict life of thermal coatings based on extrapulation and analysis of the exposed environment	o Applied to thermal protective coatings for Space Station or Near Earth Orbit (300N. M.) Spacecraft o Plotted changes as a function of equivalent Sun Hours of Exposure against Solar Absorptance	o Predict thermal coatings lifetime for near earth orbits

Figure 2-14 (Cont.)

QUANTITATIVE PREDICTION TECHNIQUES

TECHNIQUE	DESCRIPTION	APPLICATION
(7) Feasibility prediction	o Estimate of reliability of new major systems based on known experience with past systems.	o Useful in ballpark estimating life prediction of a system based on prior experience of similar complex systems.
(8) Methods of estimating life distribution characterized by linear increasing failure rate	o Describe failure data of equipment which ages with time or increased stresses or both	o Prediction accuracy requires large sample of specimens o Selected components and materials based on two parameters and estimate failure times

3.0 CONCLUSIONS

1. Quantitative techniques to determine hardware life at the subsystem or the system level have not been developed. The most acceptable technique for predicting life is design maturity and hardware evaluation. In addition real time testing is used extensively to achieve a high confidence of hardware life.

2. Accelerated Life Testing is a limited method to predict future hardware life of components and materials. The problems associated with ALT as a technique are threefold: (a) the stress level which the specimen should be subjected to (b) the effects of a multitude of stress parameters to be included in each test and the correlation of the results of the test data as to which parameter(s) should be selected in the analysis (c) the lack in confidence in analyzing the above (a) and (b) and extrapolating the results to correlate ALT to real time testing.

3. Based on an extensive review of previous failure and test data, inadequate design is the cause of over 50% of the flight failures. From this data we conclude that an inappropriate amount of effort is expended in verifying quality of hardware vs. quality of design. Based on data presented it appears that improper specifications of the operational environment is the most likely cause of the design problem. During our review, we observed a lack of a a systematic method to verify detail design requirements throughout a development program.

4. The review of results of previous test programs on major space systems verifies that extensive and exhaustive testing detects a large percentage of the defects present in space hardware. However, when compared to flight failures,

it is evident that additional steps need to be taken to remove all defects from hardware prior to deployment. Based on data presented, it appears that verification of design requirements, either by analysis or testing, could lead to a significant reduction of failures during the testing and operational phases of the programs.

4.0 RECOMMENDATIONS

1. It is recommended that further effort on the long life problem address to overall systematic approach to assuring operational lifetime through design, verification and logistics rather than through life prediction alone.

2. It is recommended that further effort be expended to define a systematic method of verifying the design of a system prior to commitment to manufacturing. It is obvious from previous programs that design reviews, development testing and qualification testing, when conducted by the design organization, do not in themselves validate the detail design requirements.

APPENDIX A

PROGRAMS

This appendix reports in summary matrix form the six (6) programs selected for final evaluation. For each the program has been identified, type of mission, known success (if any), a listing of sources, a summary of each and an evaluation.

In each evaluation the technique for assuring or verifying hardware life was examined to determine how or if any technique for predicting life was made. Also, any test methods which may reduce total test time and what basic approach was employed to achieve hardware required lifetime.

Appendix D - Bibliography lists each data source.

PROGRAM & DATA SOURCE	SUMMARY	EVALUATION
NIMBUS II - Meteorological Observatory (Successful) SOURCES: Long Life Design Features of the Nimbus II Meteorological Observatory, C. Sharp, G. E., Re-Entry Systems, Phila. Penn. (Feb. 5, 1968)	o Complex, Advanced State-of-art, & high redundancy o Prototype/Qualification Model o Commercial Electronic Piece Parts o 2-Piece Modular Structure o Part Testing Limited, High Degree Systems Test o FMEA's Limited o Quantitative Analysis of Anomolous Behavior o High Use of Models for Evaluation	o Longer Life thru Maturing Design Nimbus I & II o Models to Identify Design Deficiencies o Grossly Underestimated Hardware Life o No Quantitative Means Used to Predict Life o More Emphasis on Criteria for Redundancy Desirable
SERT II - Ion Thruster Demonstration (Successful) SOURCES: Description of SERT II Spacecraft and Mission, by Richard G. Goldman, G. S. Gurski, and W. H. Hawersaat, Lewis Research Center	o Flight Proven Hardware o Extensive Testing o Passive Control System o Experimental & Prototype Models o (1) Flight Unit - Spares thru Testing o Mission Success Extrapolate Future o Life Requirements o Mass Dummy Model o Analysis Based on Models	o Direct Extrapolation to Hardware Life Ion Thruster & Associated Hardware o Reduce Testing Use Proven Hardware o Extensive Environmental Testing - Not Used to Predict Life o Approximation of Hardware Life was Made
TIROS & ESSA - Meteorological Satellites (Successful) SOURCES: Tiros and Essa Satellite Design and Test for Mission Success, by A. Schnapf, Tiros/Tos Project Mgr. Tiros: A Case History in Reliability by R. Hoedemaker, E. Mowle, and G. Gordan, RCA Astro-Electronics Division, Princeton, N. J.	o Simple, Conservative, Passive Systems o Changed from Axial to Wheel Mode o Redundancy Initially Moderate Changed to Complete Redundancy All Major Equipment o Extensive Prelaunch Test & Test for Design Changes o Standard Parts o Extensive Test of New Parts o Malfunction Analysis o Analysis Feed Back o Recurrence Control	o Extend Life thru Maturing Design o No Prediction on Hardware Life o Estimate Life Based on Past Experience o Total System Redundancy o Prove Flight Worthiness Use Building Blocks to Extend System Life

PROGRAM & DATA SOURCE	SUMMARY	EVALUATION
Submarine Telephone Cables - Highly Successful (No passive component Failure in 13 years) SOURCES: Reliable Underwater Cable Components, By D. Feldman, M. G. Lesh, W. McMahon, Bell Labs, New Jersey Submarine Telephone Cables, By E. T. Mottram, IEEE Spectrum, May, 1965	o Passive Components o Critical Component Selection o Long Term Component Test o Establish Aging & Special Facility for Manufacture o New Components Subjected to Accelerated Environmental Tests o Large Scale Evaluation & Analysis at Parts Level o Failure Rate Predictions Based on Acceleration Factors and Conditions	o Proven Use of Accelerated Life Testing at Component Level o Extensive Use of Proven Parts for Long Life o Exact Prediction Technique Not Known
SNAP Program Power Development (Successful - 9 Years Proven) SOURCES: Space Nuclear Power Developments in the 1960-1980 Decades, By Martin-Space Systems Programs, Atomics International Division, NAR, Canoga Park, Calif.	o Maturity of Design to Increase Power Required & Extend Long Life o No Identified Prediction Technique o Life Reqmt's Limited by Electronic Components SNAP 10A o Design for 5 Years Useful Life o Extensive Analysis of Nuclear Safety Questions o Extensive Trade Studies	o Advance State-of-Art o Continued Research Space Reactors for Increased Power Reqmt's o Extensive Testing o Space Simulated Ground Test Extensive

Thermoelectric Outer Planetary (TOPS) Project - Advanced Development Program to Determine Feasibility of Spacecraft Design to Meet Extended Space Flight - 8-12 Years in Duration
 	
SOURCES:
Thermoelectric Outer Planets Spacecraft Industry Briefings, Dated Sept. 21, 27, 28, 29, 30, and Oct. 1, 1971
	o TOPS is organized as an advanced systems technology project.
	o TOPS activities include:
	  o System Design of Completed Spacecraft
	  o Demonstration of Major Technical Innovations
	  o Demonstration of the Feasibility of Systems Analysis
	o Design aims at achieving reliability, largely through existing redundancy and a selftest and repair computer.
	o Parts selection thru hi-reliability & past flight proven parts & components.
		o Transient and permanent failures detected and correct through use of Star computer
		o Greater redundancy is made possible through extensive use of LSI circuits.
		o Completely reprogrammable computer offer alternate modes of operation.
		o No analytical methods for predicting hardware life were discussed.
		o Use of advanced state of the art in achieving long life hardware.

APPENDIX B

RESEARCH PROGRAMS

This appendix is arranged in a summary matrix form using three (3) major categories. The Data and Source, Summary of the research activity, and an Evaluation of each.

For each of the twenty-three (23) research activities reported on the following information was provided:

(a) Organization conducting the research

(b) Identification of the research by RTOP number

(c) Title of effort

(d) Contacts made to determine current status

(e) Source material used in evaluation

In the evaluation of each research activity significant techniques being used for assuring hardware life are pointed out.

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - JPL RTOP -186-68-54 TITLE - Guidance & Control Technology for Outer Planet Missions 8-12 Years Operation G&C Improved Reliability CONTACTS - Tony Pearson JPL Bill Bachman JPL SOURCE - JPL Industry Briefings Oct. 1, 1971 By R. A. Crawford	o Develop guidance & control technology for 8-12 years mission life o High reliability components o Selective redundancy (block) o Conservative design techniques (Electrical mechanical) o All digital system o Established baseline requirements o Extensive testing o Advanced development special components o Fault detection & switching o Computer control testing	o No prediction techniques applied o Extend current state-of-art o High use of block redundancy o LSI & MSI development o Selective alternate modes of operation o On-board computer checkout system o Single systems approach o Simulation using development hardware o Extensive testing
ORG - JPL RTOP - 186-68-53 TITLE - Telecommunications Technology for Outer Planet Missions Part of TOPS Mars 1 Year - Grand Tour 11 Years Improve Operating Life CONTACTS - Tony Pearson JPL Lou Paulus JPL SOURCE - JPL Industry Briefings Sept. 30, 1971 By Paul Parsons	o Increase performance capability by 30 DB over Mariner '69 capability o Develop large unfurlable antenna o Develop more efficient X-Band data dump system o Digital circuits used o Micro-wave power tubes life tested (ref. RTOP125-21-09) o Low gain & medium gain antennas No major design problems o All subsystems under trade study analysis o Develop confidence in predicting lifetimes	o Demonstrated 27 DB increase capability o Extensive testing, analysis, & trade studies o Extend state-of-art o No lifetime prediction technic identified o Long life analysis based on environment o Explore all reasonable systei & subsystems o Current state-of-art 1/3 mission lifetime required

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - JPL RTOP - 120-34-10 TITLE - Planetary Batteries (7 to 12 Years) CONTACTS - Tony Pearson JPL Aiji Vchiymer JPL SOURCE - TOPS JPL Briefing Oct. 1, 1971 By H. M. Wick	o Develop long life batteries - planetary mission o Technology in heat - sterilizable batteries o Effects of environment o Design suitable battery systems o Testing components o Determine optimum power source "TOPS" AC vs. DC o Selected - centralized AC power distributor for "TOPS"	o AC power for TOPS selected based on experience o DC did not provide sufficient load isolation & switching req'ts excessive o Launch battery for TOPS eliminated - RTG inert gas back - filled to inert launch support o Analysis used to rule out batteries as power source "TOPS"
ORG - JPL RTOP - 120-27-41 TITLE - RTG Support for Deep Space Advanced Spacecraft CONTACTS - Tony Pearson JPL Vincient Truscello JPL SOURCE - TOPS JPL Industry Briefing Oct. 1, 1971 By H. M. Wick	o Develop RTG Technology o Prototype development testing - 1 year @ 950° C. Required @ 1000° C. o "TOPS" solar independent power source - long life o Power output & profile defined for 10 or 12 yr. life o Design TOPS RTG assumed projected state-of-art o Number RTG's selected - (4) o RTG sized physical, raw, power, weight, & reliability allocated	o Limited acceleration life testing now in process o Prediction based on 25% degradation for 12 yr. mission o Difficult to predict life or extrapulate: o Known mechanics of failures o Materials behavior not understood

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION

ORG - JPL
RTOP - 120-26-21
TITLE - Advanced Pulsed Discharge Thruster 10-12 Years Operational Life
 	
CONTACTS -
Phillip Moynihan JPL
Tony Pearson JPL
Bill Backman JPL
(Hamilton Standard)
 	
SOURCE -
JPL TOPS Industry Briefing
Sept. 28, 1971
By Phillip Moynihan
	o Develop improved attitude control torqueing systems
	o Pulsed plasma in micro pound to millipound range
	o Baseline requirements established
	o Trade-off studies completed
	  o Liquid hydrazine catalytic thruster
	  o Propellant supply common with TCPS
	  o High I_{sp}
	  o Few active components
	  o Lower leakage value seals liquid rather than gas
	o Reliability study
	  o Simplify system
	  o Minimum mechanical actuations
	  o Standby redundancy mode
	  o Series redundant values
	o Demonstrated 2300 cold starts objective 2600 cold starts
		o Limited use of accelerated life test - cold start program
		o Difficult to correlate data accelerated tests to real life - Example catalytic reaction to materials
		o Cold start parameter of 2600 starts based on yaw axis control required off-set C.G. to C.M.
		o Design maturity based on past experience larger thrust
		o Possible use of de-rating to obtain life required
		o 10 year life obtain thru paralle redundancy
		o Dormancy no problem except for catalytic

ORG - JPL RTOP - 125-25-20 TITLE - Extreme Temperatures and Life Test Requirements for Electronics Determine Qual & Verification Techniques for Accelerated Life Tests of Electronic Assemblies (See JPL Report JPL 701-29 ETR) CONTACTS - J. C. Arnett JPL Tom Gindorf JPL Dave Wikeston JPL	o Determine extreme temperature requirements for electronic component development. o Determine qualification standards and verification technique for ALT of electronic assemblies o Formulation of model which defines the long life mission, electronics parts types, and temperature history for the mission. o Use model to perform statistical evaluation of failure rate data available for individual electronic piece parts	o Will not do mission duration testing therefore no correlation between ALT & real life will be made o Made no use of prediction techniques o The data obtained from the model studies will be used in developing rationale used in developing the test at the subsystem level

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - JPL RTOP - 125-21-09 TITLE - Microwave Deep Space Communication and Tracking Relates to Manned Space Station Requirements Long Life Reference RTOP 125-21-18 Microwave Communication for Manned Space Station CONTACTS - Ed Posnar JPL Tony Pearson JPL SOURCE - JPL TOPS Industrial Briefing Sept. 30, 1971 By Paul Parsons	o Increase communication capability & reliability of microwave links o Use multiple mission systems o Multifrequency operations o Advanced technology in dual frequency S - X - Band o Testing tubes 4-10 Years o No scaling laws for cathods o Development analog	o No prediction techniques applicable o Simplify design o Design maturity approach o Real life testing (tubes) (4 year o No accelerated testing due to multi-parameters o Determine failure mechanisms
ORG - JPL RTOP - 125-23-12 TITLE - Advanced Digital Data System for Deep Space Grand Tour (Guarantee performance 10-20 years) CONTACTS - Ray Pearson JPL	o Provide conceptual tools & technology for centralized data systems o Support "TOPS" program o Meet needs of: o High density o Low weight o Low power o Low cost logic, memories, recorders o Insensitive to radiation & temperature extremes o Free from long term degradation in physical & electrical properties	o Prediction techniques consist of failure rate data applied to subsystem mathematical mode o No accelerated life testing is used at the subsystem level

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION

ORG - JPL
RTOP - 125-23-17
TITLE - Fault Tolerant Computer for the Space Station Survive in excess of 10 year life a digital computer with general capabilities
 	
CONTACTS -
Tony Pearson JPL
 	
SOURCE -
JPL "TOPS" Industry Briefing
Sept. 30, 1971
By D. K. Rubin
	o Develop technology required to design & build digital computer
	o Automatic checkout & automatic maintenance
	o Replacement redundancy & self test
	o Programmed control of spacecraft
	o Repairable triple modular redundancy (unpowered spares)
	o STAR = Self test & repair concept
	  o Employs selective redundancy for failure detection, protection & repair
	  o Hardware (hard core) failure detection & control of repair
		o Extensive use of mathematica modeling
		o Use statistical data to determine failure rates for piece parts
		o No use made of alt.
		o Long life obtained through extensive use of redundancy

ORG - JPL
RTOP - 125-24-13
TITLE - Advanced Imaging Systems Technology Provide for 12 year mission high image 1000 times Pluto vs that at Mars
 	
CONTACTS -
Tony Pearson JPL
 	
SOURCE -
JPL "TOPS" Industry Briefing
Sept. 29, 1971
By George Root
	o Assessment of space planetary imaging systems requirements (Support TOPS)
	o Reliability requirements
	  o 12.5 Yr. storage life
	  o 2400 Hr. operation
	  o 4500 Hr. standby mode
	o Radiation resistance
	o High resolution
	o Large frame size
	o Principle reliability problems
	  o Long mission time
	  o Jupiter radiation environment
	o Performance problems
	  o Low light levels
	  o Large fly by altitudes
		o Analyzed alternate systems
		o Performed feasibility studies
		o Test surveyor vidicons
		  (39) tested age 5-7 yrs.
		  (3) failures
		  (36) reasonable video levels
		o Test mariner sensors
		  Age 5-7 yrs.

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - JPL RTOP - 186-68-50 TITLE - Advanced System Technology/ Thermoelectric Outer Planet Spacecraft TOPS desjgn development long life assessment. Includes fabrication CONTACTS - Tony Pearson JPL Tom Gavin JPL SOURCE - JPL "TOPS" Industry Briefing Sept. 21, 1971 By W. S. Shipley	o Perform design, development, & testing spacecraft o Evaluate sub-system interactions o Selection of hardware & sub-systems concepts o Extend state-of-art o Investigate critical technologies o Demonstrate subsystem capability	o Maximum use of Mariner & spacecraft experience o Extensive parts selection program o Development of MSI & LSI to achieve longer life o Use of multi-mode selection to achieve high redundancy o No prediction other than usual reliability methods o Fault tolerant systems design STAR o Applied new state-of-art technology required (RTG) power
ORG - MSFC RTOP - 908-51-02 TITLE - Space Station Thermal Control Coatings & polymers passive & active thermal control systems. Space Station CONTACTS - Don Wilkes Charles A. Cothran MSFC Project Manager SOURCE - Lockheed Final Report May 1971	o Investigation of transient degradation/ contamination of thermal coatings o Develop analytical prediction techniques for degradation of thermal properties up to ten years o Prediction of long term degradation was made. Ref. May 1971 report by Lockheed	o (3) coatings were recommended & extrapulations were provided for each as a function of solar absorptance vs equivalent sun years o Level of confidence in data not high o Prediction accuracy considered low due to the multitude of parameters to be considered. outgassing, venting, etc. & the combined environmental effects o Minimum amount flt. test data available

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - MSFC RTOP - 908-51-04 TITLE - Space Station Attitude Control Propulsion System - Long Duration, min. refurbishment and resupply CONTACTS - Lee W. Jones MSFC Dick Sievers Hamilton Standard SOURCE -	o Establish design requirements ACPS for Space Station o Demonstrate technology o Tasks (contractor) o Resupply/repair monopellant subsystems o Resupply/repair solid &/or hybrid subsystems o Evaluation of trash rocket concepts o Thruster life estimated @ 10 years o Requirements definition & analysis o Component & system design tradeoff studies o Extend ACPS repair, resupply, and maintenance efforts	o Design margin based on wear experience o No accelerated testing (cold start JPL program ref. RTOP o Life estimates based on experience o Martin Co. assumed certain cycles for repair estimates o Derating to extend hardware life o Design maturity concept o Difficult to obtain flight data (ATS - 3 still operational Nov. 1967)
ORG - MSFC RTOP - 908-51-08 TITLE - Stabilization & Control Long Life Control Moment Gyro Development CONTACTS - Dr. G. B. Doanne III MSFC Dick Campbell MSFC	o Develop modular CMG's support Space Station/Base - (2000 H to 6000H) o Emphasis long life, repairability, monitor impending failures, & redundancy o Minimize wear of rotating components o Replaceable spin bearings o Brushless DC motors o Improved wet lubricated actuators o Diagnose using signature analysis o Redundant spin motor electronics	o Extensive testing CMG 3 years continuous - no degradation o Use of signature analysis - bearing wear - no success - no degradation o Possible limited use of accelerated testing actuators - No way to use on CMG's o Anticipated improved environment in space for GMC's due t 1 G drop o No prediction technique applie to date

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - MSFC RTOP - 908-51-18 TITLE - Checkout Deep Space Station Two approaches paint & gas type CONTACTS - M. Berkibile MSFC L. Hamitir MSFC SOURCE -	o Seven different tasks being pursued under this effort o One (1) task on study of bonding on flip chip & beam leaded devices is applicable o Development of a report on processing & control of bonding "flip chip" & "beam leaded" devices onto microcircuit sub strates o Includes fabrication, process, testing & failure analysis o Final phase step-stress testing underway	o No identified prediction techniques o Certified mfg. lines to obtain quality o Step-stress testing no final results to date o Development towards MS LSI in process
ORG - MSFC RTOP - 720-02-12 TITLE - Polymers for Fuel Tank Sealants Predict service life of polymers sealant compositions CONTACTS - W. J. Patterson - MSFC	o Development of thermally resistant polymers for use as fuel tank seal ants o Materials to withstand 500-600° F while in contact with hydrocarbon fuels under varying mechanical stresses for extended periods of time o Selection of a polymide is continuing o Quantitative assessment of first generation materials as sealants scheduled for 1973 with evaluation and testing scheduled for completion in July 1972. o Application for SST fuel tanks now scheduled for shuttle with air breathing engines o Series testing silicons to measure physical properties	o Some success in prediction - using short term testing o Extrapulate 100 hours test to 1000 hours complete o Estimate service life to sever years o Accelerated life testing using empirical methods has been employed - good possibilities o No summary report on effort to date

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - MSFC RTOP - 129-03-32 TITLE - Bearing & Lubricant Technology for Space Applications Long Lifetime Lubricants CONTACTS - Bob Schwinghamer MSFC Keith Demorest MSFC SOURCE -	o Provide solutions in lubricating systems - variety of environments for space shuttle o ATM & Skylab within current state-of-art o Develop special design for sliding & rolling devices using fluid & dry lubricants	o No prediction techniques applied o No accelerated testing -- multi parameters - environment speed, temp, & device o Operating time/cycle is problem - not dormancy o Standard test dry lubs - set specimens - many variations in results - wear is problem o Selection of lubricants requires device, cycles, environment, etc. knowledge
ORG - MSC RTOP - 125-23-14 TITLE - Space Station - Onboard Check-out Automated Techniques for assessing subsystem performance for maintenance provisions. Reference 125-23-15 Space Station - Central Multi-Processor and Man/Machine Techniques Hughes MSC CONTACTS - J. F. Hughes MSC	o Develop techniques for automatic status monitoring all check points o Automatic techniques of assessing subsystem performance for maintenance provisions o Assessment operational status integrated electronic system	o No prediction technique application o Use redundancy o No direct application to study

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - LRC RTOP - 129-03-32 TITLE - Fatigue, Fracture and Life Prediction Predict Life of Specimens Component Detail CONTACTS - John C. Freche (LRC) SOURCE - NASA TMX - 67838, Creep Fatigue Analysis by Strain-Range Partioning NASA TMX - 52999 A Specialized Model for Analysis of Creep Rupture Data by Minimum, Station-Function Approach	o Obtain better understanding of failure of fracture mechanics o Develop prediction - life of Specimens & components - subjected to complex patters of temp. & loads as a function of time o Relation of cyclic life by Manson-Coiffin type power-law equation o Linear life fraction rule is used to combine damage effects & predict life of specimens (steel specimens) o Time-temp-stress general form & includes all common parameters - defined by station functions	o Reduces creep-fatigue analysis o Application to life prediction (Limited) o Demonstrated extrapulation (By a time factor of 20) o Artificial data sets o Need to correlate test (experimental) to direct experience o Methods proposed have not received universal acceptance as a standard but looks promising
ORG - AMES RTOP - 129-03-42 TITLE - Physics & Chemistry of Solids Increase understanding of environmental effects to degradation of materials. Note: Hdqtrs. & LRC conducting studies using same RTOP No. & Similar Objectives CONTACTS - G. Goodwin	o Obtain increased understanding of influence of: o Earth o Planetary o Interplanetary Environments o On Degradation of Materials o Results should have application to design of airplanes & spacecraft	o No good way to do accelerated testing o Problem multi-environment syncretism non-linear problem o Need a degradation method o Methods Analysis o Failure Methods o When structure is well known known formation damage - estimates of long time behavior can be established (plastic rain coats)

RESEARCH & TECHNOLOGY (RTOPS) SUMMARY

DATA & SOURCE	SUMMARY	EVALUATION
ORG - LaRC RTOP - 128-32-61 TITLE - Pyrotechnic Systems Engineering Long Duration required for Space Station CONTACTS - Joe Hallisey - LaRC Carry Beaman - LaRC	o Evaluating all types performance mechanisms o Developing sterilization program for Viking o Martin Co. contract to study aging-select system components for Viking o Develop thermal impact on reaction to physical & chemical properties of hardware/explosives o Using mass spectrometry to determine outgassing characteristics o MDAC study to develop shuttle pyrotechnics	o Limited prediction techniques applied to date o o MDAC investigating minimum reported o Most to date - lack confidence o Acceleration techniques being developed - no specific application o Real life testing most common o Standard analysis has been employed to date
ORG - LaRC RTOP - 125-19-25 TITLE - Control Components and Subsystem Research and Technology for Space Station/Base (Long Life Study) CONTACTS - Harry Ricker LaRC Charles Husen LaRC Duncan McIver LaRC Jim Taylor MSFC	o Develop advanced component & subsystem technology for Space Station o Generate & analyze advanced control concepts o Advance hardware will be simulated & prototypes evaluated using real time hybrid computers & real time test facilities	o No evidence of predicting hardware life o Use of simulators & real time testing of prototypes o Philco some acceleration testing - Limited o Some use of construction analysis
ORG - LaRC RTOP- 125-25-07 TITLE - Electronic Components for Space Station/Base Long Lifetime Component Electronics CONTACTS - Duncan McIver LaRC Jim Taylor MSFC	o Develop new and improved electronic components o Demonstrate effective performance capability o Evaluation of experimental and prototype devices	o No evidence of predicted techniques o Not pursuing long life requirements (JPL is) o No indication of accelerated testing o No direct application to study primarily improving performance of component electroni[illegible] o Redundancy & maintenance concept of approach

APPENDIX C

This appendix lists in summary matrix form the technical papers and reports which were reviewed and evaluated.

The papers have been arranged in the following order based on major subject category:

(A) Testing

(B) Accelerated Life Testing

(C) Prediction Techniques

(D) General - this category covers such subjects as long life, aging of components, etc.

For each technical paper the following format was used to summarize the data: Paper title and source, objectives and findings, and an evaluation.

SUMMARY OF TECHNICAL PAPERS

MAJOR SUBJECT CATEGORY - TESTING

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Thermal Vacuum Testing for Spacecraft" by D. E. Anderson Arnold Engineering Development Center based on contract with ARO, Inc. at Symposium on Long Life Hardware for Space, March, 1969	o Considers thermal vacuum testing requirements - equipment, environment, R andD required and test requirements. o Recommends improved: o Solar Source Spectrum o Accelerated Testing to reduce test time o Contamination Control o Indicates spacecraft with systems test failure rates less than 1 in 10 vs. 1 to 5 without systems test o Estimates that 2% to 10% cost increase in added systems test may save 10%-20% in reduced failures o Necessity for total test program definition early o Recommends - One (1) significant test accurate thermal vacuum simulation	o No prediction techniques applicable. o Early test program definition. o Use of accelerated testing recommended. o Improved thermal vacuum simulation required. o Shorten Test Time - No new method suggested. o No Quantitative data to back-up systems test valve in reducing in-flight failure rates.
"Establishment of an Optimum Duration for Spacecraft Component Thermal Vacuum Tests" by W. L. Harvey (Martin) at ASTM/IES/AIAA Space Simulation Conference, Sept. 14-16, 1970	o Develop an approach to minimize or optimize thermal vacuum testing o Considers probable effects components and materials o Relates to outgassing rate time/temperature dependent o Proposes test cycle to reduce test duration	o No application to study o No mention of prediction techniques o No correlation between real-time test and thermal vacuum tests shorten duration o Outlines an approach to minimize thermal vacuum testing components

SUMMARY OF TECHNICAL PAPERS

MAJOR SUBJECT CATEGORY - TESTING

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Developing Empirical Guidelines for the Design of an Integrated Test Plan" By C. S. Bartholomew and J. R. Steding The Boeing Company At AIAA Test Effectiveness Conference April, 1970	o Points out importance Design in test plans o Measures degree of test to reduce risk o Based on-(Lunar Orbiter) problems (1400) during testing o Design errors predominate hardware problem o Thermal vacuum testing simulation most trouble o Qualification spacecraft lagged flight spacecraft in schedule - (8) problems occurred during spacecraft processing. o 58% hardware related faults attributed to design and were detected @ component level or below tests o Average incidence of problems/flight was the same during ground test and flight o Test schedule improvement - more test time in early program development	o No prediction technique applicable o Points out design as major contributor of faults and problems o Testing in early part of program@ component level and below required o Qualification spacecraft should be processed prior to flight spacecraft
"Application of Decision Theory to the Testing of Large Systems" By P. J. Wong (SRI) From IEEE Transactions on Aerospace and Electronic Systems, March, 1971	o Describes a method for determining priorities in allocating test resources among the various subsystems within a large system o The method encodes the decision maker's knowledge about the performance uncertainty and sensitivity for each subsystem o The emphasis in testing a large, complex system should be on testing subsystems rather than on testing the individual hardware components of the system	o Useful in reducing testing time through elimination of unnecessary tests o Presents a methodology for the allocation of test resources based on establishing an identifying test priorities

SUMMARY OF TECHNICAL PAPERS

MAJOR SUBJECT CATEGORY - TESTING

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION

"Goddard Space Flight Center Test Philosophy and Resultant Record"
By John H. Boeckel, A. R. Timmius, and K. R. Mercy
Goddard Space Flight Center
Greenbelt, Maryland
	o Presents Goodard Space Flight Center Philosophy
	o Defines goals of testing
	o Use of full systems testing under realistic conditions
	o Study results of using this philosophy on a sample of 24 spacecraft
	o Classified by in-house and out of house programs
	o Findings
	  o 17 Failures/spacecraft in-house
	  o 41 Failures/spacecraft out-house
		o Points out the problem of infant mortality rate to spacecraft failures
		o Demonstrates success of GSFC test philosophy
		o Emphasizes systems level testing for all types of spacecraft
		o To obtain longer life suggests simple design and more tailored testing
		o No prediction technique presented - no accelerated testing results presented

"Testing for Spacecraft Reliability - a Management Overview"
By A. M. Smith and W. R. Waltz
At Symposium on Long Life Hardware for Space,
MSFC, Huntsville, Alabama
March 17-19, 1969
	o Testing to find defects is recommended
	o Based on a study of failures from (5) spacecraft programs:
	  o Determined 50% defects required subsystem or system level assembly prior to occurance
	  o Design defects are about equal to number of defects attributed to manufacturing/test
		o Design defects account for 51% total flight defects for five (5) programs
		o Design defects normally occur @ higher levels of assembly
		o Points out the need for environmental testing
		o Passing of a test (qualification) does not qualify hardware for defect elimination
		o No prediction technique or use of acceleration testing was covered by this paper

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - Accelerated Testing.

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"A Survey of Spacecraft Testing as Applied to Long-Duration Space" by W. H. Douglas NASA (MSC) and G. W. Hewett (G. E.) NASA Study	o Study based on orbital missions 10 mos. or more. o Investigated test, accelerated life test (ALT), dynamic mission - equivalent (DME) and failure flow techniques. o Results used in AAP Command and Service Module. o Difficult to perform ALT Multimode. o Applied DME to Mariner MV 67 (Time Compression 86:1). o Failure Flow Analysis - investigate defects which escaped each successive screening during test.	o Application to Study: o ALT and DME for shortening test time. o Trade-Off test, analysis, and design o Use interface simulation devices. o Mr. Douglas was contacted on the above items and indicated that not much success He did stress limiting qualification testing and doing same sooner in test cycle.
"Study of Accelerated Testing Techniques" Chemical and Mechanical Systems Working Group for Accelerated Testing Techniques R. W. Bricker/SMD Chairman	o Conducted industry wide survey on current state of art accelerated testing. o Defined two (2) categories of ALT. o Over stressed o Time compressed o Application of ALT to level shown based on overstress testing. o Application proven for automobile industry	o Extensive study over (40) industries surveyed. o Results negative except a simple part or material level. o No evidence of correlation of accelerated test to real time test demonstrated with high level confidence.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - Accelerated Testing.

PAPER TITLE and SOURCE	*OBJECTIVE and FINDINGS*	*EVALUATION*
"A Systematic Approach to Accelerated Testing" by L. E. McCrary, M. I. Kania, and R. P. Bastian McDonnell Aircraft Company At ASTM/AIAA/IES 4th Space Simulation Conference Sept. 8-10, 1969	o Design short term test minimize long term testing. o Evaluated polymeric materials to determine Tmax (parameter Alt). o Establish procedure. o Technique: Constant Rate Rise (T) Note chemical reactions. o Monitor by thermogravimetric analysis and mass spectrometery.	o Application to study - Some correlation real time and accelerated test times shown. o *Demonstrated use of maximum intensi* of an accelerated parameter. o Demonstrated an approach to minimize amount of real time testing. o Difficult to select parameter to test and apply maximum intensity.
"Estimation from Accelerated Life Tests" by R. E. Barlow, E. M. Scheuer The Rand Corporation For United Stated Air Force Project Rand	o Presents a statistical technique for analyzing life test data from tests under overstress conditions. o This new technique assumes: (1) the failure rate is increasing on the average and (2) test items in the overstress environment tend to fail sooner than those in normal use. o Least squares estimators for the life distribution are developed, using both sets of data. o Procedures given to test the validity of the assumptions used.	o Application to fatigue life data. o Demonstrates use of acceleration testing to capacitors. o Develops computer programs for procedures proposed. o Recommends tests to verify assumptions.

SUMMARY OF TECHNICAL PAPERS

Major Category of Subject - Accelerated Testing

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION

"A Technique for Accelerated Life Testing"
by
E. Rabinowicz, R. H. McEntire and B. Shiralkar (MIT)
At ASME, Production Engineering Conference, Madison, Wis.
March 23-25, 1970
Research Sponsored by the United Aircraft Corp.
	o Use of mechanical property to estimate failure times.
	o Use reaction rate equation to predict useful life from mechanical data.
	o Data from four rest samples was used in Arrhenius plots to verify failure estimates.
	o Results between calculated and experimental data was very good.
		o Provides limited use of failure time predictions using reaction rate theory.
		o Shows application of theory to:
		  o Electric hand drills
		  o Light bulbs
		  o Ball bearings
		  o Electric motors
		o Verifies limited use of accelerated testing.

"Life Testing Using Continuous Acceleration"
by
E. Rabinowicz (MIT) and B. Shiralkar (GE)
At ASTM/IES/AIAA Space Simulation Conference, Sept. 14-16, 1970
Sponsored by United Aircraft Company.
	o To show life prediction thru continuous acceleration.
	o Apply normal stress, then accelerate at constant rate until failure.
	o Develop constant damage diagram
	  o Visual graph damage
	  o Estimate damage complex functions given failure times at various stress levels.
	o Application to light bulbs.
		o Application to study.
		o Proves limited use of accelerated testing using a constant damage diagram.
		o Determine empirically during test - increasing stress effects not necessary to know using this procedure.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - Prediction Techniques.

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Methods of Estimating the Two Parameters of a Life Distribution Characterized by a Linear Increasing Failure Rate, a+2bt" by G. R. Farmelo for the Naval Postgraduate School	o To develop and examine a life distribution function which is characterized by a linear increasing failure rate. o Can be used to describe failure data of equipment which ages with time or increased stress or both. o Identifies a variety of methods of estimating the parameters. o Simulated all failure data by use of a computer.	o Require a large sample size for any degree of prediction accuracy. o Past experience on components/materials required. o No application of this technique was noted.
"Feasibility Prediction" from Reliability Engineering by W. H. VonAlven of Arinc Research Corporation	o Feasibility Prediction is based on a design concept and its estimated complexity. o Complexity is measured in terms of the number of active element groups making up the system. o Based on the degree of complexity a "Ball Park" estimate can be made of the system reliability.	o Limited application to study. o Requires extensive history of previous failures. o Provides gross estimate based on experience used. o Confidence level of this technique low.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - Prediction Techniques

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Fracture Mechanics for Design and Failure Analysis" by V. Weiss (Syracuse U.) at Steel Founders Society of America 25th Annual Technical and Operating Conference, Cleveland, Ohio, Nov. 9-11, 1970 Work Sponsored by U.S. Navy Air Systems Command Contract No. N0019-70-C-0044	o Describes foundations of linear elastic fracture mechanics and develops equations. o Experimental determination of valid fracture toughness numbers. o Application to pressure vessel materials selection criteria demonstrated.	o Require post history of failures (crack growth rates). o Shows application to selection of materials. o Explains use of fracture mechanics in performing failure analysis(s).
"The Development of a Turbine Wheel Design Criterion Based Upon Fracture Mechanics" by D. E. Brandt (GE), at ASME, Gas Turbine Conference and Products Show, Houston, Texas, March 28-April 1, 1971	o To develop new design criterion based upon fracture mechanics. o Specifically treated are cracktip plastic zone corrections, proximity effects on a crack adjacent to a free surface, buried and surface cracks and subcritical crack growth. o Application of this criterion to past failure data verified.	o Identifies how failure points can be determined by applying critical stresses and plot against flaw size. o Demonstrates use of fracture mechanics in design selection.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - Prediction Technique.

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"A Basic Course in Fracture Mechanics, Assuring Component Life" by C. C. Osgood (RCA) for Machine Design, Sept. 2, 1971	o To illustrate use of Fracture Mechanics to proof testing of a pressure vessel. o The life of a pressure vessel under cyclic loading depends on the initial crack size in the vessel. o Several methods of using proof test data to determine life expectancy are described. o A Fracture Control Plan is shown for components of systems that must not fail.	o Limited application to study. o The Fracture Control Plan discussed provided useful guidelines for design of Pressure Vessel with no past experience. o Note: The curves used for the life prediction must be derived for the material used.
"Signature Analysis For Mechanical Devices" by L. F. Sturgeon (GE) at Symposium on Long Life Hardware for Space, NASA/ASQC Huntsville, Ala., March 17-19, 1971	o Illustrates use of mechanical signature analysis and wide range of application. o Requires knowledge of acoustic noise source and characteristics. o Sophisticated instrumentation techniques correlating the analytically derived signature are discussed.	o Signature analysis is a useful tool in predicting pending hardware failures. o Limited to predicting imminent failures as opposed to distant failures. o Requires degradation of speciman to predict failure points. o Application limited.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - Prediction Techniques.

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Signature Analysis - Non-Intrusive Techniques for Incipient Failure Identification Application to Bearings and Gears" by B. Weichbrodt and K. A. Smith (GE) At ASTM/IES/AIAA/NBS Space Simulation Conference Gaitherburg, Maryland, Sept. 14-16, 1970	o Use of non-intrusive techniques in incipient failure identification using acoustic and vibration signals generated by machinery under study. o Application to bearing and gear diagnosis Can be applied to most types of machinery. o Use in predicting life performance by testing only on the new products. o Useful in identifying specific failure modes by sutdying external effects. o This analysis technique successfully applied to machines which generate repetitive signatures.	o Some application to study. o Provides limited use in predicting life performance of mechanical assemblies. o Requires past history of failures and signatures. o Requires degradation of hardware - if no degradation application of signature cannot be made.
"Construction Analysis - A Tool To Evaluate Parts Integrity" by W. R. Rumza (Boeing) at Symposium on Long Life Hardware for Space, NASA/ASQC, Huntsville, Ala., March 17-19, 1971	o Construction analysis is defined as the detail analysis of parts for the purpose of identifying part design, process and workmanship defects. o Presents some specific design advantages in that it actually changes hardware quality by identifying and demanding the removal of defects. o Construction analysis can be used to: a) Identify the weak points in part design or manufacturing process. b) Identify stresses which will accelerate the weak points. c) Define the design margin of parts. d) Evaluate the integrity and compatability of materials used in a device. e) Monitor vendor production.	o Does not predict or determine hardware life. o Use as an analysis tool in determining why parts failed. o No application demonstrated.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Future Needs and Trade-offs for Long Life Spacecraft" by R. W. Slocum, E. I. Roberts and R. J. Smith (Aerospace Corp.)	o Discuss Spacecraft Systems Performance versus Cost. o Discuss Reliability Tradeoffs in developing the Initial Defense Communication Satellite Program (IDCSP). o Identifies what a specification for the life of spacecraft must consider. o Presents means for assuring reliability and quality assurance.	o Identifies principal items requiring attention for cost effectiveness. o Does not identify prediction techniques o use of accelerated life testing.
"The Long-Life Spacecraft Problem" by R. W. Burrows (Martin) at AIAA 4th Annual Meeting and Technical Display, Anaheim, Calif., Oct. 23-27, 1967	o To summarize selected investigations directed toward achieving higher reliability and longer life in complex spacecraft. o In a given program cost and schedule environment, mechanical equipment is less reliable because design margins are not as well established. o Several findings: 1) Several major post-development problems could have been detected much earlier had the development test hardware been more extensively instrumented. 2) Several major problems were the result of inaccurate predictions, analyses and testing for the transient environments. 3) Structural assemblies fabricated from non-metallic materials have created major program problems.	o Additional Testing is necessary to verify design margin early in program. o Identifies and supports other findings on testing to the actual environmental conditions. o Does not attempt to predict hardware life.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Voyger's Most Challenging System Requirements" by B. H. Caldwell (GE) at 6th Reliability and Maintainability Conference, July 1967	o Findings from GE study on spacecraft failures: 1) One-third of the flight failures were in simple components. 2) Electromechanical components had a failure rate twice that of electronic components. 3) "Off-the-Shelf" components failed almost twice as frequently as those designed specifically for the program in which they were used. 4) Design Deficiencies account for about half of all flight failures. 5) Ignorance of the Space environment was an insignificant cause of flight failures. 6) Infant Mortality was a serious problem.	o Supports previous findings of spacecraft failure. o Item (5) is in contrast to several other findings. o Design defects account for 50% failures but no reason is given for why.
"Systems Life Time Considerations" by C. L. Gould and G. S. Canetti (NAR) at AIAA 6th Annual Meeting and Technical Display Oct. 20-24, 1969	o Objective - Discuss Requirements imposed on design and test long-life subsystems. o Emphasizes in-flight maintenance and in-flight checkout. o Space Station - Ground Support Development Testing. o Analytical effort to determine environments subsystems in operating. o Maintainability alleviates problem with 80% confident wear-out. o Min. Qual test duration equal initial resupply time. o Reduddant equipment and back-up operational modes.	o Estimation of reactor life times based on works of atomic international. o Identifies types of parts to use and those not to use (high cyclic items). o Implies real life testing up to 6 mos. (1st re-supply time) as a minimum. o No prediction techniques identified. o Suggests and points out the need for major analytical efforts required.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"An Engineering Approach to Long Life Complex Space Systems" by Dr. B. H. Caldwell (GE)	o Determine if there are any systematic or generic problems existing in complex spacecraft. o A review of planned life vs. achieved life causes used physics of failure. o Developed failure source data. o 50% failures in flight caused by inadequate design. o 20% by mfg., 5% test, and 20% random failures.	o No application of prediction technique. o Supports previous findings on causes of failures of light spacecraft. o Points out improved criteria for redundancy required.

"Study of Reliability Data From In-Flight Spacecraft"
PRC R-948
March 1967
 	
by
E. E. Beam, E. Bloomquiste and E. W. Kimball
	o Surveyed over 255 launches from 32 Space Programs.
	o Objective to update reliability data based on the above operational experience.
	o Results indicated that:
	  o 20% occurred no reason
	  o 35% assignable causes
	  o 45% no conclusions
	o Of the 35% assignable causes
	  o 60% attributed to design
	  o 20% attributed to mfg.
	  o 10% attributed to operation
	  o 10% attributed to other
		o Identifies areas that contribute to defec
		o Supports previous findings on failure causes.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Methodology to Define, Monitor and Control Life-Limited Components During Storage" by J. C. DuBusson (Martin Corp.) for NASA-MSFC	o Determine technical methods limited life of components in storage. o Extensive survey of Gov't and industry to obtain data. o Seven (7) methods are presented to determine, extend and/or recertify life of existing components. o Prevent excessive replacement frequencies due to pessimistic life estimates. o Prevent deficient service life and reliability due to optimistic life estimates.	o Of 40 org. visited no one would extend life of component based on analysis alone. o Real-time testing most accepted. o Accelerated testing not too acceptable low confidence in correlation and selection of environment and stresses. o Assignment of component life conservative rather than realistic max. life.
"Dormant Operating and Storage Effects on Electronic Equipment and Part Reliability" by D. F. Cottrell, T. R. Gagner and E. W. Kimball Martin Marietta Corp. for Rome Air Development Center RADC-TR-G7-307 July 1967.	o Survey industry for storage failure rate data. o Develop quantitative data to define reliability of electronic equipment and parts when subjected to dormant and storage stresses.	o Establish criteria for new equipment to withstand long life storage. o No prediction technique other than establishing MTBF for selected hardware.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Use of the Ben Franklin Submergible as a Space Station Simulator" by M. J. Fergurson (Grumman) C. B. May (NASA-MSFC) at ASTM/IES/AIAA Space Simulation Conference, Sept. 14-16, 1970 Study sponsored by NASA/MSFC	o Use of the Ben Franklin Submergible as a Space Station analog. o Identifies real time maintenance func tions to predicted times. o Indicates automatic detection systems will be required. o Recommends expansion to further develop technology and to support skylab space station and space base programs.	o No prediction of hardware life. o Application to maintenance predictability tasks for manned missions defines required times to perform on board maintenance functions.
"Microcircuits, 10-15 years Space Mission" by M. F. Nowakowski and F. Villella	o Discusses necessary technology to determine if microcircuits will satisfy performance requirements for 10-15 year space mission. o Discusses large and medium scale integration LSI and MSI and the advantages of each. o Discusses required testing, use of redundancy, and the in process controls required. o Proposes certified lines in manufacturing microcircuits. o Estimates 7 years required to verify 10-15 years life if accelerated testing is not developed.	o Suggests improvement in accelerated testing must be development. o Proposes advanced state of art in development of LSI and MSI. o No prediction techniques proposed. o Improved confidence levels in LSI and MSI are required to achieve long life 10-15 years.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Reliability in Long-Life Missions" by R. F. Draper (JPL) at AIAA 7th Annual Meeting and Technical Display, Houston, Tex., Oct. 19-22, 1970 In addition, the following papers relate to the subject. "Exploration of the Outer Planets" by J. E. Long presented at the AIAA 7th Annual Meeting and Display Houston, Tex., Oct. 14-22, 1970 "System Design of an Outer Planet Spacecraft for Long-Life Reliability" by R. R. Bowman presented at the AIAA Space Systems Meeting, Denver, Colo., July 19-20, 1971 (Continued)	o Discusses Reliability approach to the Grand Tour Mission. o Design approaches chosen for reliability include utilization of a self-test and repair computer and elimination of single point failure allowing partial survival capability. o Using the two longest mission phases will allow an estimation of the system reliability to be made mathmatically at any point in time using the exponential failure distribution. o In all systems, decisions to allocate resources for redundant units are dependent on the mathematical estimation of reliability based on piece-part failure rates and failure mode effects and criticality analysis. o In a complex electronic system where the probability of failure is approximately the same for all intervals, the system displays a constant failure rate which may be used as a predictor of reliability during a specified interval. o Those parts with no detectable failure mechanisms are subjected to qualification testing to verify the inherent reliability under selected accelerated environments and simulated flight conditions.	o This évaluation includes a summary of (15) papers on the (TOP'S) "Therm electric Outer Planetary Spacecraft" Program. o Extensive use of past experience. o Selection of parts based on flight proven or highly tested certified new parts. o Selective redundancy and alternate mode of operation. o In flight checkout and maintenance advance state of art.

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General (Continued)

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"To the Outer Planets", Astronautics and Aeronautics Vol. 7, No. 6 by J. E. Long June 1969	See previous page.	See previous page.
"TOPS - Outward Bound" Astronautics and Aeronautics by R. R. McDonald and W. S. Shipley September 1970	See previous page.	See previous page.
"Why Go to the Outer Planets?" by R. L. Newburn, Jr., W. S. McDonald, R. L. Gasteiger and A. R. Eisenman ibid	See previous page.	See previous page.
"TOPS Spacecraft and the Missions" by E. L. Divita, R. F. Draper, H. K. Frewing and W. Stavio ibid	See previous page.	See previous page.
"Data Subsystems for 12-Year Missions" by B. D. Martin ibid	See previous page.	See previous page.

(Continued)

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General (Continued)

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"Communicating with Outer-Planet Spacecraft" by L. A. Couvillon, Jr., J. P. Eyraud, A. W. Kermode, L. B. Paulos and K. E. Woo ibid	See previous page.	See previous page.
"Electronic Parts for Long-Duration Missions" by T. R. Gavin, W. H. Lockyear ibid	See previous page.	See previous page.
"Navigating the Grand Tours" by J. E. Ball and T. C. Duxbury ibid	See previous page.	See previous page.
"TOPS Spacecraft Propulsion Subsystem" by L. E. Baughman ibid	See previous page.	See previous page.
"Attitude Control for TOPS" by W. E. Dorroh, Jr. ibid	See previous page.	See previous page.
(Continued)		

SUMMARY OF TECHNICAL PAPERS

Major Subject Category - General (Continued)

PAPER TITLE and SOURCE	OBJECTIVE and FINDINGS	EVALUATION
"TOPS: Solar-Independent Power" by H. M. Wick ibid	See previous page.	See previous page.
"Structuring the Outer-Planet Spacecraft" by R. H. Dawe, J. G. Fisher, M. B. Gram, J. O. Lonborg J. W. Smith and D. J. Starkey ibid	See previous page.	See previous page.

APPENDIX D

REFERENCES

This appendix is a reference of source data used during this study effort. It is arranged in three (3) sections; section (3) has several sub-sections as shown below.

Section 1	Papers on Programs
Section 2	Listing of Research & Technology Operating Plans (RTOP's) Used
Section 3	Papers are arranged by:

- (a) Testing
- (b) Accelerated Testing
- (c) Prediction Techniques
- (d) General

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SECTION 1

PAPERS ON PROGRAMS

PROGRAM	TITLE
NIMBUS II	Long Life Design Features of the Nimbus II Meteorological Observatory, C. Sharp, General Electric Company, Re-Entry Systems, Phila., Penn. (Feb. 5, 1968)
SERT II	Description of SERT II Spacecraft and Mission by Richard G. Goldman, G. S. Gurski, and W. H. Hawersaat, Lewis Research Center, No. 4, 1970
SERT II	Qualification and Testing of an Electrically Propelled Spacecraft - SERT II, by J. F. DePauw and L. R. Ignacek, Lewis Research Center, Nov. 4, 1970
TIROS & ESSA	TIROS and ESSA Satellite Design and Test for Mission Success by A. Schnapf, Tiros/Tos Project Manager
TIROS	TIROS: A Case History in Reliability by R. Hoedemaker, E. Mowle, and G. Gordan, RCA Astro-Electronics Div., Princeton, New Jersey
Submarine Telephone Cables	Reliable Underwater Cable Components, D. Feldman, M. G. Lesh, and W. McMahon, Bell Labs., New Jersey
Submarine Telephone Cables	Submarine Telephone Cables, IEEE Spectrum, May, 1965, by E. T. Mottram
Nuclear Power Development SNAP Program	Space Nuclear Power Developments in the 1960-1980 Decades by A. M. Martin, Space Systems Programs, Atomics International Division, NAR, Canoga Park, Calif.

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SECTION 1

PAPERS ON PROGRAMS

Thermoelectric Outer Planets Spacecraft, Industry Briefing, Sept. 21, 1971

Thermoelectric Outer Planets Spacecraft, Industry Briefing, Sept. 27, 1971

Thermoelectric Outer Planets Spacecraft, Industry Briefing, Sept. 28, 1971

Thermoelectric Outer Planets Spacecraft, Industry Briefing, Sept. 29, 1971

Thermoelectric Outer Planets Spacecraft, Industry Briefing, Sept. 30, 1971

Thermoelectric Outer Planets Spacecraft, Industry Briefing, Oct. 1, 1971

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SECTION 2

RESEARCH & TECHNOLOGY OPERATING PLANS (RTOP'S)

ORG.	RTOP NUMBER	TITLE	MONITOR TELEPHONE
JPL	186-68-54	Guidance & Control Technology for Outer Planet Missions 8 - 12 Years Operation G & C Improved Reliability	McDonald, R.R. 213-354-6186
JPL	186-68-53	Telecommunications Technology for Outer Planet Missions Part of TOPS Mars 1 Year - Grand Tour 11 Years Improve Operating Life.	McDonald, R.R. 213-354-6186
JPL	120-34-10	Planetary Batteries (7 to 12 Years)	Briglio, A. 213-354-6137
JPL	120-27-41	RTG Support for Deep Space Advanced Spacecraft	Briglio, A. 213-354-6137
JPL	120-26-21	Advanced Pulsed Discharge Thruster 10-12 Years Operational Life	Briglio, A. 213-354-6137
JPL	125-25-20	Extreme Temperatures and Life Test Requirements for Electronics Determine Qual & Verification Techniques for Accelerated Life Tests of Electronic Assemblies (See JPL Report JPL 701-29 ETR)	Powell, 213-354-6586
JPL	125-21-09	Microwave Deep Space Communication and Tracking Relates to Manned Space Station Requirements Long Life-Reference RTOP 125-21-18 Microwave Communication for Manned Space Station	Powell, 213-354-6586
JPL	125-23-12	Advanced Digital Data System for Deep Space Grand Tour (Guarantee performance 10 - 20 Years)	Powell, 213-354-6586
JPL	125-23-17	Fault Tolerant Computer for the Space Station Survive in excess of 10 year life a digital computer with general capabilities	Powell, 213-354-6586
JPL	125-24-13	Advanced Imaging Systems Technology Provide for 12 year mission high image 1000 times Pluto vs that at Mars.	Powell, 213-354-6586

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SECTION 2

RESEARCH & TECHNOLOGY OPERATING PLANS (RTOP'S)

JPL	186-68-50	Advanced System Technology/Thermo-electric Outer Planet Spacecraft TOPS design development long life assessment. Includes fabrication	Saipley, W.S. 213-354-4450
MSFC	908-51-02	Space Station Thermal Control Coatings & polymers passive & active thermal control systems. Space Station	Miles, G. 205-453-1120
MSFC	908-51-04	Space Station Attitude Control Pro-pulsion System - Long Duration, min. refurbishment and resupply	Miles, G. 205-453-1120
MSFC	908-51-08	Stabilization & Control Long Life Control Moment Gyro Development	Miles, G. 205-453-1120
MSFC	908-51-18	Checkout Deep Space Space Station Two approaches paint & gas/tape.	Miles, G. 205-453-1120
MSFC	720-02-12	Polymers for Fuel Tank Sealants Predict service life of polymers sealant compositions.	Miles, G. 205-453-1120
MSFC	129-03-32	Bearing & Lubricant Technology for Space Applications Long Lifetime Lubricants	Miles, G. 205-453-1120
MSC	125-23-14	Space Station - Onboard Checkout Automated Techniques for assessing subsystem performance for maintenance provisions. Reference 125-23-15 Space Station - Central Multi-Processor and Man/Machine Techniques Hughes MSC	Hughes, J.F. MSC 713-483-4162
LRC	128-32-61	Pyrotechnic Systems Engineering Long Duration required for space station	Hughes, J.F. MSC 713-483-4162
LRC	125-19-25	Control Components and Subsystem Research and Technology for Space Station/Base (Long Life Study)	Nelson, C.H. 703-827-3285
LRC	125-25-07	Electronic Components for Space Station/Base Long Lifetime Component Electronics	Nelson, C.H. 703-827-3285

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SECTION 2

RESEARCH & TECHNOLOGY OPERATING PLANS (RTOP'S)

LRC	129-03-32	Fatigue, Fracture and Life Prediction Predict Life of Specimens - Component Detail	Ault, G.M. 216-433-4000
AMES	129-03-42	Physics & Chemistry of Solids - Increase understanding of environmental effects to degradation of materials. Note: Hdqts. & LRC conducting studies using same RTOP No.	Goodwin 415-961-2265

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SECTION 3

(a) TESTING

Anderson, D. E., Arnold Engineering Development Center based on contract with ARO, Inc., "Thermal Vacuum Testing for Spacecraft," presented at the Symposium on Long Life Hardware for Space, March, 1969

Harvey, W. L. (Martin), "Establishment of an Optimum Duration for Spacecraft Component Thermal Vacuum Tests," presented at the ASTM/IES/AIAA Space Simulation Conference, Sept. 14-16, 1970

Bartholomew, C. S. (Boeing) and Steding, J. R., "Developing Empirical Guidelines for the Design of an Integrated Test Plan," presented at the AIAA Test Effectiveness Conference, April, 1970

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(b) ACCELERATED TESTING

Douglas, W. H. (NASA/MSC), and Hewett, G. W. (G.E.), "A Study of Spacecraft Testing as Applied to Long-Duration Space," NASA Study

Bricker, R. W./SMD-MSC-Chairman, "Study of Accelerated Life Testing," March, 1970

McCrary, L. E., Kania, M. I., and Bastian, R. P. (McDonnell), "A Systematic Approach to Accelerated Life Testing," presented at the ASTM/AIAA/IES 4th Space Simulation Conference, Sept. 8-10, 1969

Barlow, R. E., and Scheuer, E. M. (Rand Corp.), "Estimation from Accelerated Life Tests" for United States Air Force Project Rand.

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Rabinowicz, E., McEntire, R. H., and Shiralkar, B. (MIT), "A Technique for Accelerated Life Testing," presented at the ASME, Production Engineering Conference, Madison, Wis., March 23-25, 1970 Research Sponsored by the United Aircraft Corp.

Rabinowicz, E., and Shiralkar, B., "Life Testing Using Continuous Acceleration," presented at ASTM/IES/AIAA Space Simulation Conference, Sept. 14-16, 1970. Research Sponsored by United Aircraft Corp.

(c) PREDICTION TECHNIQUES

Farmelo, G. R., "Methods of Estimating the Two Parameters of a Life Distribution Characterized by a Linear Increasing Failure Rate, a +2bt," for the Naval Postgraduate School

Von Alven, W. H. of Arinc Research Corporation, "Feasibility Prediction," from Reliability Engineering

Weiss, V. (Syracuse U.), "Fracture Mechanics for Design and Failure Analysis," presented at the Steel Founders Society of America 25th Annual Technical and Operating Conference, Cleveland, Ohio, Nov. 9-11, 1970. Work Sponsored by U. S. Navy Air Systems Command, Contract No. N00019-70-C-0044.

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SECTION 3

(d) GENERAL

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