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A Thermal Vacuum Test Optimization Procedure

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SUMMARY

An analytical model has been developed that can be used to establish certain parameters of a thermal vacuum environmental test program based on an optimization of program costs. This model is in the form of a computer program that interacts with a user insofar as the input of certain parameters. The program provides the user a list of pertinent information regarding an optimized test program and graphs of some of the parameters.

The model is a first attempt in this area and includes numerous simplifications. For instance, it deals only with the first flight of a unit and also is limited as to the size of the facilities in which tests take place. No solar simulation or temperature cycling testing is included.

The model appears useful as a general guide and provides a way for extrapolating past performance to future missions.

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1. INTRODUCTION

The development of a thermal vacuum test program* for spacecraft and their component parts has been based largely on subjective judgement. This judgement is shaped by the experiences of the particular test program designer as modified by influences such as the availability of time and funding and the perceived importance of the mission. The intent of this study was to develop a more objective approach to the design of a thermal vacuum test program.

Because of the wide variety of requirements, materials, fabrication techniques, etc. that go into the make-up of a spacecraft, it was considered impractical (certainly in this first attempt) to approach the problem of defining the effects of a thermal vacuum test program and operations in orbit on a microscopic or piece-part level (e.g., a resistor or a transistor). Instead it was decided to proceed on a macroscopic level; that is, how do components such as transmitters and higher levels of assembly act as a group under the thermal vacuum environment.

This approach was taken with the recognition that the group of all spacecraft components is far from homogeneous in their reaction to stress. (Eventually, it is hoped that finer grained models for describing component performance can be developed to account for differences among types of components.) The same assumption, having the same shortcomings, was applied to the spacecraft system level of assembly; that is, all spacecraft were taken as constituting a homogeneous group. No intermediate level of assembly was designated (e.g., sub-assembly) because of the difficulty in assigning specific items to the groups and in collecting data bases into the different groupings.

*The thermal vacuum test program is a portion of the overall environmental test program to which spacecraft equipment is subjected in order to demonstrate its preparedness to perform in orbit. During the thermal vacuum test program, the equipment is exposed to vacuum and temperature conditions related to those that will be experienced in orbit and operated in a simulation of the mission. The performance of the equipment under this environment is used to assess its readiness.

The concept of reliability growth, that is, the decrease in component failure rate with time, was selected to describe the basic changes in the performance of items. This reliability growth is modified by the environment under which the item is operating. A decreasing component failure rate has previously been demonstrated (Ref. 1); that is, on the average, spacecraft in test and in orbit exhibit a decreasing failure rate (up to some point that may be described as wearout) rather than the classical constant failure rate.

Using concepts such as failure flow analysis (as in Ref. 17), one can hypothesize the existence of a relationship between the performance of equipment during component level test and system level test and between system level test and orbital operation. Ref. 1 describes mathematical models that simulate spacecraft performance during system test and during orbital operation. Given these relationships, one can predict the effect of a test program upon the performance of a payload in orbit.

This study has taken the single criterion of cost as the parameter upon which optimization is based. (All costs used in this study are normalized to 1978 dollars.) Only certain costs were considered relevant in this study; they include launch costs, recurring payload costs (those needed to produce a second, identical payload), and test costs. In order to utilize these costs in an optimization scheme that considers the performance of the item during its mission, the concept of "availability" was introduced.

This concept, described in Refs. 2 and 3, assigns a value to the performance of a spacecraft that can relate its capability after some number of malfunctions to its capability had there been no malfunctions. Using functions of availability and cost, a "lost value", or money lost because of less than perfect performance, was developed and used to determine the optimum program; the lowest lost value indicates the optimum program of a group that is investigated.

Because of the availability of a desktop calculator (Hewlett Packard Model 9831A) plus a few peripheral pieces of equipment and the expected simplicity of the program that would be generated during this study, it was decided to develop the program using a modified form of BASIC, a computer language compatible with that machine.

Section 2 provides a continuing thread describing the development of various areas in this study. Use is made of Appendices to provide the detailed background in these areas.

2. DEVELOPMENT OF THE THERMAL VACUUM TEST OPTIMIZATION MODEL

As noted in Section 1 of this report, previous studies have been conducted into the performance of spacecraft during test and in orbit. These studies (Ref. 1, 4, 5, 6) grouped the spacecraft into a large class and dealt with the class as being homogeneous. These studies, while providing analytical models describing performance during system test and during orbital life, described their performance on a component basis.* However, none of these studies investigated the performance of the spacecraft components when they were tested on an individual (or component level) basis.

This study conceived of decreasing failure rate as a process that could be intercepted at the component level and followed on through into the mission. Also, the optimization process was to include both component and system level testing. Therefore it became necessary to develop an analytical model that could be used to describe the reliability growth of equipment during the component level test phase.

Data from 109 component level tests were selected from files at the Goddard Space Flight Center (GSFC). No specific effort was made to randomize the selection of these data; the major objectives were to determine whether the available data was usable in a study such as this and, if so, using this small sample, to develop a reasonable analytical model to describe the component level test program.

Appendix A contains an example of this data and the methods of and programs for analyzing it. The data are presented as they are retained in the computerized files except that information identifying specific projects or dates has been omitted.

*The term "component" is defined in Appendix B.

It was recognized that the GSFC data provided a unique opportunity to investigate not only reliability growth as a function of time, but also to investigate the effects of the environmental factors operating on the item under test. The specific factors of interest were the temperatures to which the items were exposed and the periodicity of the temperature applications. Appendices B and C respectively deal with the development of those portions of the analytical model that deal with these two parameters.

Appendix D describes the development of the analytical model used in describing the process of reliability growth through the component test phase, the system test phase, and during the orbital mission.

A basic problem inherent to the development of a model that performs optimizations based on cost is the establishment of parameters that describe the way in which costs are affected by the other parameters. In the development of this model, the costs themselves that were considered relevant were: (a) the cost of the launch, (b) the recurring costs of the payload [illegible], the cost to produce a second one), and (c) the thermal vacuum test costs.

Launch costs were considered as those recurring costs associated with placing the payload in orbit. Appendix E provides a description of the methods used in establishing these costs. Many simplifications were employed in order not to unduly delay the completion of the overall model; most of the major costs are believed included. The launch cost model contains options that permit the user to consider an expendable launch vehicle (a Scout, a 2900 series Delta, or a 3900 series Delta) or the Space Transportation System with a number of the options it provides.

It can be seen that an important parameter in establishing launch costs is payload weight. The program provides for a user input as to payload weight. However, if the user is unable to provide this information, a weight is estimated internally by the program based on the number of components (as described in Appendix D), the type of mission (free-flier or not), and the type of instrument involved. This estimating feature was particularly helpful in developing the program. Appendix F describes the approach used in estimating the total payload weight.

As noted previously, the cost of the payload plays a part in the cost optimization equation. This cost is requested of the user. If the value is unknown, the program will internally generate an estimated cost based on payload weight, whether it is or is not a free flier, and the type of instrument system involved. A more complete explanation of the process is contained in Appendix G.

The last cost item that is included in the optimization equation is that of the tests costs. Test costs were derived from data obtained from aerospace and government sources. Some of the data was considered sensitive insofar as they indicated management practices of the corporations. Since it was desired that this report be distributed without restriction, the details of the evaluations of this test cost are omitted from this report. They will be included in a separate document. Appendix H provides information as to the final figures derived from the amalgamation of the industry and government data. As such, it is considered not to present any information that an industry source would be reluctant to divulge to other corporations. It does present cost figures for component testing, system level testing, and repairs including the algorithms used within the program.

One of the key items needed in the development of a cost optimization model was a parameter that could be used to relate the performance of an item in orbit to cost. The concept of a lost value, i.e., that money that would be lost because of less than perfect performance, is one that lends itself to an optimization concept. While costs themselves can be defined (to within some degree of accuracy), the selection of a parameter that describes the performance of an item in a general way is subject to a good deal of question.

In this study, it was decided to use the concept of availability as described in Ref. 2 and 3. Essentially, this concept involves a determination of the remaining capability of an item to perform its mission after having undergone some number of malfunctions. The basic parameter that is derived is that of "instantaneous availability" as described in Ref. 2 and 3; it is the percentage of the initial capability of the equipment to perform its mission that remains at some point in time after a number of failures. From the instantaneous availability, A, is derived an average availability, $\overline{A}$, that is considered a measure of the accomplishment of the mission. Appendix I describes the development of the availability parameters. It also contains graphs showing how they vary with mission parameters and a description of an application.

Having developed cost data and a parameter that can describe the success of a mission, it becomes possible to derive an expression that may be minimized or maximized in order to obtain an optimum result. The expression used in this model is:

$$\text{Lost Value} = (1 - \overline{A})\left(\text{Launch Costs} + \frac{\text{Recurring Payload Costs}}{\text{Number of Missions}}\right) + \text{Component Test Costs} + \text{System Test Costs.} \qquad (1)$$

In operation the model iterates through a number of test programs including certain user defined inputs and designates that combinations of parameters that minimizes the lost value. If a user designates a desired average availability, $\overline{A}$, this becomes a fixed parameter. If this is not designated, the iteration process includes a determination of $\overline{A}$ and again determines a minimum lost value with a corresponding $\overline{A}$.

The model currently is applicable only to single flight missions although it does treat reusable payloads to the extent that this cost is ammortized over the number of flights. Similarly, another current shortcoming of the model is that refurbishment costs are not included; this is not seen as a problem since the model does deal only with the first flight where no refurbishment is involved. It is apparent that a very important extension of the model will be to extend the availability concept to multiple flights of the same payload so as to account for this very important STS mode of operation.

Appendix J presents information pertaining to the computer program itself including a listing of the program. The listing is heavily annotated with remark statements to assist a user; it could be significantly shortened merely by removing these statements. In addition, Appendix J contains a large number of trial cases conducted using the model. These are included to demonstrate model operation and to provide information upon which some general conclusions may be based.

3. CONCLUSIONS AND REMARKS

The analytical model that has been developed is capable of selecting a thermal vacuum test program (from among a number of alternate approaches) that results in an optimized cost function to a user. The model is extremely flexible in that it allows a user to investigate programs in which the test program parameters and mission parameters are variable.

The user is required to define the number of components that comprise the payload. Other parameters (such as weight and cost) can be entered by the user or he may elect to allow the model to determine these parameters. The user may also select from a number of launch options.

The model is restricted in a number of aspects; however, these restrictions are due not to the implicit design of the model but rather are due to the desire to complete a workable analytical model in a timely manner. For instance, only three expendable launch vehicles are included; there is no technical reason why all expendable launch vehicles could not be included.

The model is based in large part on assumptions of average component performance. Therefore, it is best suited to be used as a guide rather than for developing hard and fast programs. In time, the model could be greatly sophisticated to involve much less averaging.

No sensitivity studies have been conducted to define those areas in which added work would provide the greatest yield. In addition, the statistical limits of the assumptions have also not been established.

Costs of tests are based on extremely limited data. It is hoped that this data can be improved by discussions with readers of this report. Costs of the payload are based on models developed by others. The TVTO model, for expediency, has used these other models in simplified form. Costs for the launch vehicles are based on information of a preliminary nature.

However, with all of these shortcomings, given a user defined average availability, the optimum programs selected by the analytical model appear not unreasonable. When the model is allowed to select a test program without the restriction of a fixed average availability, the optimum program results in an unexpectedly long test. While at first one might choose to disregard this solution, it is arrived at in exactly the same manner that solutions resulting from a user defined average availability are arrived at, and those yield "reasonable" results. It may then be that we must rethink our test policies and to understand what, in fact, the model indicates.

Because of the intimate relationship between test temperature and test profile within the algorithm, it is virtually impossible to predict the optimum program. However, it appears possible to make certain generalities. Most evident is the trend of decreased costs arising from extended temperature limits. Since the model assumes that no new failure modes are introduced by extending the temperature limits, one might expect this result. A user would then be advised to select the optimum temperature by selecting the widest temperature range over which the equipment is capable of operating.

The effect of the ratio of time spent during transition to time spent during dwell is not clear; however, it does appear from the case shown in Appendix J that long transition times to not yield optimum results. The case shown in Appendix J and other runs that were conducted indicate that ratios of transition to dwell times of 1:2 are close to optimum cases. However, the better case as seen in Appendix J was a ratio of 1:11.

The model does indicate that with the 1:2 ratio, the shorter the period, the less the lost value. The optimum test duration must be established by use of the model; it is impossible to predict the optimum program by inspection.

It appears that programs having a low cost result in a no-test option or a component-test-only option. The trade-off points have not as yet been established since they depend not only on the cost but on the desired availability (plus, of course, the many other variables such as component count).

The concept of availability appears to provide a way for a user to establish performance criteria that can be translated into a function usable by an analytical model.

4. RECOMMENDATIONS

Throughout the development of this model, areas for improvement became evident constantly; only the desire to reach some fixed point in time with a stable working model prevented pursuing these areas. The following is a list of some of the more important areas that should be developed.

(1) Establish the Statistical Correlation Between Test and Orbital Performance

The current analytical model is based on the assumption that payload performance during test is related to its performance in orbit. This assumption has been used previously (Ref. 17 et al.). However, this hypothesis needs to be verified by determining the correlation between system test and orbital performance. It is believed that sufficient data exists to define that correlation. It is believed that it would be impractical to attempt a correlation between component and system performance based on past data because of the difficulty in establishing the history of individual components.

(2) Establish the Uncertainties and Sensitivities Within the Model

The variances or confidence intervals need to be established in many areas (e.g., the reliability growth expressions) as well as determining the sensitivity of the model to various parameters.

(3) Improve the Data Base

One of the most difficult aspects of the study has been to relate the model to past performance. In great part, this is because the raw data base has not been recorded in a systematic manner; every program conducts its business its own way. In many cases, the data base was developed by discussions with individuals who were associated with a program and who were asked to recall some item from memory.

Two areas in particular need improvement. First, the data base on component testing needs to be greatly expanded. The current conclusions based on the existing base (Appendix

A) are grounded on very tenuous relationships. Many more tests need to be analyzed to verify effects of the test parameters.

Secondly, the cost of testing needs to be better defined. Current accounting practices and work breakdown structures do not permit the separation of test from other costs, most notably from integration. In great part, the current model is based on data generated from estimates as to the way in which past costs should be allocated.

Consideration must be given to the need for a data base and a systematic data collection program. Old data needs to be recorded in an appropriate format and new data continually added to maintain a record of the most recent trends.

(4) Revise the Initial Failure Rates for Follow-On Units

While the cost algorithm currently contains data for follow-on units (i.e., those where a similar payload has previously been flown), the decreasing failure rate model does not. There is data from a number of programs that indicates that the failure rate for second, third, etc., similar models (up to but not including the last of a series) decreases. This change in failure rate needs to be accounted for.

(5) Include the Effect of Multiple Flights

The current optimization algorithm considers only the first mission and assumes that the availability is required for this first mission. It would be more in keeping with the STS concept to account for those cases where multiple flights are used to accomplish a mission objective. Two other factors would enter the algorithm. One is that the mission itself, even though it might not be a success, would contribute to the reliability growth of the payload and this would have to be factored into the test program. The other is that the cost of repair and refurbishment would have to be factored into the model.

(6) Introduce Greater Sophistication into the STS Cost Portion

The present model is greatly simplified insofar as establishing STS costs. For instance, only the costs that very evidently exceed $200,000 (e.g., OMS kits) have been included. Less apparent costs – but ones that may far exceed $200,000 such as the cost for additional power – should be included. An opposite approach using a user provided cost input, is an alternative.

(7) Develop Marching Army Costs

The "Marching Army" costs (Appendix H) are based on very gross assumptions. It would appear relatively simple to develop more appropriate costs based on existing models for program cost as a function of time.

(8) Devise a "Finer-Grained" Model

This recommendation cuts across a number of areas and includes effort to do such things as establish component test costs for various sized chambers, adding a smaller chamber (e.g., 7 ft. x 8 ft.) to the system test group, break components into classes (e.g., experiment vs. non-experiment related or electronic, electro-mechanical, mechanical, etc.) and break payloads into various classes. This would also result in a significant change to the model itself since, with finer grained identification of components for instance, one would follow the effect of degradation in a particular area to its impact on the mission. It could result in the model treating the payload as a combination of series and parallel paths as is done in Ref. 16. It would provide a way to better tailor the test plan to a specific program.

(9) Use the Analytical Model Form for the Space Environment

The analytical model currently takes the space performance of the payload as being an average of the spacecraft in the data base. It is a relatively simple matter to input the mission values for period and temperature to more closely simulate the performance of a particular payload that is under study.

(10) The Availability Concept Should be a Subject for Further Study

As part of Appendix I, it was shown how the concept of availability could fit actual mission profile requirements. It is believed that this can be further refined to become a useful tool in itself in the development of other project criteria.

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APPENDIX A

GSFC DATA BASE, 109 COMPONENT LEVEL TESTS

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GSFC DATA BASE, 109 COMPONENT LEVEL TESTS

In order to develop a model that is representative of a situation, one must be able to define the situation as it exists. In the area of thermal vacuum testing, a data bank exists at GSFC that has been compiled by the organization that has been responsible for thermal vacuum testing. This data was begun in the early 1960's until 1976 when a reorganization took place and the data bank input changed. The data in the system prior to the reorganization contained information on all tests conducted by the group in various sized temperature chambers, thermal vacuum chambers, and solar simulation facilities. The tests were conducted at all levels of assembly of spacecraft. As time passes, data is sent to storage where it is retained for a number of years and then destroyed. Therefore, the available data includes a period of about 10 years.

The data bank itself consists of the handwritten records of the tests indicating such things as the name of the project, the name of the item tested, the dates of the test, the TAR (Test Action Request, authority for the test plus some data), the times at which temperature changes took place, and failure information.

In order to make this data amenable to computer operations, it was transcribed onto a magnetic tape cassette (Hewlett-Packard 9162-0061 Data Cartrige) using a Hewlett-Packard 9831A calculator (which was used for most of the analyses conducted under this study). 109 data files were so established. Addendum A-A is a listing of the information in these files (with information that identifies the particular item omitted).

The four columns listed in each data file include (a) the matrix row in which that line of data is contained, (b) the hour of the year at which the temperature change took place, and (c) the failure status. Under "failure status," a 1 indicates that an anomaly took place some time between the hour indicated on that row and the hour of the next row; a zero indicates no anomaly. The number "2" in that column indicates a break in the test, a "3" indicates that no functional tests were performed during the exposure, a "4" indicates the continuation of a test beyond the last entered data, and a "5" indicates that the anomaly occurred somewhere within the time period within which the "5s" are noted.

Fig. A-1 shows the format of the array in which the data is stored. In order to simplify various analyses, this data was compressed into two other arrays (72 col. x 50 rows each). The format for these arrays is shown in Fig. A-2.

Addendum A-B is the program for storing the data and Addendum A-C is the program for listing the data from file.

ROWS	COLUMNS 1	2	3	4	5	6	7	8
1	TAR NUMBER XX XXX		PROJECT NAME P$ (6 SPACES)			JOB ORDER NO. XXX XXXX		RETEST X
2	ITEM NAME N$ (16 SPACES)							
3	LEVEL OF ASS'Y X	ITEM TYPE X	MATURITY X	TEST TYPE X	FACILITY NO. XXX	OUTCOME X	NO. OF COMP	
4	TOTAL TEST TIME (COMPUTED)	T(MAX) °C	T(MIN) °C	NO. HALF CYCLES	TOTAL TIME AT T(MAX) (COMPUTED)	TOTAL TIME AT T(MIN) (COMPUTED)		
5	MONTH XX	DAY XX	YEAR XX	HOUR XXXX	TEMP °C	SUN ON? X	FAIL BTWN NOW & NEXT PERIOD? X	HOUR OF THE YEAR (COMPUTED)
⋮	DATA CONTINUES ↓							
35								

NOTES:

[1,8]	1 ENTERED FOR YES, ∅ FOR NO
[3,1]	1=COMPONENT, 2=SUBSYSTEM, 3=SYSTEM, 4=THERMAL MODEL
[3,2]	1=HOUSEKEEPING, 2=EXPERIMENT, 3=BOTH, 4=UNKNOWN
[3,3]	1=PROTOFLIGHT, 2=PROTOTYPE, 3=THERMAL MODEL, 4=UNKNOWN, 5=FLIGHT, 6=SPARE
[3,4]	1=THERMAL VACUUM, 2=THERMAL CYCLING, 3=THERMAL BALANCE, 4=OTHER
[3,6]	1=SATISFACTORY, 2=UNSATISFACTORY, 3=INDETERMINATE
[4,4]	A HALF-CYCLE IS A TRANSITION FROM ONE TEMPERATURE TO ANOTHER WHERE THE NEXT TEMPERATURE CHANGE WOULD REVERSE THE DIRECTION
[5,X] TO [35,X]	DATA FOR EACH TEMPERATURE CONDITION
[5,7]	1=YES; ∅=NO; 2=TEST INTERRUPTED AT THIS TIME, CONTINUES AT NEXT TIME; 3=NO FUNCTIONAL TEST PERFORMED; 4=TEST CONTINUES BEYOND THIS POINT; 5=FAILURE SOMEWHERE IN THIS TIME

Figure A-1. Format of Array DI[35, 8]

COL. NO.	1	2	3	4	5	6	7	8
	D(1,1)[a]	D(1,2)	D(1,3)	D(1,4)	D(1,5)	D(1,6)	D(1,7)	D(1,8)
	TAR NUMBER		PROJECT NAME			JOB ORDER NO.		RETEST?

COL. NO.	9	10	11	12	13	14	15	16
	D(2,1)	D(2,2)	D(2,3)	D(2,4)	D(2,5)	D(2,6)	D(2,7)	D(2,8)
	NAME OF TEST ITEM							

COL. NO.	17	18	19	20	21	22	23	24
	D(3,1)	D(3,2)	D(3,3)	D(3,4)	D(3,5)	D(3,6)	D(3,7)[b]	D(3,8)
	LEVEL OF ASS'Y	ITEM TYPE	MATURITY	TEST TYPE	FACILITY NUMBER	OUTCOME	NUMBER OF COMPONENTS	–

COL. NO.	25	26	27	28	29	30	31	32
	D(4,1)	D(4,2)	D(4,3)	D(4,4)	D(4,5)	D(4,6)		
	TOTAL TEST TIME	T(MAX)	T(MIN)	NO. OF 1/2 CYCLES	TIME AT T(MAX)	TIME AT T(MIN)	WAS FIRST 1/2 CYCLE HOT OR COLD	–

COL. NO.	33	34	35	36	37	38	39	40
	NUMBER OF FAILURES (≤ 3)	EARLIEST TIME OF FAILURE			LATEST TIME OF FAILURE			TEMPERATURE
		FAILURE #1	#2	#3	FAILURE #1	#2	#3	FAILURE #1

COL. NO.	41	42	43	44	45	46	47	48
	AT EARLIEST TIME OF FAILURE		NUMBER OF 1/2 CYCLES AT			TEMPERATURE AT LATEST TIME OF FAILURE		
	#2	#3	FAILURE #1	#2	#3	FAILURE #1	#2	#3

COL. NO.	49	50	51	52	53	54	55	56
	T(MAX) AT TIME OF FAILURE			T(MAX) AT LATEST TIME OF FAILURE			T(MIN) AT EARLIEST	
	FAILURE #1	#2	#3	FAILURE #1	#2	#3	FAILURE #1	#2

COL. NO.	57	58	59	60	61	62	63	64
	TIME OF FAILURE	T(MIN) AT LATEST TIME OF FAILURE			NUMBER OF TESTS OR RETESTS	MONTH	DAY	YEAR
	#3	FAILURE #1	#2	#3				

COL. NO.	65	66	67	68	69	70	71	72
	TIME AT THE COMPLETION OF EACH 1/2 CYCLE							

NOTES: (a) THESE DESIGNATIONS INDICATE THE CORRESPONDING ELEMENT FROM ARRAY DI[35,8]; WHERE NO ELEMENT IS INDICATED, THE VALUE HAS BEEN COMPUTED FROM THE DATA.
(b) MUST BE EQUAL OR GREATER THAN THE NUMBER OF FAILURES.

Figure A-2. Format of Array AI [50, 72]

ADDENDUM A-A

SAMPLE DATA FROM 109 COMPONENT LEVEL TESTS

DATA FROM FILE # 1

TAR XX,XXX J.O. XXX-XX-XX Proj: ABCD
Level: SSys; Maturity: PFlt; Type: Exper; Item: EFGH
Number of components: 4
Type of test: TV Facility Nr. 239

Outcome of test: Undetermined
Total test time: 109 hrs
Time at Tmax (40 deg C): 32 hrs
Time at Tmin (-10 deg C): 30 hrs

Row	Hour	Temp,deg C	Failure Status
5	2901	25	0
6	2917	25	0
7	2923	-10	1
8	2928	-10	0
9	2937	40	0
10	2944	40	0
11	2953	-10	0
12	2978	-10	0
13	2984	40	0
14	3009	40	0
15	3010	25	0

DATA FROM FILE # 2

TAR XX,XXX J.O. XXX-XX-XX Proj: ABCD
Level: Comp; Maturity: PFlt; Type: Exper; Item: EFGH
Number of components: 1
Type of test: TV Facility Nr. 240

Outcome of test: Undetermined
Total test time: 98 hrs
Time at Tmax (40 deg C): 36 hrs
Time at Tmin (-10 deg C): 36 hrs

Row	Hour	Temp,deg C	Failure Status
5	2629	25	0
6	2635	40	0
7	2659	40	0
8	2665	-10	0
9	2677	-10	0
10	2682	40	0
11	2694	40	0
12	2699	-10	0
13	2723	-10	0
14	2726	25	0
15	2727	25	0

ADDENDUM A-B

PROGRAM FOR STORING DATA FROM GSFC DATA BASE

PROGRAM FOR STORING DATA FROM GSFC DATA BASE

```
10 COM D[35,8],P$[6],N$[16],L$[4],T$[5],M$[4],C$[2],O$[14]
20 REM - PROGRAM TO STORE DATA FROM CODE 755 FOLIOS
30 FORMAT "TAR No.",F3.0,",",F4.0
40 FORMAT "J.O. No.",F4.0,"-",F3.0,"-",F3.0
50 FORMAT F3.0,2X,F3.0,1X,F3.0,1X,F3.0,3X,F5.0,6X,F4.0,8X,F2.0,11X,F2.0
60 FORMAT F3.0,5X,F5.0,7X,F4.0,9X,F2.0,11X,F2.0
70 MAT D=ZER[35,8]
80 LOAD  KEY 2
81 CFLAG 0
83 DISP "List data from file";
85 INPUT A
86 IF  NOT FLAG0 THEN 99
88 SFLAG 0
90 DISP "FILE NUMBER";
92 INPUT F
94 LOAD  DATA #1,F
96 GOTO 480
99 DISP "File Nr. for storage";
100 INPUT F
110 PRINT "File Nr."; F
120 PRINT
130 FIND F
140 DISP "TAR Nr. (AS XXXXX)";
150 INPUT J
160 D[1,1]=INT(J/1000)
170 D[1,2]=J-1000*D[1,1]
180 DISP "Proj name (P$, 6 SPA)";
190 INPUT P$
200 TRANSFER P$ TO D[1,3]
210 DISP "J.O. Nr. (AS XXXXXXX)";
220 INPUT J
230 D[1,6]=INT(J/10000)
240 D[1,7]=J-10000*D[1,6]
250 DISP "Retest? 1=Y,0=N                    ";
260 INPUT D[1,8]
270 DISP "Item name (N$, 16 SPA)";
280 INPUT N$
290 TRANSFER N$ TO D[2,1]
300 DISP "Lvl of ass'y (1=C,2=SS,3=S,4=TM)";
310 INPUT D[3,1]
312 IF D[3,1]=1 THEN 318
313 IF D[3,1]=4 THEN 320
314 DISP "HOW MANY COMP MAKE UP THE ITEM";
316 INPUT D[3,7]
317 GOTO 320
318 D[3,7]=1
320 DISP "Item type (1=Hskpg,2=Exp,3=Both or ?";
330 INPUT D[3,2]
340 DISP "Maturity (1=PF,2=PT,3=TM,4=UNK,5=FltA,6=SPARE;etc.";
350 INPUT D[3,3]
360 DISP "Test type (1=TV,2=TC,3=TB,4=?)";
370 INPUT D[3,4]
380 DISP "Facility Nr. (AS XXX)";
390 INPUT D[3,5]
400 DISP "Outcome (1=Sat,2=Unsat,3=Indtrm)";
410 INPUT D[3,6]
420 DISP "Tmax, deg C";
430 INPUT D[4,2]
440 DISP "Tmin, deg C";
```

```
450 INPUT D[4,3]
460 DISP "Number of half-cycles";
470 INPUT D[4,4]
480 WRITE (2,30)D[1,1],D[1,2]
490 WRITE (2,40)D[1,6],INT(D[1,7]/100),D[1,7]-((INT(D[1,7]/100))*100)
500 PRINT "Project: ";P$,SPA10,"Item: ";N$
505 IF FLAG0 THEN 870
510 GOTO D[3,2] OF 560,580,600
520 GOTO D[3,3] OF 620,640,660,680,700,720
530 GOTO D[3,1] OF 740,760,780
540 PRINT "Lvl of ass'y: ";L$,"Maturity: ";M$,"     Type: ";T$
550 GOTO D[3,4] OF 800,820,840,860
560 T$="Hskpg"
570 GOTO 520
580 T$="Exper"
590 GOTO 520
600 T$="Both "
610 GOTO 520
620 M$="PFlt"
630 GOTO 530
640 M$="Ptyp"
650 GOTO 530
660 M$="TMod"
670 GOTO 530
680 M$="Unkn"
690 GOTO 530
700 M$="FltA"
710 GOTO 530
720 M$="SPR "
730 GOTO 530
740 L$="Comp"
750 GOTO 540
760 L$="SSys"
770 GOTO 540
780 L$="Syst"
790 GOTO 540
800 C$="TV"
810 GOTO 870
820 C$="TC"
830 GOTO 870
840 C$="TB"
850 GOTO 870
860 C$="??"
870 PRINT "Type of test: ";C$,"       Facility Nr. ";D[3,5]
880 GOTO D[3,6] OF 950,970,990,1010
890 PRINT "Outcome of test: ";O$
900 PRINT "Tmax:";D[4,2];"deg C.   Tmin:";D[4,3];"deg C."
905 IF FLAG0 THEN 1030
910 PRINT
920 DISP "USE FN KEYS TO CHANGE OR CONT    "
930 STOP
940 GOTO 1030
950 O$="Satisfactory"
960 GOTO 890
970 O$="Unsatisfactory"
980 GOTO 890
990 O$="Indeterminate"
1000 GOTO 890
1010 O$="Unknown"
1020 GOTO 890
1030 PRINT "Col:   1   2   3      4         5          6           7"
1040 PRINT "Row   Mo  Da  Yr    Time    Temp,deg C    Sun    Failure Status"
1050 FOR I=5 TO 35
```

```
1055 IF FLAG0 THEN 1220
1060 DISP "Mo,Da,Yr (XX,XX,XX;if end;0,0,0)";
1070 INPUT D[I,1],D[I,2],D[I,3]
1080 IF D[I,1]=0 THEN 1240
1090 DISP "Hour (XXXX)";
1100 INPUT D[I,4]
1110 DISP "Temp, deg C";
1120 INPUT D[I,5]
1130 IF D[3,4]#3 THEN 1160
1140 DISP "Sun on ? 1=Yes, 0= No          ";
1150 INPUT D[I,6]
1160 DISP "Fail btwn now and next per? 1=Y,0=N,2=Unknown";
1170 INPUT D[I,7]
1180 DISP "TEST INTRPT  NOW(1=Y,0=N)";
1190 INPUT A
1200 IF A=0 THEN 1220
1210 D[I,7]=2
1215 IF D[I,1]=0 THEN 1240
1220 WRITE (2,50)I,D[I,1],D[I,2],D[I,3],D[I,4],D[I,5],D[I,6],D[I,7]
1230 NEXT I
1240 PRINT
1245 IF FLAG0 THEN 1920
1250 DISP "USE FN KEYS TO CHANGE OR CONT    "
1260 STOP
1270 REM - This routine converts MoDaYr to Hour of Year (adding last
1280 REM - year if the test crosses a year.
1290 FOR I=5 TO 35
1300 IF D[I,1]=0 THEN 1730
1310 REM - This section determines whether this is the same year as at the
1320 REM - start of the test and if that was a leap year.
1330 IF D[5,3]=(D[I,3]-1) AND INT(D[5,3]/4)=D[5,3]/4 THEN 1360
1340 IF D[5,3]=(D[I,3]-1) AND INT(D[5,3]/4)#D[5,3]/4 THEN 1380
1350 GOTO 1400
1360 Y1=366
1370 GOTO 1410
1380 Y1=365
1390 GOTO 1410
1400 Y1=0
1410 REM - This section calc the hr of the yr (adding last yr if req'd).
1420 T1=0
1430 FOR G=1 TO 12
1440 K=D[I,1]-G
1450 IF K=0 THEN 1640
1460 IF K=1 THEN 1540
1470 IF K=2 AND INT(D[G,3]/4)-D[G,3]/4 THEN 1580
1480 IF K=2 AND INT(D[G,3]/4)#D[G,3]/4 THEN 1600
1490 IF K=3 OR K=12 THEN 1540
1500 IF K=4 OR K=6 THEN 1560
1510 IF K=5 OR K=7 THEN 1540
1520 IF K=8 OR K=10 THEN 1540
1530 IF K=9 OR K=11 THEN 1560
1540 D1=31
1550 GOTO 1620
1560 D1=30
1570 GOTO 1620
1580 D1=29
1590 GOTO 1620
1600 D1=28
1610 GOTO 1620
1620 T1=T1+D1
1630 NEXT G
1640 T1=(T1+D[I,2]-1+Y1)*24
1650 H2=INT(D[I,4]/100)
```

```
1660 REM - Rounding to the nearest whole hour.
1670 H3=(D[I,4]-H2*100)/60
1680 IF H3<0.5 THEN 1710
1690 D[I,8]=T1+H2+1
1700 GOTO 1720
1710 D[I,8]=T1+H2
1720 NEXT I
1730 REM - Calculate time @ Tmax and Tmin; also total test time.
1740 D[4,5]=D[4,6]=D[4,1]=L1=0
1750 FOR L=5 TO 35
1760 IF D[L,7]#2 THEN 1790
1770 L1=D[L+1,8]-D[L,8]+L1
1790 IF D[L,1]=0 THEN 1900
1800 REM - Compute time @ Tmax and Tmin.
1810 IF D[L,5]#D[4,2] AND D[L,5]#D[4,3] THEN 1880
1820 IF D[L,5]=D[4,2] AND D[L-1,5]=D[4,2] THEN 1850
1830 IF D[L,5]=D[4,3] AND D[L-1,5]=D[4,3] THEN 1870
1840 GOTO 1880
1850 D[4,5]=D[4,5]+D[L,8]-D[L-1,8]
1860 GOTO 1880
1870 D[4,6]=D[4,6]+D[L,8]-D[L-1,8]
1880 NEXT L
1890 REM - Compute total test time.
1900 D[4,1]=D[L-1,8]-D[5,8]-L1
1910 PRINT
1920 PRINT "Col:       8          5           6           7"
1930 PRINT "Row      Hour    Temp, deg C     Sun    Failure Status"
1940 FOR Z=5 TO 35
1950 IF D[Z,1]=0 THEN 1980
1960 WRITE (2,60)Z,D[Z,8],D[Z,5],D[Z,6],D[Z,7]
1970 NEXT Z
1980 PRINT "Total test time: ";D[4,1];" hrs"
1990 PRINT "Time at Tmax (";D[4,2];" deg C): ";D[4,5];" hrs"
2000 PRINT "Time at Tmin (";D[4,3];" deg C): ";D[4,6];" hrs"
2010 PRINT
2020 DISP "All OK (1=Y,0=N)? 0 results in STOP";
2030 INPUT A
2040 IF A=0 THEN 2090
2050 STORE  DATA #1,F
2060 F=F+1
2070 MAT D=ZER[35,8]
2080 GOTO 110
2090 STOP
2100 END
2110 DISP "USE FN KEY 6 TO RETURN TO PROG."
2120 END
```

ADDENDUM A-C

PROGRAM FOR LISTING DATA FROM FILES

PROGRAM TO PRINT GSFC DATA FROM FILES

```
10 COM D[35,8],P$[6],N$[16],L$[4],T$[5],M$[4],C$[2],O$[14]
20 REM - PROGRAM TO LIST DATA FROM CODE 755 FOLIOS
30 FORMAT "TAR ",F3.0,",",F4.0,"      J.O. ",F4.0,"-",F3.0,"-",F3.0,"      Proj: "
40 FORMAT F3.0,2X,F3.0,1X,F3.0,1X,F3.0,3X,F5.0,2X,F5.0,5X,F4.0,11X,F2.0
50 MAT D=ZER[35,8]
60 DISP "ENTER 1st & LAST FILES FOR LSTNG";
70 INPUT F1,F2
80 FOR F=F1 TO F2
90 PRINT "DATA FROM FILE #";F
100 PRINT
110 LOAD  DATA #1,F
120 D1=INT(D[1,7]/100)
130 WRITE (2,30)D[1,1],D[1,2],D[1,6],D1,D[1,7]-D1*100,
140 PRINT P$
150 GOTO D[3,2] OF 200,220,240
160 GOTO D[3,3] OF 260,280,300,320,340,360
170 GOTO D[3,1] OF 380,400,420
180 PRINT "Level: ";L$;"   Maturity: ";M$;"   Type: ";T$;"   Item: ";N$
190 GOTO D[3,4] OF 440,460,480,500
200 T$="Hskpg"
210 GOTO 160
220 T$="Exper"
230 GOTO 160
240 T$="Both "
250 GOTO 160
260 M$="Pflt"
270 GOTO 170
280 M$="Ptyp"
290 GOTO 170
300 M$="TMod"
310 GOTO 170
320 M$="Unkn"
330 GOTO 170
340 M$="Flt "
350 GOTO 170
360 M$="Spr "
370 GOTO 170
380 L$="Comp"
390 GOTO 180
400 L$="SSys"
410 GOTO 180
420 L$="Syst"
430 GOTO 180
440 C$="TV"
450 GOTO 510
460 C$="TC"
470 GOTO 510
480 C$="TB"
490 GOTO 510
500 C$="??"
510 PRINT "Number of components: ";D[3,7]
520 PRINT "Type of test: ";C$,"        Facility Nr. ";D[3,5],LIN1
530 GOTO D[3,6] OF 560,580,600,620
540 PRINT "Outcome of test: ";O$
550 GOTO 630
560 O$="Satisfactory"
570 GOTO 540
580 O$="Unsatisfactory"
590 GOTO 540
```

```
600 O$="Undetarmined"
610 GOTO 540
620 O$="Unknown"
630 PRINT "Total test time: ";D[4,1];" hrs"
640 PRINT "Time at Tmax ("D[4,2];" deg C): ";D[4,5];" hrs"
650 PRINT "Time at Tmin ("D[4,3];" deg C): ";D[4,6];" hrs"
660 PRINT
670 PRINT
680 PRINT "Col:    1    2    3       4       8          5              7"
690 PRINT "Row    Mo   Da   Yr     Time    Hour    Temp,deg C  Failure Status"
700 FOR I=5 TO 35
710 IF D[I,1]=0 THEN 750
720 WRITE (2,40)I,D[I,1],D[I,2],D[I,3],D[I,4],D[I,8],D[I,5],D[I,7]
730 NEXT I
750 PRINT LIN2
760 NEXT F
770 END
```

APPENDIX B

CORRELATION OF COMPONENT FAILURE RATES WITH TEST TEMPERATURES

APPENDIX B

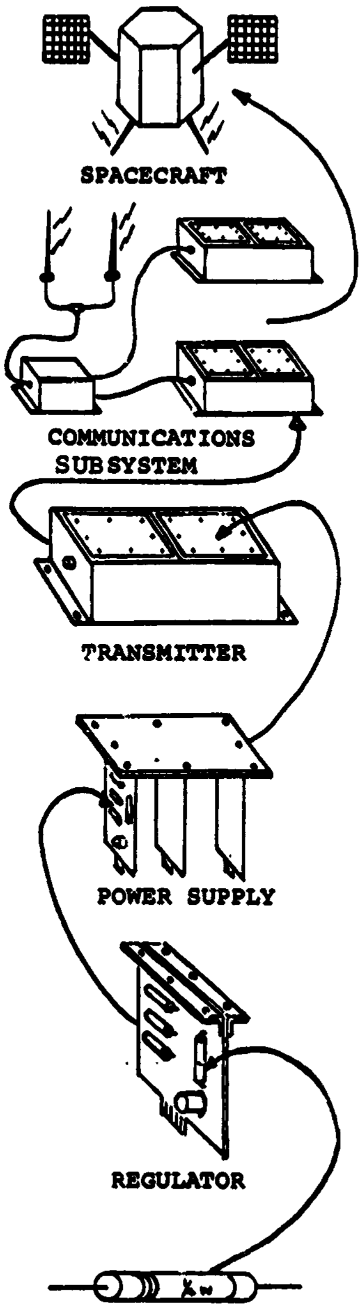
CORRELATION OF COMPONENT FAILURE RATES WITH TEST TEMPERATURES

There was insufficient data in the GSFC data bank (Appendix A) to establish a significant relationship between temperature and failure rates. In view of this it was decided to take an approach that assumed a certain make-up of parts within an average component, compute failure rates of the parts as a function of temperature using thermal characteristics based on Military Handbook 217-B (Ref. 12), and thus arrive at a measure of component failure rates over a given temperature range.

A "spacecraft component," as used throughout this report, refers to a sub-section of a spacecraft system which is essentially a self-contained combination of parts performing a unique function within the spacecraft system.

General definitions of system subdivisions are given in Fig. B-1. As used herein, equivalent failure rates of components within the system are implied. In an ideal situation, all identified components would have the same failure rates or reliability characteristics. In actual practice this condition does not exist. However, good analytical results have been consistently obtained in the past using essentially a count of system components to represent the system complexity. Also, this level of assembly is a convenient unit to use since it fairly well represents the system complexity, and it is the level of assembly generally used in identifying failures or anomolies that occur in space operation.

Parts for a typical spacecraft electronic component used in an unpublished presentation by W. Smith, GSFC Product Assurance Division, were taken as a reasonable representation of a component unit, or "black box." Generic failure rates of these parts at temperatures from 20 to 100° Centigrade were then derived using the guidelines of Ref. 12. Table B-1 (output of computer program, Addendum B-A) shows the piece part composition of the "average" spacecraft



DEFINITIONS:

System - A major subdivision of a given launch vehicle such as a propulsion system or spacecraft system. The system embraces all its own subsystems including checkout equipment and servicing equipment.

Subsystem - The next functional subdivision of a system and is generally composed of two or more components designed to perform an operation.

Component - The next functional subdivision of a subsystem and generally is a self-contained combination of assemblies performing a function necessary to the subsystem's operation.

Assembly - The next functional subdivision of a component and consist of parts and subassemblies which perform functions necessary to the operation of the component as a whole.

Subassembly - An assembly within a larger assembly.

Part - An element of a component, assembly or subassembly which is not normally subject to further subdivision or disassembly without destruction of the designed use.

Figure B-1. Definitions of Subdivision of a Spacecraft

Table B-1
Single Device Failure Rates/10↑6 Hrs.

TEMP. (oC)	MONOL.	HYBRID	TRANS.	DIODES	RESIS.	CAPAC.
20	0.0257	0.3121	0.0007	0.0002	0.0003	0.0002
30	0.0312	0.4512	0.0008	0.0003	0.0005	0.0002
40	0.0388	0.6392	0.0009	0.0003	0.0007	0.0002
50	0.0510	0.9024	0.0010	0.0004	0.0010	0.0002
60	0.0681	1.2408	0.0012	0.0005	0.0015	0.0002
70	0.0941	1.6544	0.0015	0.0006	0.0023	0.0002
80	0.1246	2.1808	0.0018	0.0008	0.0033	0.0003
90	0.1734	2.8576	0.0023	0.0011	0.0049	0.0003
100	0.2374	3.6472	0.0031	0.0017	0.0072	0.0004

TYPICAL BLACK BOX COMPOSITION

PIECE PART	NO. OF PARTS
MICRO ELECTRONIC DEVICES-MONOLITHIC	107
MICRO ELECTRONIC DEVICES-HYBRIDS	107
TRANSISTORS	11
DIODES	43
RESISTORS	160
CAPACITORS	75
TOTAL	503

BLACK BOX FAIL. RATE/10↑6 HRS.

TEMP. (oC)	MONOL.	HYBRID	TRANS.	DIODES	RESIS.	CAPAC.	TOTAL
20	2.75	33.39	0.01	0.01	0.05	0.02	36.23
30	3.34	48.28	0.01	0.01	0.08	0.02	51.73
40	4.16	68.39	0.01	0.01	0.11	0.02	72.70
50	5.46	96.56	0.01	0.02	0.17	0.02	102.23
60	7.29	132.77	0.01	0.02	0.25	0.02	140.35
70	10.06	177.02	0.02	0.03	0.36	0.02	187.51
80	13.33	233.35	0.02	0.03	0.53	0.02	247.28
90	18.55	305.76	0.03	0.05	0.78	0.02	325.19
100	25.40	390.25	0.03	0.07	1.15	0.03	416.95

END

component, along with the individual part and component failure rates over the stated range of temperatures. An exponential curve of the form, $Ae^{B(T+g)}$ was fitted to the computed failure rates with the constants as shown:

$$h(T) = 7.9 \times 10^{-6} e^{0.0306(T+32)},$$

where T = temperature in degrees Celsius.

This function is plotted in Fig. B-2.

On the basis of these results, one would conclude that failure rates increase with increasing temperature, and conversely, decrease with decreasing temperatures. Results of a study of thermal vacuum test failures conducted by Timmins, Heuser, and Strain (Ref. 6), show that on an average basis, hot temperature related test failures are greater than those experienced during ambient temperature conditions; however, cold temperature related test failures are also greater and moreover are essentially of the same relative magnitude as those experienced under hot temperature conditions. These conditions can be discerned from Fig. B-3 (Fig. 5 of Ref. 6). A possible explanation of this is that the temperature function thus far developed applies only to the reliability degradation of the physical/molecular mechanisms within the piece part; and that other degrading thermal forces must be acting upon the larger structure of the "black box," or component, such that there is an "equal" degradation of component reliability under colder than ambient conditions – to those higher than ambient.

Using this hypothesis, a mirror image of the temperature function was developed, (increasing failure rate with decreasing temperatures), with the failure rates equal at 20°C. The sum of these two curves results in an expression for the total effect of temperature on the component failure rate given by:

$$h(T) = h(T_o)(e^{0.0306(T+32)} + e^{0.0306(72-T)}),$$

where T = temperature °Centigrade and $h(T_o)$ = basic failure rate at 20°C.

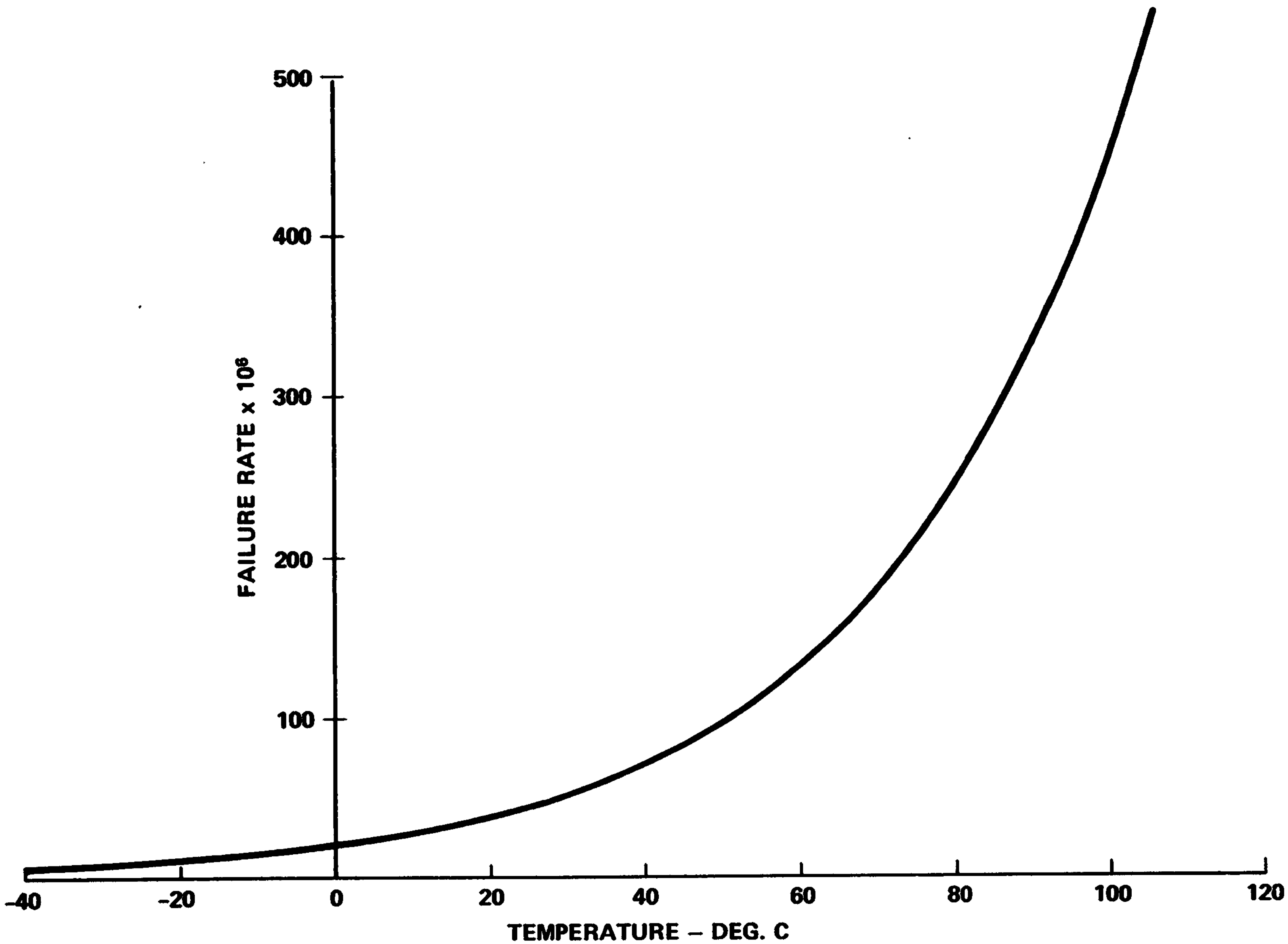
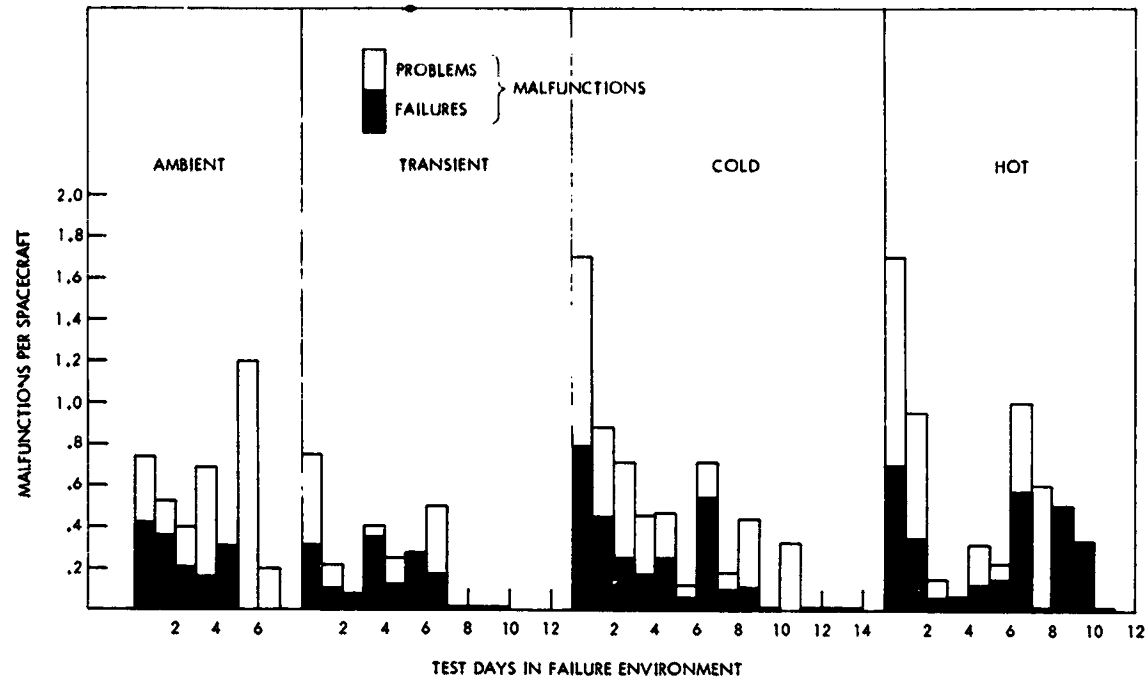


Figure B-2. Failure Rate vs. Temperature $h(T) = Ae^{B(T+G)}$



Reference: NASA TN D-7408, Nov. 1973, "Analysis of Flight Model Spacecraft Performance During Thermal-Vacuum Tests," Timmins, Heuser, Strain

Figure B-3. Thermal-Vacuum Malfunctions per Spacecraft of Flight Spacecraft by Day and Environment

The net effect of this transformation is shown in Fig. B-4. While somewhat arbitrary, it is believed to be a reasonable approach to the total component temperature function, referred to in subsequent sections of the report as part of the "environmental intensity factor," E. A test of its applicability was made through an independent analysis of the data in Appendix A, using a rather unique approach.

While the data bank was insufficient to permit a straight forward determination of the relationship, it was felt that some indication could be obtained by developing an indirect approach, that is, by developing groupings that excluded certain failure probabilities.

The data was analyzed without regard to time or the number of cycles and it was assumed that the grouping was sufficiently homogeneous so that the effects of these other two stresses would apply overall. It is possible to investigate the homogeneity but this has not been done as yet.

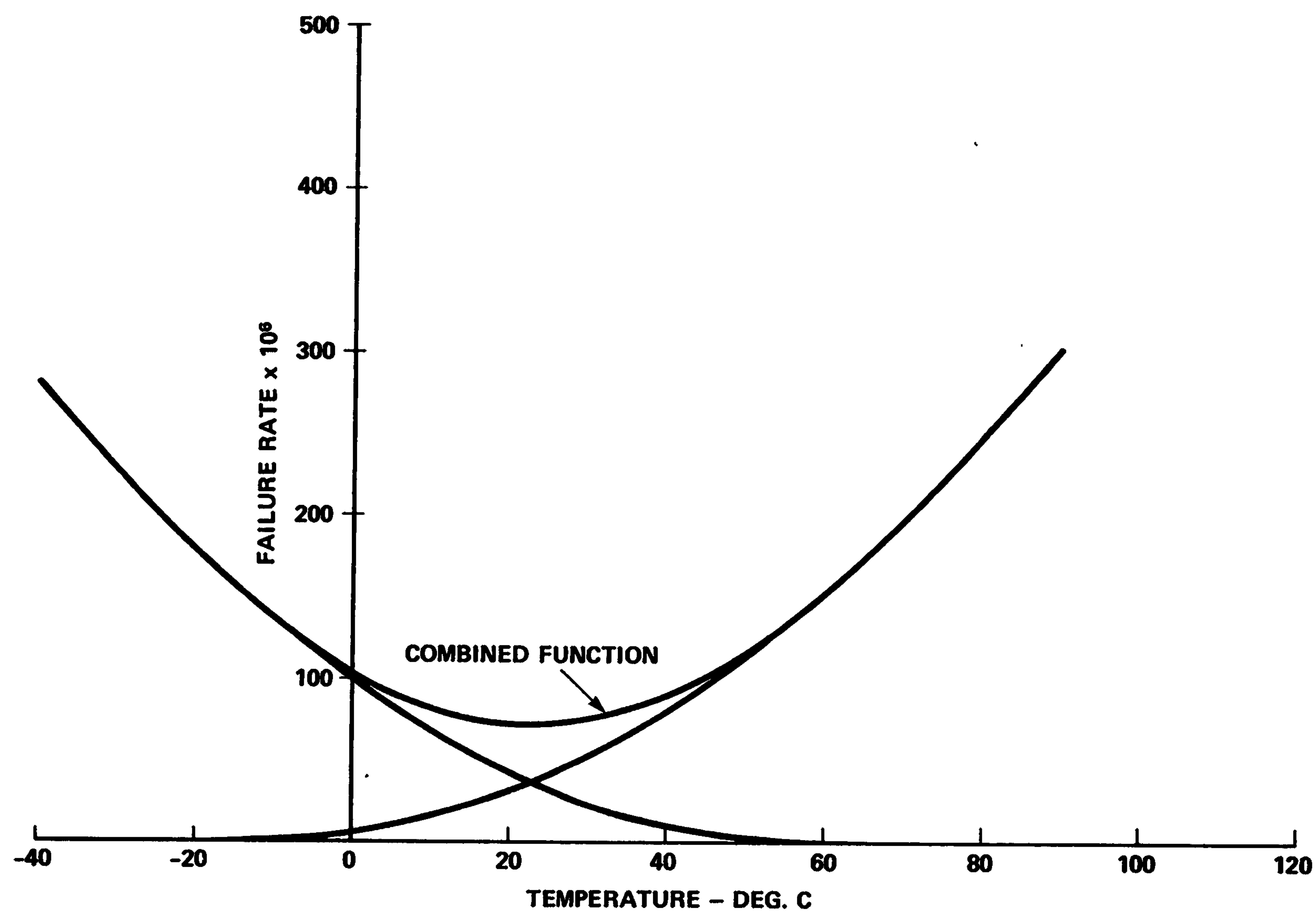


Figure B-4. Failure Rate vs. Temperature $h(T) = K(T+G)^2$

A binomial approach was taken; that is, a component either passed or failed a test. If more than one failure occurred during a test, it was assigned as another component. (No more than three failures were encountered during any test; multiple failures were very infrequent.)

Since we were interested in failures (tests concerning binomial distributions generally deal with successes and we simply interchanged the terminology), a computer program was written to search through the data and determine (a) how many failures occurred out of n components tested at temperatures down to (T – 1)°C and (b) how many failures occurred out of n components tested up to (T + 1)°C. This is equivalent to saying for case (a) at $\leq$T and for case (b) at $\geq$T. A point estimator, $\overline{p}$, of the probability of failure was found by dividing the number of failures by the number of components. (This nomenclature and much of the following is consistent with that found in Ref. 13).

The confidence interval or band within which the true failure probability lies is (Ref. 13, Chap. 2, Sec 3)

$$\overline{p} - Z_{\alpha/2}\sqrt{\frac{\overline{p}\overline{q}}{n}} \leq p \leq \overline{p} + Z_{\alpha/2}\sqrt{\frac{\overline{p}\overline{q}}{n}} \qquad \text{(B-1)}$$

where $\overline{p}$ is the number of failures divided by the number of units tested, n ; $\overline{q} = (1 - \overline{p})$; $Z_{\alpha/2}$ is a standard normal random variable; and the choice of α determines the $1 - \alpha$ percent confidence interval for p, the true probability of failure. By choosing $\alpha = 0.05$, $Z_{\alpha/2} = 1.96$ and the confidence limits approach 95%; that is, we are 95% confident that p lies within the limits expressed by Eq. B-1. (This approximation becomes subject to significant error when n is small or $\overline{p}$ or $\overline{q}$ approach zero.)

Figs. B-5 and B-6 are graphs on which are plotted the 95% confidence bands within which the probability of failure exists. These are shown as brackets open to the right or left and indicate data based on the probability of failure above or below the temperature minus or plus one degree. It can be seen that no significant difference exists between the two figures. Also plotted is a bar that indicates the intersection of these two confidence bands. Since one band applies to temperatures $\leq T$ and the other to temperatures $\geq T$, the intersection provides an indication of the location within which the probability of failure at T exists. The word "indication" must be emphasized.

Also plotted on each figure is the function

$$P(F) = 1.0088 \times 10^{-2} [(\exp(0.0306(T + 32))) + (\exp(0.0306(62 - T)))] \quad \text{(B-2)}$$

where P(F) is the probability of a failure as found earlier and T is the temperature in degrees Celsius. The numerical values were adjusted to match an indicated minimum at 15°C suggested by the data plotted in Figs. B-5 and B-6.

It is interesting to note that the function expressed in Eq. B-3 was developed independently of the data and that the only modification was to select the point at which the minimum failure rate occurs to be consistent with the data.

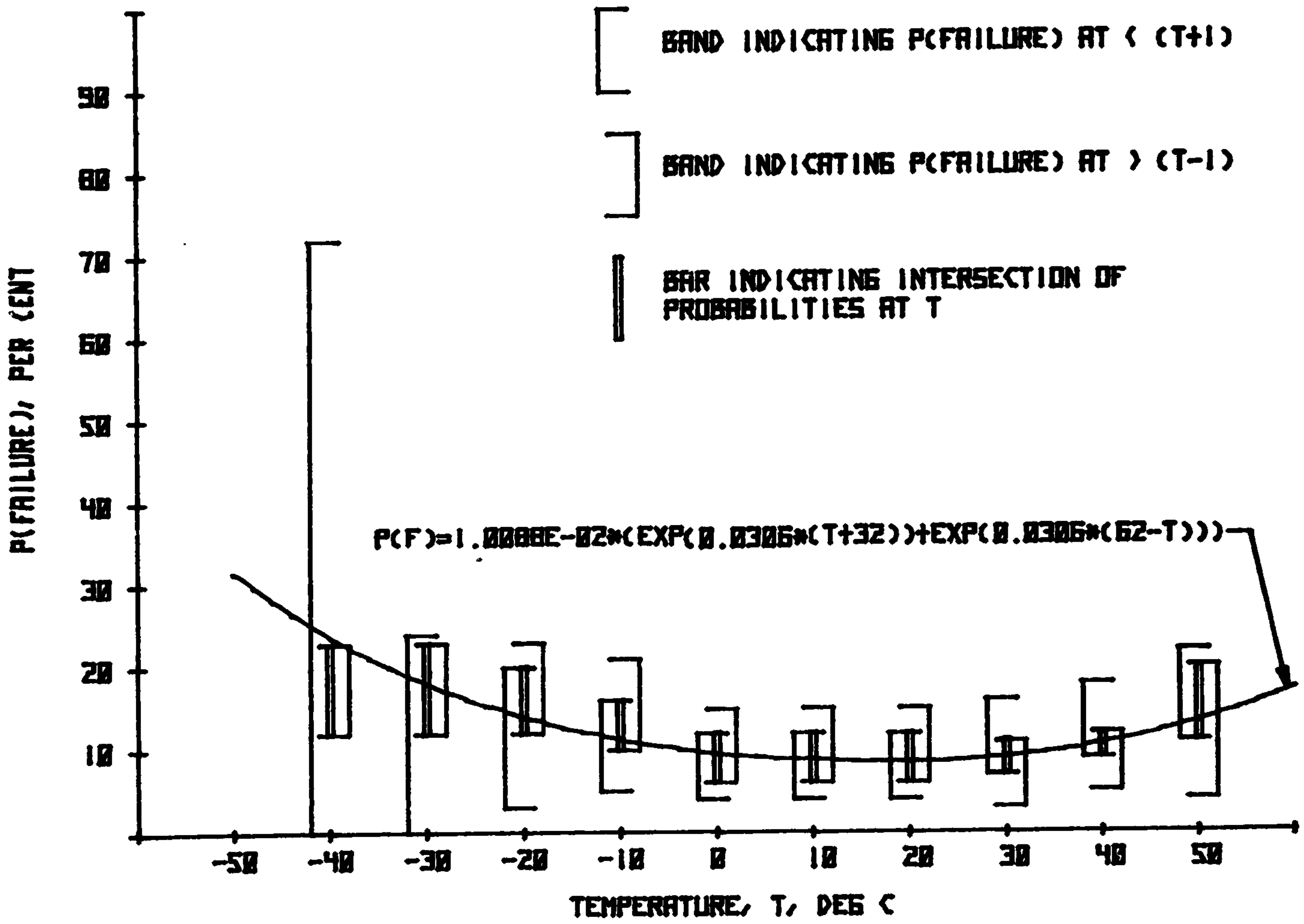


Figure B-5. Bands Within Which the Probability of Failure Lies With a Confidence of 95% (Failure Taken at Start of Time Interval)

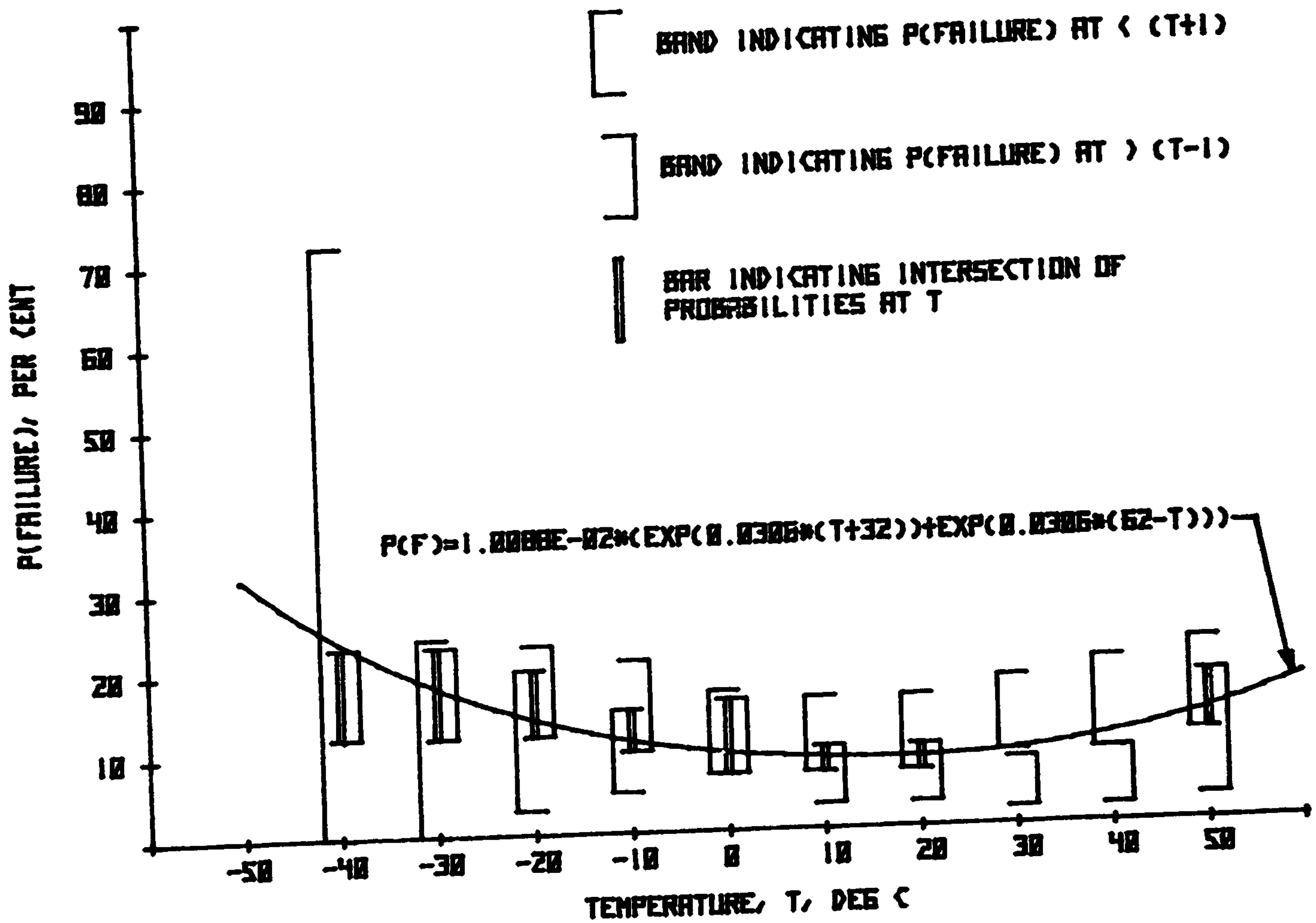


Figure B-6. Bands Within Which the Probability of Failure Lies With a Confidence of 95%
(Failure Taken at End of Time Interval)

ADDENDUM B-A

PROGRAM FOR DEFINING FAILURE RATES AS A FUNCTION OF TEMPERATURE

```
LOAD#0,1
LIST

10 DIM A[9,7]
20 F2=0
30 T=10
40 DATA 0.13,0.83,0.22,1.2,0.345,1.7,0.545,2.4,0.825,3.3,1.,5,4.4,1.75,5.2,2.55
50 DATA 7.6,3.6,9.7
60 FORMAT F5.0
70 FORMAT 6F8.4
80 FORMAT 6F8.2,F9.2
90 FOR I=1 TO 9
100 T=T+10
110 READ P1
120 A[I,1]=T
130 A[I,2]=0.061*P1+0.0178
140 READ P2
150 A[I,3]=0.??*P2
160 A[I,4]=0.0163328*EXP(((348+T)/448)↑12.4-1188/(348+T))
170 A[I,5]=0.0756*EXP(((348+T)/448)↑17.7-2138/(348+T))
180 A[I,6]=(3.96/10↑9)*EXP(12*(T+273)/343)(T+273)/273)
190 A[I,7]=(19.8/10↑5)*EXP(2.5*((T+273)/398)↑18)
200 NEXT I
210 PRINT
220 DATA 107,107,11,43,160,75
230 PRINT TAB15,"SINGLE DEVICE FAILURE RATES/10↑6 HRS.",LIN2
240 PRINT "TEMP."
250 PRINT "(oC)   MONOL.  HYBRID  TRANS.  DIODES  RESIS.  CAPAC."
260 PRINT "-----  ------  ------  ------  ------  ------  ------",LIN1
270 FIXED 4
280 FOR I=1 TO 9
290 WRITE (2,60)A[I,1];
300 FOR J=2 TO 7
310 WRITE (2,70)A[I,J],
320 NEXT J
330 WRITE (2,*)
340 NEXT I
350 WRITE (2,*)
360 PRINT LIN1
370 STANDARD
380 PRINT TAB15,"TYPICAL BLACK BOX COMPOSITION",LIN1
390 PRINT TAB10,"PIECE PART",TAB60,"NO. OF PARTS"
400 PRINT TAB10,"----------",TAB60,"------------"
410 PRINT TAB5,"MICRO ELECTRONIC DEVICES-MONOLITHIC",TAB64,"107"
420 PRINT TAB5,"MICRO ELECTRONIC DEVICES-HYBRIDS",TAB64,"107"
430 PRINT TAB5,"TRANSISTORS",TAB65,"11"
440 PRINT TAB5,"DIODES",TAB65,"43"
450 PRINT TAB5,"RESISTORS"TAB64,"160"
460 PRINT TAB5,"CAPACITORS",TAB65,"75"
470 PRINT TAB10,"TOTAL",TAB64,"503",LIN2
480 FIXED 2
490 PRINT TAB15,"BLACK BOX FAIL. RATE/10↑6 HRS.",LIN2
500 PRINT "TEMP."
510 PRINT "(oC)   MONOL.  HYBRID  TRANS.  DIODES  RESIS.  CAPAC.  TOTAL"
520 PRINT "-----  ------  ------  ------  ------  ------  ------  ------"LIN1
530 FOR I=1 TO 9
540 RESTORE 220
550 WRITE (2,60)A[I,1];
560 FOR J=2 TO 7
570 READ P
580 WRITE (2,80)A[I,J]*P;
590 F2=F2+A[I,J]*P
600 NEXT J
610 WRITE (2,80)F2
620 F2=0
630 NEXT I
640 WRITE (2,*)
650 PRINT "END",LIN2
660 END
```

APPENDIX C

DEVELOPMENT OF THE RELIABILITY GROWTH MODEL FOR COMPONENTS

APPENDIX C

DEVELOPMENT OF THE RELIABILITY GROWTH MODEL FOR COMPONENTS

This section of the report covers the development of a mathematical model chosen to reflect the influence of time, temperature, and temperature cycling on the state of component reliability. The need for the model was basic to this study since it was the means by which a quantitative assessment could be made of the generation of failure and failure rates – the former required as a direct input to the cost model and the latter required for projecting component reliability to space operations.

Several published reports were reviewed to arrive at an appropriate form of a failure probability function, F/N, from which failures and failure rates during tests could be derived. The "power" functions developed in Ref. 1, with respect to time as a variable, served as the basis for this work.

Other published reports verified reliability growth through temperature tests, with the number of temperature cycles as a variable. Ref. 14 is a report of an extensive survey of aerospace industry practices for achieving high reliability including the beneficial use of temperature cycling as a means to this end. High rates of change of temperature during the test were suggested. Ref. 15 is a report of experimental test results achieved by subjecting 200 units of avionics communication equipment to temperature cycling during burn-in tests at two different cycling rates; half were tested using a cyclic period of four hours and the other half using six hours per cycle. The conclusion reached was that the four hour cyclic burn-in resulted in the same effectiveness as a burn-in with six hour cycles, but in 2/3 of the total test time. Unfortunately, mathematical models showing the separate effects of time and temperature along with the number of temperature cycles were not provided. These reports, however, were useful in establishing basic assumptions for determining thermal vacuum test effects on component reliability. These assumptions are as follows:

(1) Thermal–vacuum test failures can be categorized according to the phase of the temperature cycle. High temperature failures occur during, and only during, the high temperature phase (or dwell), cold temperature failures occur only during the cold test phase, and temperature transition failures occur only during transition periods. A fourth category is included to account for those failures due to unspecified causes. Stated mathematically,

$$F = F_O + F_H + F_C + F_T \tag{C-1}$$

where: F = total number of failures, F_O = failures due to unspecified causes, and F_H, F_C, F_T = failures due to the cyclic phases of hot, cold, and transitional temperatures respectively.

(2) Reliability growth takes place in each of the cyclic temperature phases, to a degree dependent on the amount of time spent in each phase. In other words, the specific failure rates decrease with total time within a specified phase using the models proposed in Ref. 1, this assumption is equivalent to,

$$h(t)_x = KE_x Bt_x^{B-1} \tag{C-2}$$

and

$$F(t)_x = KE_x Nt_x^B \tag{C-3}$$

where: $h(t)_x$ = a failure (hazard) rate function, $F(t)_x$ = a cumulative failure function, N = number of components, K = initial cumulative failure rate at t = 1 hour (or day), t_x = total time spent in a specific test phase, x, and E_x = environmental intensity of a specific test phase, x. (See Appendix B.)

(3) Dwell times at the high and low test temperature are equal and in turn equal yp. The total time spent at the maximum and minimum temperatures is:

$$t_H = t_C = \frac{n}{2} yp \tag{C-4}$$

where: n = the number of cycles (one cycle includes one dwell plus one transition), p = the time for one cycle, and y = dwell time/p.

(4) The environmental intensity factor during temperature transitions is equal to a function of the average rate of change of temperature during the portion of a cycle equal to (1 - y). Then:

$$E_T = G\left(\frac{T_H - T_C}{(1 - y)\,p}\right)^z \tag{C-5}$$

where: G = proportionality constant, z = an unknown power of the average rate of change of temperature.

These assumed conditions are believed reasonable in light of the analytical results presented in the referenced reports. In particular, Ref. 6 reports failures classified in a similar manner and shows the accumulation of failures separately for each class as a function of accumulated time within the class. A general expression for the failure probability in terms of time, temperature, and the degree of temperature cycling was developed using the relationships described above.

From assumption 1,

$$F/N = (F/N)_O + (F/N)_H + (F/N)_C + (F/N)_T \tag{C-6}$$

From assumptions 2 and 3,

$$(F/N)_H = KE_H t_H^B.$$

Letting $t_H = \frac{n}{2}\,yp$ and the total test time $t = n\,p$,

$$(F/N)_H = KE_H\left(\frac{y}{2}\right)^B t^B \tag{C-7}$$

Similarly,

$$(F/N)_C = KE_C\left(\frac{y}{2}\right)^B t^B\text{, and} \tag{C-8}$$

$$(F/N)_T = KE_T(1 - y)^B\, t^B \tag{C-9}$$

From assumption 4, since

$$E_T = G\left(\frac{T_H - T_C}{(1 - y)\,p}\right)^Z,$$

then

$$(F/N)_T = KG(1-y)^B\left(\frac{T_H - T_C}{(1 - y)\,p}\right)^Z t^B \qquad \text{(C-10)}$$

By substituting Eqs. C-7, C-8, C-9, and C-10 in Eq. C-6, combining terms, and simplifying, the final expression for F/N becomes:

$$F/N = (F/N)_0 + K\left[(E_H + E_C)\left(\frac{y}{2}\right)^B + G(1-y)^B\left(\frac{T_H - T_C}{(1 - y)\,p}\right)^Z\right]t^B \qquad \text{(C-11)}$$

where: E_H, E_C = environmental intensity factor during the hot and cold temperature dwell phase, respectively, as defined in Appendix B. (e.g., $E_H = \exp(0.0306(T_H + 32)) + \exp(0.0306(62 - T_H))$.)

Solution for the unknown parameters of Eq. C-11 were obtained by first normalizing the data from Appendix A and then determining least squares solutions for K and B for each set of values of $(F/N)_0$, y, G, and Z iterated over their expected ranges. Both Chi-Square and Kolmogorov-Smirnoff (K-S), goodness of fit statistics were computed for each set of values in order to find the best fit parameters.

The results of this exercise are given in the following equation as the solution for failure probability:

$$F/N = 0.02 + K\left[(E_H + E_C)\left(\frac{y}{2}\right)^B + 3(1 - y)^B\left(\frac{T_H - T_C}{(1 - y)\,p}\right)^{1/2}\right](t + \gamma)^B \qquad \text{(C-12)}$$

where $K = 424 \times 10^{-6}$ failures per unit-hour and B = reliability growth factor (0.7 for component tests).

Note: The actual least squares solution included an additional "location" parameter, γ (gamma). While this required an additional iteration for the solution, it was felt worthwhile since the use of gamma helps to "linearize" initial time variations in the data.

Eq. C-12 is the equation used for determining the effects of component testing. It was also applied to the system test and space operations phases using the appropriate values of K, B, γ, and E for each phase.

The computer program for normalizing the basic data in Appendix A is included in Addendum C-A. The output of the program is shown in Addendum C-B. The program developing the least squares solution for the unknown parameter of Eq. C-11, is shown in Addendum C-C. A sample output is shown in Addendum C-D.

In conclusion, it should be noted that the acceptability of the analytical model was assesed by using the K-S statistic. The computed value for the best fit case was 0.015. Since it is less than the critical value of 0.086, the ability of this model to simulate component test conditions can not be discounted on statistical grounds. Therefore, an inference exists for accepting the model for reliability determinations. It would have been more convincing had this statistical acceptance been supported by the Chi Square statistic as well; however, because of the relatively small sample size of data, compared to the number of "data cells" and the large number of variables required, the number of degrees of freedom was equal to zero. Thus, no conclusion as to goodness of fit could be reached with this statistic.

Additional data beyond the 109 files noted in Appendix A is required in order that an acceptable number of degrees of freedom can be obtained.

ADDENDUM C-A

PROGRAM FOR NORMALIZING THE DATA FROM ADDENDUM A-A

LOAD#6,6
T/V OPTIMIZ. TAPE II

```
10 COM DI[35,8],P$[6],N$[16],L$[4],T$[5],M$[4],C$[2],O$[14]
20 DIM AS[75,12],BS[75,12],A$[20]
30 REM"PROGRAM REDUCES RAW DATA FROM DI(35,8), AND COMPUTES AND STORES"
40 REM"INTERMEDIATE STATISTICS IN AS(75,12); WITH FINAL DATA IN BS(75,12)"
50 REM"FOR FINAL SOLUTION OF F/N=f(n,t,T). THESE ARRAYS ARE THEN STORED"
60 REM"IN #1,1 AND #1,2  OF TAPE II"
70 DISP "DATE";
80 INPUT A$
90 DISP "CHANGE TAPES(C/E)";
100 STOP
110 V=0.0306
120 MAT A=ZER
130 MAT B=ZER
140 FOR K=2 TO 75
150 A[K,1]=6*(K-1)
160 B[K,1]=6*(K-1)
170 NEXT K
180 M=0
190 FOR I=1 TO 109
200 LOAD  DATA #1,I
205 T=T7=0
210 N=D[3,7]
220 C1=D[4,2]
230 C2=D[4,3]
240 B[1,6]=B[1,6]+N
245 CFLAG 6
250 FOR K=5 TO 35
260 IF  D[K,1]=0 THEN 390
270 IF  FLAG6 THEN 350
280 IF  D[K,5]=C1 THEN 290
285 IF  D[K,5]#C2 THEN 380
290 SFLAG 6
300 T7=D[K,8]-D[5,8]
310 T=0
320 A[1,7]=A[1,7]+T7*N
330 A[1,9]=A[1,7]
340 GOTO 380
350 IF  K=5 THEN 380
360 IF  D[K-1,7]=2 THEN 380
370 T=T+D[K,8]-D[K-1,8]
380 NEXT K
390 CFLAG 6
400 M=M+N
410 K1=INT(T/6)
420 IF  K1=T/6 THEN 440
430 K1=K1+1
440 IF  K1<74 THEN 460
450 K1=74
460 FOR K=1 TO 75
470 A[K,2]=B[K,2]=B[K,7]=A[K,11]=0
480 A[K,4]=A[K,5]=0
490 NEXT K
500 FOR K=1 TO K1+1
510 A[K,2]=N
520 NEXT K
530 FOR J=5 TO 35
540 IF  D[J,1]=0 THEN 1040
550 IF  J>5 THEN 570
```

```
560 T1=T2=T3=T4=0
565 GOTO 1030
570 IF  D[J-1,7]=2 THEN 1030
580 T2=T1+D[J,8]-D[J-1,8]
590 IF  D[J-1,7]#1 THEN 830
600 T5=(T1+T2)/2
610 IF  T5 >= T7 THEN 730
620 A[1,6]=A[1,6]+1
630 FOR K=1 TO 75
640 GOSUB 670
650 NEXT K
660 GOTO 830
670 A[K,8]=A[K,8]+1
680 IF  K>K1+1 THEN 720
690 A[K,4]=A[K,4]+1
700 IF  A[K,2] <= 1 THEN 720
710 A[K,2]=A[K,2]-1
720 RETURN
730 T5=T5-T7
740 T6=INT(T5/6)
750 IF  T6*6=T5 THEN 770
760 T6=T6+1
770 IF  T6<74 THEN 790
780 T6=74
790 FOR K=T6+1 TO 75
800 GOSUB 670
810 NEXT K
820 A[T6+1,6]=A[T6+1,6]+1
830 T4=INT(T2/6)
840 IF  T4*6=T2 THEN 860
850 T4=T4+1
860 IF  T4<74 THEN 880
870 T4=74
880 IF  T1>T7 THEN 930
890 IF  T2 <= T7 THEN 1020
900 T3=0
930 FOR K=T3+2 TO T4+1
940 IF  D[J,5]#25 THEN 970
950 V1=23
960 GOTO 980
970 V1=D[J,5]
980 B[K,7]=C1-C2
990 A[K,11]=EXP(V*(V1+32))+EXP(V*(62-V1))
1000 NEXT K
1010 T3=T4
1020 T1=T2
1030 NEXT J
1040 FOR K=1 TO 75
1050 DISP I;K;K1
1060 IF  K>K1+1 THEN 1110
1070 A[K,5]=A[K,2]+A[K,4]
1080 IF  K=1 THEN 1110
1090 B[K,8]=B[K,8]+B[K,7]*A[K,5]*6
1100 A[K,12]=A[K,12]+A[K,11]*A[K,5]*6
1110 A[K,10]=A[K,10]+A[K,2]
1120 NEXT K
1130 X1=X2=X3=0
1140 CFLAG 1
```

```
1150 CFLAG 2
1160 CFLAG 3
1170 CFLAG 4
1175 CFLAG 5
1178 CFLAG 6
1180 FOR J1=5 TO 35
1190 IF FLAG4 THEN 1820
1200 IF D[J1,2]#0 THEN 1290
1210 J=J1-1
1220 IF FLAG1 THEN 1250
1230 IF FLAG2 THEN 1270
1240 GOTO 1820
1250 CFLAG 1
1260 GOTO 1272
1270 CFLAG 2
1272 IF D[J,8]-X3-X1=P2 THEN 1820
1280 GOTO 1540
1290 J=J1
1300 IF D[J,7]#2 THEN 1360
1310 CFLAG 1
1320 CFLAG 2
1330 X2=D[J+1,8]-D[J,8]
1335 SFLAG 6
1340 SFLAG 3
1350 GOTO 1540
1360 IF  NOT FLAG1 THEN 1410
1370 IF D[J,5]#C2 THEN 1720
1380 CFLAG 1
1390 SFLAG 2
1400 GOTO 1540
1410 IF D[J,5]=C1 THEN 1510
1420 IF FLAG2 THEN 1720
1430 IF D[J,5]#C2 THEN 1720
1440 SFLAG 2
1445 IF FLAG6 THEN 1505
1450 X1=D[J,8]
1460 P2=D[J,8]-D[5,8]
1470 GOSUB 1740
1480 P=0
1490 P1=1
1500 GOTO 1720
1505 CFLAG 6
1507 GOTO 1720
1510 SFLAG 1
1520 IF  NOT FLAG2 THEN 1445
1530 CFLAG 2
1540 P2=D[J,8]-X3-X1
1550 GOSUB 1740
1560 IF P3<74 THEN 1590
1570 SFLAG 4
1580 P3=74
1590 P4=6/(P2-P)
1600 IF FLAG5 THEN 1630
1610 SFLAG 5
1620 A[1,3]=A[1,3]+(P2-P)*N
1630 FOR K=(P1+1) TO P3
1640 A[K,3]=A[K,3]+(P2-P)*A[K,5]*6
1650 B[K,2]=P4*A[K,5]
1660 NEXT K
1670 IF  NOT FLAG3 THEN 1700
1680 X3=X3+X2
1690 CFLAG 3
1700 P=P2
```

```
1710 P1=P3
1720 NEXT J1
1730 GOTO 1820
1740 P3=INT(P2/6)
1750 IF P3=P2/6 THEN 1770
1760 P3=P3+1
1770 RETURN
1820 CFLAG 4
1830 CFLAG 5
1840 CFLAG 3
1845 CFLAG 6
1850 FOR K=2 TO K1+1
1860 B[K,3]=B[K,3]+B[K,2]
1870 NEXT K
1880 CFLAG 1
1890 CFLAG 2
1900 NEXT I
1910 A[1,1]=B[1,1]=A[1,9]/B[1,6]
1920 A[1,3]=A[1,3]/M
1930 FOR K=2 TO 75
1940 A[K,7]=(A[K,8]+A[K,10])*6
1950 IF K>2 THEN 2000
1960 A[K,9]=A[K,7]
1970 B[K,4]=B[K,3]
1980 B[K,9]=B[K,8]
1990 GOTO 2050
2000 A[K,9]=A[K-1,9]+A[K,7]
2005 A[K,3]=A[K-1,3]+A[K,3]
2010 B[K,4]=B[K-1,4]+B[K,3]
2020 A[K,12]=A[K-1,12]+A[K,12]
2030 B[K,9]=B[K-1,9]+B[K,8]
2050 B[K,6]=A[K,9] A[K,1]
2055 B[K,5]=B[K,4]/B[K,6]
2060 B[K,10]=B[K,9]/A[K,9]
2070 B[K,12]=A[K,12]/A[K,9]
2080 NEXT K
2090 PRINT TAB55,A$,LIN2
2100 PRINT "     TIME      df       F       Nr      dNT      NT      Ns'"
2110 PRINT "     ----      --      ---      --      ---      --      ---"
2120 FORMAT 5F8.0,F9.0,F8.0
2130 FOR J=1 TO 75
2140 WRITE (2,2120)A[J,1],A[J,6],A[J,8],A[J,10],A[J,7],A[J,9],B[J,6]
2150 NEXT J
2160 PRINT LIN2
2170 PRINT "     TIME   p(c/2)     N-n       n'        d(c-C)     f(TEMP)"
2180 PRINT "     ----   ------     ---      ---        ------     --------"
2190 FORMAT F8.0,F10.4,F11.4,F9.4,F12.2,F13.3
2200 FOR J=1 TO 75
2210 A[J,3]=A[J,3]/A[J,9]
2220 WRITE (2,2190)B[J,1],A[J,3],B[J,4],B[J,5],B[J,10],B[J,12]
2230 NEXT J
2235 REWIND
2240 PRINT LIN2
2250 DISP "TO STORE-(CONT.,EXEC.)";
2260 STOP
2280 DISP "CHANGE TAPES";
2290 STOP
2300 DISP "INPUT #1 TRACK FILES";
2310 INPUT N1,N2
2320 STORE  DATA #1,N1,A
2330 PRINT
2340 STORE  DATA #1,N2,B
2350 PRINT "DATA IS STORED IN T/V OPTIMIZ. TAPE II AS FOLLOWS:"
```

```
2360 PRINT TAB10,"AS(75,12) IN#1,";N1
2370 PRINT TAB10,"BS(75,12) IN #1,";N2,LIN2
2380 DISP "RUN NOW COMPLETE!!"
2385 REWIND
2390 END
```

ADDENDUM C-B

NORMALIZED DATA FROM ADDENDUM A-A

APRIL 30, 1979

TIME	df	F	Nr	dNT	NT	Ns'
10	4	4	198	1985	1985	199
6	5	9	197	1236	1236	206
12	4	13	192	1230	2466	206
18	2	15	187	1212	3678	204
24	0	15	182	1182	4860	203
30	2	17	163	1080	5940	198
36	4	21	161	1092	7032	195
42	0	21	156	1062	8094	193
48	2	23	152	1050	9144	191
54	1	24	148	1032	10176	188
60	0	24	134	948	11124	185
66	0	24	130	924	12048	183
72	1	25	128	918	12966	180
78	1	26	125	906	13872	178
84	0	26	123	894	14766	176
90	3	29	115	864	15630	174
96	0	29	105	804	16434	171
102	0	29	99	768	17202	169
108	1	30	91	726	17928	166
114	0	30	89	714	18642	164
120	0	30	87	702	19344	161
126	0	30	83	678	20022	159
132	0	30	78	648	20670	157
138	0	30	73	618	21288	154
144	0	30	69	594	21882	152
150	0	30	66	576	22458	150
156	0	30	65	570	23028	148
162	0	30	65	570	23598	146
168	0	30	65	570	24168	144
174	0	30	63	558	24726	142
180	0	30	57	522	25248	140
186	0	30	50	480	25728	138
192	2	32	47	474	26202	136
198	0	32	39	426	26628	134
204	0	32	39	426	27054	133
210	2	34	33	402	27456	131
216	0	34	29	378	27834	129
222	0	34	26	360	28194	127
228	0	34	24	348	28542	125
234	0	34	22	336	28878	123
240	0	34	22	336	29214	122
246	0	34	22	336	29550	120
252	0	34	22	336	29886	119
258	0	34	19	318	30204	117
264	0	34	19	318	30522	116
270	0	34	17	306	30828	114
276	0	34	17	306	31134	113
282	0	34	14	288	31422	111
288	0	34	14	288	31710	110
294	0	34	10	264	31974	109
300	0	34	3	222	32196	107

306	0	34	3	222	32418	106
312	0	34	3	222	32640	105
318	0	34	3	222	32862	103
324	0	34	3	222	33084	102
330	0	34	1	210	33294	101
336	0	34	1	210	33504	100
342	0	34	1	210	33714	99
348	0	34	1	210	33924	97
354	0	34	1	210	34134	96
360	0	34	1	210	34344	95
366	0	34	1	210	34554	94
372	0	34	1	210	34764	93
378	0	34	1	210	34974	93
384	0	34	1	210	35184	92
390	0	34	1	210	35394	91
396	0	34	1	210	35604	90
402	0	34	1	210	35814	89
408	0	34	1	210	36024	88
414	0	34	1	210	36234	88
420	0	34	1	210	36444	87
426	0	34	1	210	36654	86
432	0	34	1	210	36864	85
438	0	34	1	210	37074	85
444	0	34	1	210	37284	84

TIME	p(c/2)	N-n	n'	d(o-C)	f(TEMP)
10	0.0341	0.0000	0.0000	0.00	0.000
6	26.6262	63.0171	0.3059	56.65	13.028
12	26.8004	119.6540	0.5823	56.56	12.858
18	27.1386	170.7580	0.8357	56.34	12.686
24	27.2000	214.5720	1.0596	55.85	12.517
30	27.8282	259.5000	1.3106	55.53	12.363
36	28.1117	306.1180	1.5672	55.28	12.294
42	28.3350	351.9530	1.8263	55.09	12.209
48	28.6102	393.6440	2.0664	54.96	12.123
54	28.8201	429.8400	2.2810	54.83	12.039
60	29.3656	465.4570	2.5106	54.70	11.968
66	29.8794	496.3900	2.7193	54.54	11.884
72	30.5155	528.0030	2.9320	54.38	11.847
78	31.1033	556.8940	3.1313	54.23	11.827
84	31.6659	591.7060	3.3661	54.09	11.810
90	32.2330	610.7390	3.5167	53.87	11.783
96	32.8561	626.6830	3.6608	53.61	11.746
102	33.4059	641.5810	3.8043	53.34	11.704
108	33.8828	659.0150	3.9700	53.07	11.644
114	34.3447	675.8550	4.1330	52.81	11.596
120	34.9001	688.4090	4.2705	52.54	11.538
126	35.3446	701.4950	4.4146	52.30	11.488
132	35.7404	714.2580	4.5613	52.03	11.432
138	36.1158	724.1160	4.6941	51.78	11.379
144	36.4845	732.8870	4.8230	51.50	11.321
150	36.7317	742.0320	4.9561	51.23	11.266
156	36.9637	755.6070	5.1188	50.97	11.213
162	37.1159	766.6430	5.2630	50.73	11.164
168	37.2207	777.3450	5.4036	50.50	11.111
174	37.2751	785.9440	5.5308	50.26	11.059
180	37.3367	793.5040	5.6571	50.04	11.007
186	37.4207	802.5160	5.8018	49.83	10.954
192	37.3773	810.7160	5.9407	49.63	10.905
198	37.4028	818.9160	6.0893	49.44	10.859
204	37.4177	824.9230	6.2203	49.25	10.814
210	37.4439	829.9300	6.3478	49.07	10.768
216	37.4531	834.1680	6.4734	48.84	10.714
222	37.4303	839.0400	6.6066	48.61	10.661
228	37.4136	841.9120	6.7254	48.37	10.605
234	37.4132	844.7800	6.8453	48.14	10.549
240	37.4128	847.6480	6.9636	47.91	10.494
246	37.4125	850.5160	7.0805	47.68	10.440
252	37.3686	853.2770	7.1949	47.47	10.386
258	37.3480	856.0380	7.3123	47.25	10.334
264	37.2154	859.0070	7.4300	47.05	10.282
270	37.0929	863.9050	7.5664	46.80	10.225
276	36.9673	865.3740	7.6715	46.56	10.169
282	36.8652	866.8430	7.7796	46.31	10.112
288	36.6717	868.2500	7.8857	46.06	10.055
294	36.4017	868.6680	7.9874	45.81	10.000
300	36.1833	869.08[illegible]	8.0981	45.52	9.939
306	35.9679	869.50[illegible]	8.2074	45.24	9.879

312	35.7555	869.9220	8.3155	44.97	9.819
318	35.5459	870.3400	8.4222	44.69	9.760
324	35.3270	870.3950	8.5240	44.42	9.702
330	35.1240	870.4490	8.6277	44.16	9.643
336	34.9235	870.5030	8.7300	43.89	9.585
342	34.7256	870.5570	8.8311	43.63	9.528
348	34.5301	870.6110	8.9309	43.37	9.472
354	34.3370	870.6650	9.0296	43.12	9.416
360	34.1462	870.7190	9.1270	42.87	9.360
366	33.9578	870.7730	9.2233	42.62	9.306
372	33.7717	870.8270	9.3185	42.37	9.252
378	33.5878	870.8810	9.4125	42.13	9.199
384	33.4060	870.9350	9.5054	41.89	9.146
390	33.2265	870.9890	9.5973	41.65	9.094
396	33.0490	871.0430	9.6881	41.42	9.043
402	32.8737	871.0970	9.7778	41.19	8.992
408	32.7004	871.1510	9.8665	40.96	8.942
414	32.5291	871.2050	9.9542	40.74	8.893
420	32.3597	871.2590	10.0408	40.51	8.844
426	32.1923	871.3130	10.1265	40.29	8.795
432	32.0269	871.3670	10.2113	40.07	8.747
438	31.8633	871.4210	10.2951	39.86	8.700
444	31.6838	871.4210	10.3774	39.64	8.653

ADDENDUM C-C

PROGRAM FOR LEAST SQUARES SOLUTIONS FOR TEST CYCLE PARAMETERS

```
LOAD#(,18
T/V OPTIMIZ. TAPE II


LIST

10 REM "PROGRAM TAKES COMP. TEST DATA,F/N,TIME,Tmax,Tmin,P,AND DOES A LEAST SQ."
20 REM "MULTIPLE REGRESSION ANAL. TO SOLVE PARAM. OF: F/N=F/No+KE*(t-to)↑B2,"
30 REM "WITH A LOGARITHMIC PROGRESSION WEIGHTING. IT THEN GIVES GOODNESS OF FIT"
40 REM "STATISTICS (CHI SQUARE,NULL CHI SQ., AND KOLMOGOROV-SMIRNOV),FOR "
50 REM "EACH OF THE VALUES USED IN THE ITERATIVE SOLUTION."
60 DIM AS[75,12],BS[75,12],C[2,2] D[2,1],E[2,1],FS[75,12],A$[20]
70 DIM T$[40],U$[40],X$[20],Y$[20],W$[5]
80 DISP "DATE";
90 INPUT A$
100 LOAD  DATA #1,5,A
110 LOAD  DATA #1,6,B
120 N1=39
130 REDIM A[N1,12]
140 REDIM B[N1,12]
150 REDIM F[N1,12]
160 N2=34
165 GOTO 190
170 MAT PRINT A;
180 MAT PRINT B;
190 DISP "IF ERROR-1,OK-0";
200 INPUT Z
210 IF Z=0 THEN 233
220 DISP "MAKE CHGE;--CONT.,EXEC. ;
230 STOP
233 DISP "MAX. TIME";
234 INPUT T8
240 E[2,1]=0.6
245 F8=A[1,8]
250 FORMAT F5.2,F7.2,F7.2
260 FORMAT F5.2,F8.3,F8.3,F8.0,F9 3,F4.0,F6.0,2F7.3
265 FOR Z=0.5 TO 0.5 STEP 0.2
270 PRINT LIN2
280 PRINT TAB55,A$,LIN2
290 PRINT TAB20,"GSFC COMPONENT TEST DATA PARAMETERS",LIN1
300 PRINT TAB23,"(*10↑6)",TAB45,"NULL"
310 PRINT "  Y    ";
320 PRINT "  G      BETAt  LAMBDA  Chi Sq/DEGR   Chi2   K-S   K-S*"
330 PRINT "----   ";
340 PRINT " -----  -----  ------  -----------   ----   ---   ----"
360 FOR A=2.5 TO 3.5 STEP 0.5
370 PRINT "  Z";TAB9,"A"
380 PRINT "----";TAB9,"-   ****** ********************************************"
382 WRITE (2,250)Z,A
385 H5=100
390 FOR Y4=0.9 TO 0.9 STEP 0.1
415 PRINT "-------------"
420 FOR G=-0.8 TO -0.4 STEP 0.1
430 FOR Y5=1 TO 2
440 DISP Z;A;Y4;G
450 MAT F=A
460 GOSUB 540
470 GOSUB 750
480 NEXT Y5
490 NEXT G
500 NEXT Y4
510 NEXT A
520 NEXT Z
530 GOTO 1170
540 F1=X1=Y1=F2=X2=Y2=F3=Y3=M=L=0
```

```
550 GOTO 570
560 L=0
570 FOR I=2 TO N1
580 L=L+LOG(B[I,1]+G)
590 M=M+L
600 F[I,5]=(A[I,8]-F8)/B[I,6]
610 F=LOG(F[I,5])
620 E=(B[I,10]/(A[I,3]*(1-Y4)))↑Z
630 E=E*A*(1-Y4)↑E[2,1]
640 E=E+B[I,12]*2*(Y4/2)↑E[2,1]
650 F[I,4]=E
660 X=LOG(F[I,4])
670 F=F-X
680 F1=F1+L*F
690 Y=LOG(B[I,1]+G)
700 Y1=Y1+L*Y
710 F3=F3+L*F*Y
720 Y3=Y3+L*Y*Y
730 NEXT I
740 RETURN
750 C[1,1]=M
760 C[1,2]=Y1
770 D[1,1]=F1
780 D[2,1]=F3
790 C[2,1]=Y1
800 C[2,2]=Y3
810 MAT C=INV(C)
820 MAT E=C*D
830 IF E[1,1]>200 OR E[1,1]<-200 THEN 980
840 E[1,1]=EXP(E[1,1])
850 GOSUB 990
890 M1=M1-5
900 D1=1.22/(200↑0.5)
910 H1=2*N2/E[2,1]
920 REM"D1=K-S* FOR 0.1 LEVEL OF SIGNIFICANCE"
930 REM"H1=NULL CHI SQ. VALUE"
940 IF H>H5 THEN 980
950 WRITE (2,260)Y4,G,E[2,1],(E[1 1]*10↑6),H,M1,H1,S1,D1
960 H5=H
980 RETURN
990 M1=S1=H=0
1000 F1=F3=0
1010 FOR J1=2 TO N1
1020 DISP Z;A;Y4;G;J1
1030 F=E[1,1]*F[J1,4]*(B[J1,1]+G)↑E[2,1]
1040 S2=ABS(F-F[J1,5])
1050 IF S2<S1 THEN 1070
1060 S1=S2
1070 F=F*B[J1,6]
1080 F=F-F1
1090 IF F<5 THEN 1150
1100 F1=F1+F
1110 F2=A[J1,8]-F3-F8
1120 H=H+((F2-F)↑2)/F
1130 F3=F3+F2
1140 M1=M1+1
1150 NEXT J1
1160 RETURN
1170 PRINT LIN1
1180 PRINT "tmax=";B[N1,1];"HRS." TAB45,(2*N2);"DEG. FREEDOM",LIN3
1190 DISP "WANT COMPARISON WITH DATA-(C/E)";
1200 STOP
1210 DISP "INPUT:Y,G,Bt,K*(10↑6)"
1220 INPUT Y4,G,B2,K
1230 K=K/10↑6
1240 DISP "ENTER:Z,A ";
```

```
1250 INPUT Z,A
1260 PRINT LIN2
1261 PRINT TAB55,A$
1262 PRINT "PARAMETERS ARE:",LIN1
1263 PRINT "Y=";Y4
1264 PRINT "G=";G
1265 PRINT "B=";B2
1266 PRINT "K=";K;"*10↑-6"
1267 PRINT "Z=";Z
1268 PRINT "A=";A
1270 PRINT "F/N(E,p,T)=F/No+K*(2E(Y/2)↑B+A(1-Y)↑B(Tx-Tn)/(1-y)p)↑z)(T+G)↑Bt"
1280 PRINT "   TIME    F/Ndata   F/N(E,T)"
1290 PRINT "   ----    -------   --------"
1300 FORMAT F6.0,2F11.3
1310 FOR I=2 TO N1
1320 E=(B[I,10]/((1-Y4)*A[I,3]))↑Z
1330 E=E*A*(1-Y4)↑B2
1340 E=E+2*B[I,12]*(Y4/2)↑B2
1350 F=F8/B[1,6]+K*E*(B[I,1]+G)↑B2
1360 WRITE (2,1300)A[I,1],A[I,8]/B[I,6],F
1370 NEXT I
1380 PRINT "THIS IS IT!!!",LIN3
1390 STANDARD
1400 REWIND
1410 END
```

ADDENDUM C-D

SAMPLE OUTPUT OF PROGRAM FOR LEAST SQUARES SOLUTION

(ADDENDUM C-C)

GSFC COMPONENT TEST DATA PARAMETERS

Y	GAMMA	BETAt	(*10↑6) LAMBDA	Chi Sq/DEGR		NULL Chi2	K-S	K-S*
Z	G							
0.50	2.50							
0.90	-0.800	0.653	420	1.460	-1	104	0.015	0.086
0.90	-0.700	0.654	442	1.451	-1	104	0.015	0.086
0.90	-0.600	0.655	441	1.441	-1	104	0.015	0.086
0.90	-0.500	0.656	439	1.431	-1	104	0.015	0.086
0.90	-0.400	0.656	437	0.412	0	104	0.015	0.086
Z	G							
0.50	3.00							
0.90	-0.800	0.654	432	1.458	-1	104	0.015	0.086
0.90	-0.700	0.655	429	1.446	-1	104	0.015	0.086
0.90	-0.600	0.656	427	1.435	-1	104	0.015	0.086
0.90	-0.500	0.656	426	1.425	-1	104	0.015	0.086
0.90	-0.400	0.657	424	0.405	0	103	0.015	0.086
Z	G							
0.50	3.50							
0.90	-0.800	0.655	420	1.453	-1	104	0.015	0.086
0.90	-0.800	0.655	419	1.453	-1	104	0.015	0.086
0.90	-0.700	0.656	416	1.442	-1	104	0.015	0.086
0.90	-0.600	0.656	415	1.431	-1	104	0.015	0.086
0.90	-0.600	0.656	415	1.431	-1	104	0.015	0.086
0.90	-0.500	0.657	413	1.420	-1	103	0.015	0.086
0.90	-0.400	0.658	412	1.410	-1	103	0.015	0.086

tmax= 228 HRS. 68 DEG. FREEDOM

PARAMETERS ARE:

Y= 0.9
G=-0.4
B= 0.657
K= 4.24000E-04 *10↑-6
Z= 0.5
A= 3

F/N(E,p,T)=F/No+K*(2E(Y/2)↑B+A(1-Y)↑B(Tx-Tn)/(1-y)p)↑z)(T+G)↑Bt

TIME	F/Ndata	F/N(E,T)
6	0.044	0.044
12	0.063	0.059
18	0.073	0.070
24	0.074	0.080
30	0.086	0.089
36	0.108	0.098
42	0.109	0.105
48	0.121	0.113
54	0.127	0.119
60	0.129	0.126
66	0.131	0.132
72	0.139	0.138
78	0.146	0.144
84	0.148	0.150
90	0.167	0.155
96	0.169	0.161
102	0.172	0.166
108	0.181	0.170
114	0.183	0.175
120	0.186	0.180
126	0.189	0.184
132	0.192	0.188
138	0.194	0.192
144	0.197	0.196
150	0.200	0.200
156	0.203	0.204
162	0.206	0.208
168	0.209	0.211
174	0.211	0.215
180	0.214	0.218
186	0.217	0.222
192	0.234	0.225
198	0.238	0.229
204	0.241	0.232
210	0.260	0.235
216	0.264	0.238
222	0.268	0.241
228	0.272	0.244

APPENDIX D

DEVELOPMENT OF THE OVERALL RELIABILITY GROWTH MODEL

APPENDIX D

DEVELOPMENT OF THE OVERALL RELIABILITY GROWTH MODEL

Component reliability growth functions within each thermal vacuum test phase are discussed in Appendix C. This appendix, D, covers the concept and development of mathematical expressions which transfer reliability growth from one phase to another, (e.g., component level testing to system level testing and on to space flight).

There are two approaches that may be used for this purpose. One method assumes a continuous function with time measured from the beginning of component testing all the way through to the end of life; other function parameters are associated with given phases and are used as needed. In the second method, separate functions are used to represent component reliability within each phase, and appropriate adjustments are made at the beginning of each phase based on the end conditions of the preceding phase.

The first method results in a smooth transition of failure rates and total failures. In the second method, a new time base is established for each phase. This results in a failure rate at time t = 0 that theoretically approaches infinity; this is followed by a rapid drop so that at time t = 1 the failure rate is equivalent to the final value achieved in the previous phase. As a consequence, there is a slight increase in the number of failures over those generated when using only one continuous time variable.

The second method is believed to represent the process that occurs between the three phases considered in this study more correctly; it has been used for the following reasons:

(1) The functions for failure rate, h(t), and cumulative failures per component, F/N, for each phase were initially derived independantly, (Ref. 1 and Ap. C). The computed values of the location parameter, gamma (γ), used in each case did not indicate the need for further adjustments to the time base.

(2) Ref. 1 infers a correlation between final system test failure rate and the space failure rate function at time t = 1. Mathematically, this can be expressed as:

$$h(t)_{TEST} = (KEB)_{SPACE} \quad \text{(D-1)}$$

where K, E, and B are the reliability growth function parameters defined in Appendix C.

Also, as in Eq. C-2 of Appendix C (but with $t + \gamma$ substituted for t), the function

$$h(t) = KEB(t + \gamma)^{B-1} \quad \text{(D-2)}$$

describes the failure rate at any time, t, during system test (see Ref. 1).

(3) The ability of the model to simulate an increase in the number of failures at the start of system test and also during space flight is a highly desirable feature that accounts for those defects introduced because of the interactive effects of one component on another (resulting, perhaps, from system integration and the disruptive or transient thermal stresses present during the launch). In the techniques used in "failure flow analysis," these perturbations are taken into account and added to the defect population in subsequent events (Ref. 17).

In the approach of the second method described above, an allowance for these initial anomalies is automatically included at each successive phase. The first method does not simulate this situation.

A graphical representation of this process is shown in Fig. D-1 (using a constant environmental intensity). Both failure rate, $h(t) \times 10^4$, and cumulative failure per component, $(F/N) \times 100$, are plotted. Had these functions been plotted using full logarithmic coordinate paper, system, they would both appear as straight line functions of time. (This is a convenient characteristic of a "power distribution" or the Duane growth model.) Note that there is a continual decrease in failure rate (increase in reliability), except for the time between successive phase.

As noted above, Fig. D-1 represents a reliability process with the environmental intensity held constant for each phase. If the intensity factor in any phase were increased, the failure rate

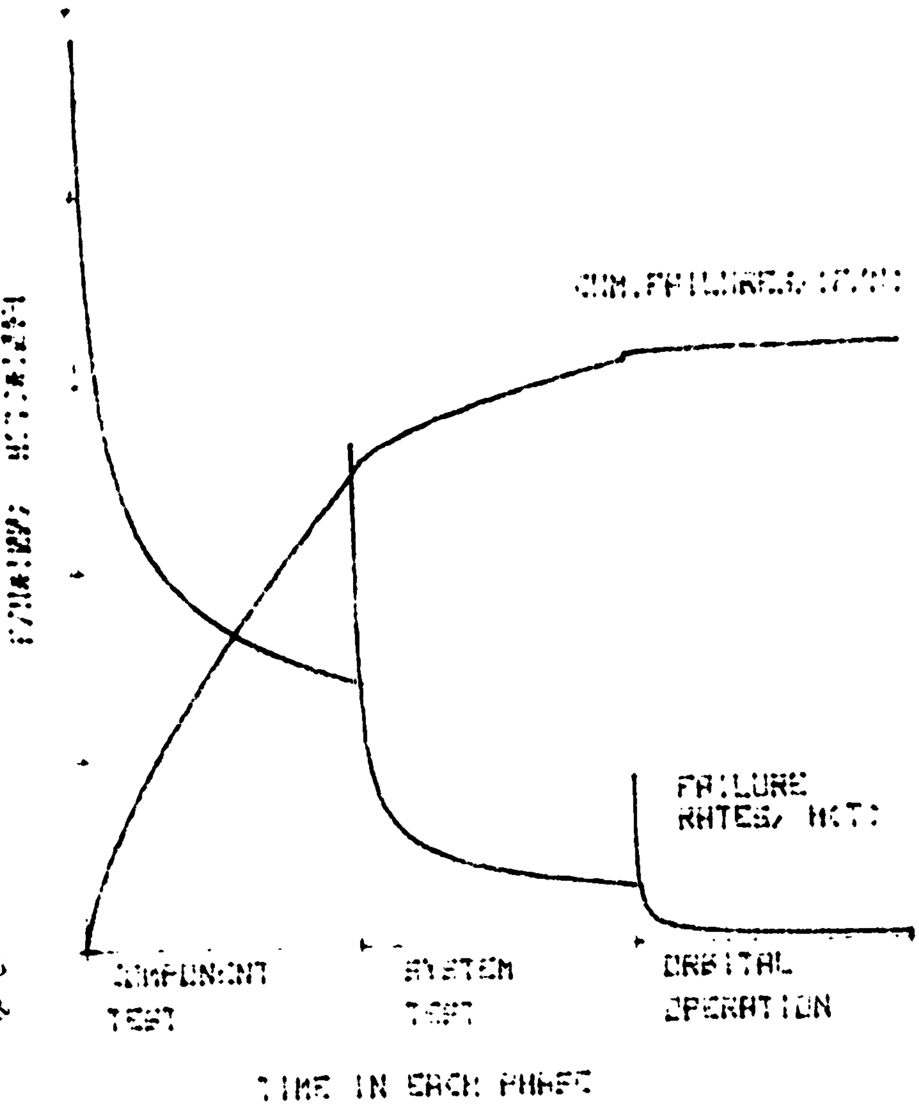


Figure D-1. Analytical Model Trends of Failures and Failure Rates for Test and Operational Phases

would be higher and more failures would be expected in a given period of time. A corollary to this statement is that the same number of failures in a test will result in a shorter period of time if the environmental intensity is increased.

An interpretation of this relationship is represented graphically in Fig. D-2 which shows the relationship between time and failure rate on a logarithmic scale. Total failures are represented as the areas under the curves. Using the concepts of failure flow analysis and the above, we can write the following relationship:

$$(F/N)_I + (F/N)_{II} = (F/N)_I + (F/N)_{III} \qquad \text{(D-3)}$$

where (F/N) is the number of failures per component and the Roman numeral subscript indicates the appropriate enclosed area in Fig. D-2.

d' is chosen such that

$$(F/N)_{II} = (F/N)_{III} \qquad \text{(D-4)}$$

Substituting the equations for F/N developed as a function of E and t (Appendix C, Eq. C-3) into Eq. D-3, leads to the solution of the equivalent time, d', a function of environmental intensity E.

$$d' = \left(\frac{E}{E'}\right)^{1/B} d \qquad \text{(D-5)}$$

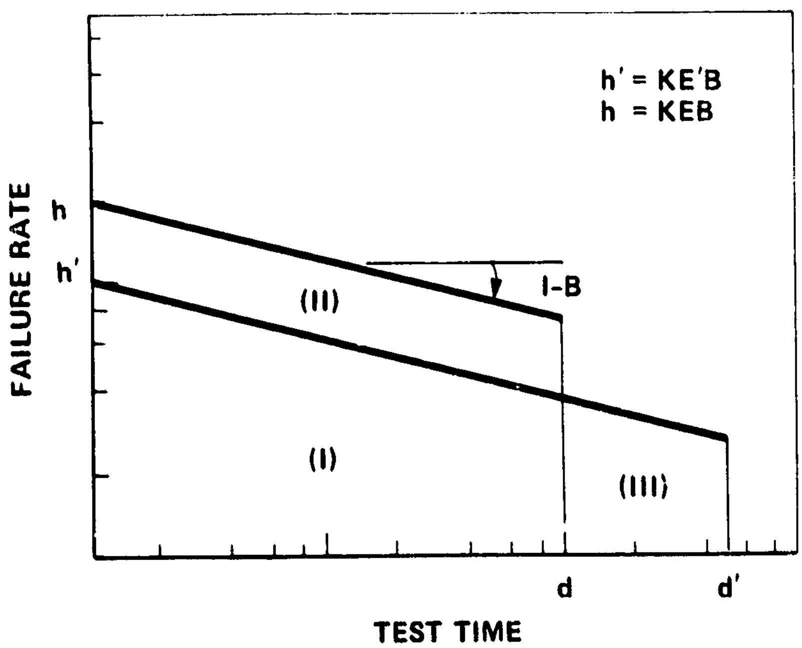


Figure D-2. Effects of Environmental Intensity Factor, E, on Failure Rate

Thus, the failure rate of an item under test at an environmental intensity of E for a duration d results in a failure rate of the item at an intensity of E′ of

$$h(t, E') = KE'B\left(\frac{E}{E'}\right)^{\frac{B-1}{B}} (t + \gamma)^{B-1} \qquad \text{(D-6)}$$

where $t + \gamma = d$.

As can be seen from Fig. D-2, the immediate effect of increasing environmental intensity is an increase in the inherent failure rate inferring a decreased failure rate (and a commensurate increase in reliability) in subsequent operation assuming that the operating environmental intensity is returned to the lower value, E. (It is assumed that no unrealistic failure modes are introduced by the various values of the environmental intensity.)

This philosophy, together with Eqs. D-5 and D-6, was used in deriving the mathematical relationship for component failures and failure rates from component testing through space operation. These relationships are given in Addendum A to this appendix. They are used within the total algorithm contained in the computer program (see Addendum J-C) which, in turn, is designed to compute component reliability parameters in space as a function of the component and system test plan.

Fig. D-3 is a plot of failure rates generated by the analytical model. Typical parameters as observed in the analysis of actual data from GSFC spacecraft programs from 1960 to 1970 were used to generate these graphs. The results are in good agreement with the average values of the data sample of 57 spacecraft (Ref. 1).

An environmental intensity factor for space of 14.26 is used in this model. This value was arrived at as follows. First, a set of assumptions was made as to the average orbital conditions. These were:

(a) The temperature ranges between 5°C and 35°C,

(b) It takes six months to go from one temperature to another,

(c) The temperature varies linearly with time,

(d) There is no short-term thermal cycling effect.

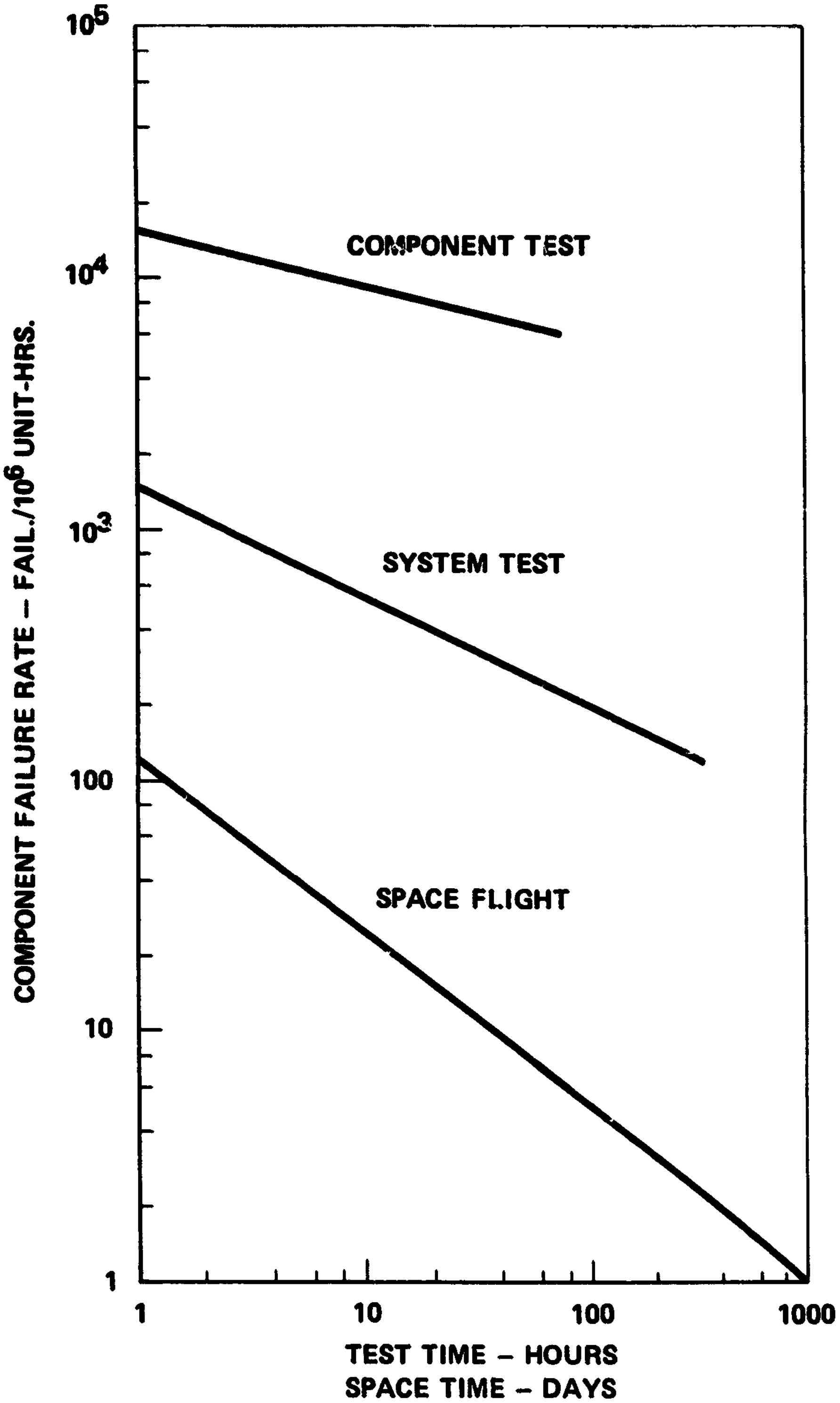


Figure D-3. Typical Failure Rates for GSFC Spacecraft

In view of the very slowly varying temperature (30°C in six months), it was considered more appropriate to apply an "average temperature" approach to deriving an environmental intensity. Eq. D-A-4 (of Addendum D-A) provides an equation for the environmental intensity at constant temperature as

$$E_{H/C} = e^{0.0306(T_{H/C} + 32)} + e^{0.0306(62 - T_{H/C})} \qquad \text{(D-7)}$$

(The subscript H/C indicates a maximum or minimum temperature condition as appropriate.)

Over the range of 5°C to 35°C, E_H is approximately equal to E_C. One can then say that $E_H + E_C$ is equal to twice some average environmental intensity, $\overline{E}$, that can be expressed as

$$\overline{E} = \frac{1}{\Delta T} \int_{T_1}^{T_2} E_{H/C}\, dT$$

$$= \frac{1}{\Delta T} \left[\int_{T_1}^{T_2} e^{0.0306(T + 32)}\, dT + \int_{T_1}^{T_2} e^{0.0306(62 - T)}\, dT \right] \qquad \text{(D-8)}$$

so that the environmental intensity can be expressed as:

$$E_H + E_C = 2\overline{E} \qquad \text{(D-9)}$$

Although the temperature profile actually consists only of very long transitions (of six months duration) and zero length dwells, the value for y is selected as unity. This is done in consonance with the concept that the very long transitions induce a stress comparable to that which would arise from the application of an average temperature; the long transitions then become essentially dwell times at the average temperature. What would normally be considered dwell time (the time spent at a constant temperature) is zero for the triangular temperature functions. Therefore, this triangular function results only in a dwell (equal in length to the time to go from one temperature extreme to the other) and no transition. Since p is defined as transition plus dwell time and y is defined as dwell time divided by p, y then equals unity.

The bracketed term on the right hand side of Eq. C-12 of Appendix C may be seen to be the total environmental intensity factor. Substituting Eq. D-9 and the value for y of unity into this expression yields, as the total environmental intensity,

$$E_{TOTAL} = (2\overline{E})\left(\frac{1}{2}\right)^{B} + 3(1 - y)^{B}\left(\frac{T_H - T_C}{(1 - y)\,p}\right)^{1/2} \qquad \text{(D-10)}$$

The second term in the right hand side of Eq. D-10 actually accounts for stresses in the transition phase and since, as shown before, the transition time is taken as zero, this term becomes zero.

Performing the integration of Eq. D-8 yields, as the solution for the average environmental intensity,

$$\overline{E} = \frac{1}{0.0306(T_H - T_C)}\left[e^{0.0306(T_H+32)} - e^{0.0306(62-T_H)} - e^{0.0306(T_C+32)} + e^{0.0306(62-T_C)}\right] \qquad \text{(D-11)}$$

Taking $T_H = 35°C$ and $T_C = 5°C$ yields a value of $E_{TOTAL} = 14.26$.

It is recognized that this method yields only an approximate solution for the space environmental intensity. However, because of time limitation and a lack of data, further effort in this area was not possible. Continued study and refinement should be pursued in the final phase of study so that the parameter, E, may be determined for any specified orbital condition.

ADDENDUM D-A

MATHEMATICAL RELIABILITY RELATIONSHIPS FOR TEST AND SPACE PERFORMANCE

ADDENDUM D-A

MATHEMATICAL RELIABILITY RELATIONSHIPS FOR TEST AND SPACE PERFORMANCE

Definitions:

B,	Reliability growth parameter; equal to the slope (on a log-log graph) of the relationship between cumulative failures and time. (B_2 = 0.7, B_1 = 0.6, B_0 = [illegible]314)
E,	Environmental intensity
h( ),	Hazard or failure rate
K,	Initial cumulative failure rate at time = 1
N,	Number of components
p,	Dwell time + transition time; dwell time is the time that the item spends at the hot or the cold temperature (taken as equal), transition time is the time that the item takes in going from the hot to the cold condition or vice versa (taken as equal in the two cases)
T,	Temperature, degrees Celsius
t,	Time within a specific phase (test or orbital); hours or days as appropriate
y,	Dwell time/p
γ,	Gamma, location parameter; applied to a particular function so that it may more closely represent initial variations in data. (γ_2 = -0.4h, γ_1 = -0.8 days, γ_0 = 3 days)

Subscripts:

2, 1, 0,	Component test, system test, or orbital phase related (respectively)
4,	Transformation to space environmental intensity and time units in days
H,	Maximum temperature condition
C,	Minimum temperature condition
H/C,	A convention indicating the maximum or minimum case depending on whether the H portion or the C portion is considered

I. COMPONENT TEST PARAMETERS

1. Failure (Hazard) Rate (see Eq. D-2)

$$h(t_2, E_2) = K_2 E_2 B_2 (t_2 + \gamma_2)^{B_2 - 1} \text{ failures per unit hour*} \qquad \text{(D-A-1)}$$

2. Failures (see Eq. C-12)

$$F_2 = 0.02N + NK_2E_2(t_2 + \gamma_2)^{B_2} \text{ failures} \qquad \text{(D-A-2)}$$

3. Environmental Intensity

$$E_{H/C} = e^{0.0306(T_{H/C} + 32)} + e^{0.0306(62 - T_{H/C})} \qquad \text{(D-A-3)}$$

$$E_2 = (E_H + E_C)\left(\frac{y}{2}\right)^{B_2} + 3(1 - y)^{B_2}\left(\frac{T_H - T_C}{(1 - y)\, p}\right)^{1/2} \qquad \text{(D-A-4)}$$

4. Failure Rate Related to the Environmental Intensity of Space, E_0, (from Eq. D-6)

$$h(t_2, E_0) = (24^{B_2})\, K_2 E_0 B_2 \left(\frac{E_2}{E_0}\right)^{\frac{B_2 - 1}{B_2}} (t_2 + \gamma_2)^{B_2 - 1} \qquad \text{(D-A-5)}$$

where 24^{B_2} is necessary to convert failure rate units from hours to days, letting

$$K_4 = (24^{B_2})\, K_2 \left(\frac{B_2}{B_1}\right)\left(\frac{E_2}{E_0}\right)^{\frac{B_2 - 1}{B_2}} \qquad \text{(D-A-6)}$$

then, the final failure rate can be expressed as

$$h(t_2, E_0) = K_4 E_0 B_1 (t_2 + \gamma_2)^{B_2 - 1} \qquad \text{(D-A-7)}$$

II. SYSTEM TEST PARAMETERS

A. Without Component Test

1. Failure rate related to an environmental intensity of space, E_0,

$$K_1 = K_4$$

*Note: K_2, the initial cumulative failure rate for components, is taken as 424×10^{-6}. This is based on past history. Variations in the inherent failure rates that may accompany new techniques may cause this value to change.

then,

$$h(t, E_0) = K_1 E_0 B_1 \left(\frac{E_1}{E_0}\right)^{\frac{B_1 - 1}{B_1}} (t_1 + \gamma_1)^{B_1 - 1} \quad \text{(D-A-8)}$$

2. Failures

$$F_1 = 0.02N + NK_1 E_1 (t_1 + \gamma_1)^{B_1} \quad \text{(D-A-9)}$$

B. With Component Test

1. Failure rate related to an environmental intensity of space, E_0

$$K_1 = K_4 (t_2 + \gamma_2)^{B_2 - 1} \quad \text{(D-A-10)}$$

where t_2 is the final time of component test. Then,

$$h(t_1, E_0) = K_1 E_0 B_1 \left(\frac{E_1}{E_0}\right)^{\frac{B_1 - 1}{B_1}} (t_1 + \gamma_1)^{B_1 - 1} \quad \text{(D-A-11)}$$

2. Failures

$$F_1 = NE_1 K_1 (t_1 + \gamma_1)^{B_1} \quad \text{(D-A-12)}$$

III. SPACE OPERATION PARAMETERS AT AN ENVIRONMENTAL INTENSITY OF E_0

A. No System Test

(a) No component test

1. Failure rate; using K_4 from Eq. D-A-6,

$$K_0 = K_4 (B_1/B_0) \quad \text{(D-A-13)}$$

$$h(t_0) = K_0 E_0 B_0 (t_0 + \gamma_0)^{B_0 - 1} \quad \text{(D-A-14)}$$

2. Failures

$$F_0 = 0.02N + NE_0 K_0 (t_0 + \gamma_0)^{B_0} \quad \text{(D-A-15)}$$

(b) With component test:

1. Failure rate

$$K_0 = K_4 (B_1/B_0) (t_2 + \gamma_2)^{B_2-1} \quad \text{(D-A-16)}$$

where t_2 is the time at the end of component test

$$h(t_0) = K_0 E_0 B_0 (t_0 + \gamma_0)^{B_0-1} \quad \text{(D-A-17)}$$

2. Failures

$$F_0 = N_0 E_0 K_0 (t_0 + \gamma_0)^{P_0} \quad \text{(D-A-18)}$$

B. With System Test

(a) With or without component test

1. Failure rate

$$K_0 = K_1 (B_1/B_0) \left(\frac{E_1}{E_0}\right)^{\frac{B_1-1}{B_1}} (t_1 + \gamma_1)^{B_1-1} \quad \text{(D-A-19)}$$

where t_1 is the time at the end of system test

$$h(t_0) = K_0 E_0 B_0 (t_0 + \gamma_0)^{B_0-1} \quad \text{(D-A-20)}$$

2. Failures

$$F_0 = N_0 K_0 E_0 (t_0 + \gamma_0)^{B_0} \quad \text{(D-A-21)}$$

APPENDIX E

LAUNCH COSTS

APPENDIX E

LAUNCH COSTS

The analytical model provides t' ∘ user with the ability to determine the cost of launching a payload, it includes a large number of options. Either an expendable launch vehicle or the Space Transportation System can be selected. Payload project launch costs (e.g., manpower) are not included.

In order to keep the program simple, only three expendable launch vehicle options are included, the Scout, the 2900 series Delta, and the 3900 series Delta. Other options can easily be added to the model since they are simply fixed inputs.

Using the value of the 1978 dollar as a basis, the cost of a Scout launch (obtained from a project that uses a Scout launch vehicle) is taken as 2.4 million dollars (abbreviated in this report as $2.4M) of which $2.2M was for vehicle costs and $0.2M for support services.

The cost of using the 2900 series Delta (Castor II) was estimated as $15.4M and the 3900 series Delta (Castor IV) as $19.0M. Both of these costs were obtained as rough estimates from the GSFC Delta project office; the costs include support service costs from the contractor.

STS costs were derived from Ref. 7. This reference describes the way in which STS costs may be assessed against a user and contains a large number of options. The descriptions contained in Ref. 7 lend themselves to an interactive computer approach and this approach was followed.

Again, in the interests of simplicity, only certain of the options are included in the analytical model. Basically they include:

(a) a dedicated or a shared mission,

(b) free-flier attached, or Spacelab payload configurations (small, self-contained payloads are not included),

(c) if Spacelab, a dedicated or shared element. Also, whether pallets only or pallets and the pressurized module are used.

(d) Orbital Maneuvering Systems (OMS) kits are available in the free-flier or attached payload configuration options (OMS kit weight and length are internally added as payload parameters).

The model is designed to construct costs based on either weight or length depending on which parameter is determined as governing within the model. The volume parameter applicable to the Spacelab payload configuration was not included in the interests of simplicity.

The model assumes a 60,000 pound STS capability and develops costs based on this. Also, the user is considered as Civilian, U.S. Government. In the Spacelab configuration, only the long pressurized module is considered. The number of pallets required is a user input and checks are made internally to determine that Spacelab element weight constraints are not exceeded.

The user is also provided the option of adding an upper stage to an STS payload. Five configurations are available. Estimates as to cost, weight, and length were obtained verbally from NASA Headquarters. They include support services. The values used (normalized to 1978 dollars) are:

(a) SSUS-D: $3.2M, 7,500 lbs, 7.5 ft.

(b) SSUS-A: $3.6M, 12,200 lbs, 8 ft.

(c) IUS-two stage: $12.4M, 32,000 lbs, 16.4 ft.

(d) IUS-twin stage: $14.5M, 48,700 lbs, 21.8 ft.

(e) IUS-twin stage + spinner: $15.3M, 55,900, 27.2 ft.

The section of the program that deals with launch costs is contained in File #2 and runs from step 25 to step 2113 and subroutines from step 5990 to 7240 and from step 8000 to 9680.

APPENDIX F

ESTIMATION OF PAYLOAD WEIGHT BASED ON COMPONENT COUNT

APPENDIX F

ESTIMATION OF PAYLOAD WEIGHT BASED ON COMPONENT COUNT

In instances where the payload weight is unknown, it may be estimated based solely on component count. This is obviously a very rough approximation but provides a user with a way of exercising the program.

The estimating algorithm was derived by comparing the number of components in a number spacecraft (taken from Refs. 1, 4, 5, and 6) with the total spacecraft weight as listed in Ref. 8. Spacecraft from the time frame 1965–1969 (29 samples, Fig. F-1) and 1970–1975 (26 samples, Fig. F-2) were compared using a least squares solution to an equation of the form

$$y = c \cdot \exp(mx) \qquad \text{(F-1)}$$

Inasmuch as the data from Fig. F-2 were the more recent and therefore felt to be more representative, the equation:

$$\text{Payload Weight, pounds} = 118.28 \cdot \exp(0.0301 \times \text{Number of Components}) \qquad \text{(F-2)}$$

was used as the algorithm to establish payload weight for a free-flier payload.

The instrument portion of a free-flier payload was taken to be 1/4 of the total payload weight. This proportion was arrived at from data taken from Table 1 of Ref. 9. Table 1 also provides data on gross weight and experiment weight for 17 GSFC spacecraft. This data is plotted in Fig. F-3 together with the straight line describing the relationship. This line is fitted by eye.

If the payload is an STS attached or Spacelab payload, the entire weight, as computed by Eq. F-2 is taken as the instrument weight.

The portion of the program that performs the estimating is contained in the subroutine steps 4000 to 4300 in File #2.

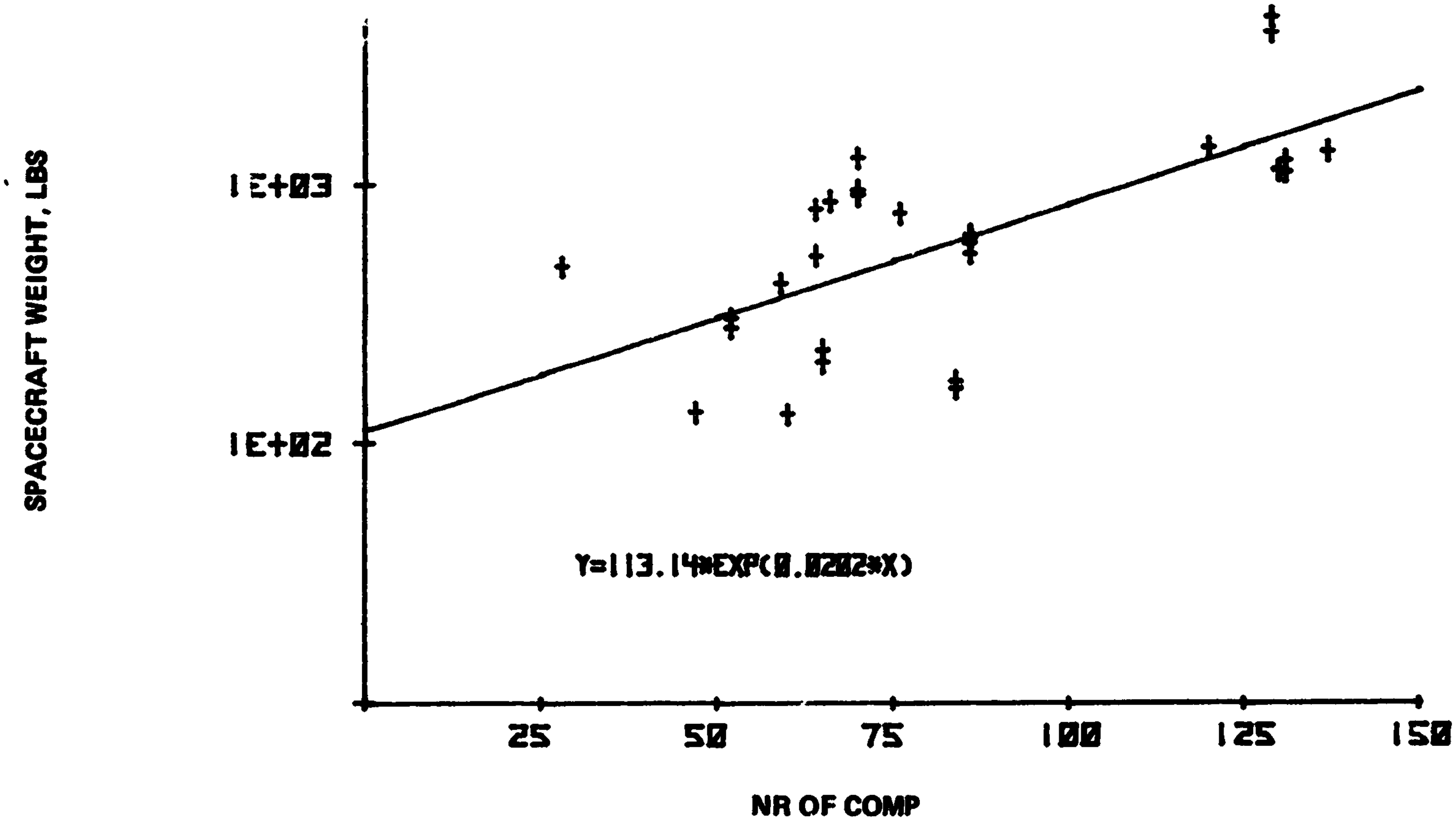


Figure F-1. Total Components per Spacecraft (1965-1969) vs. Spacecraft Weight

C-2

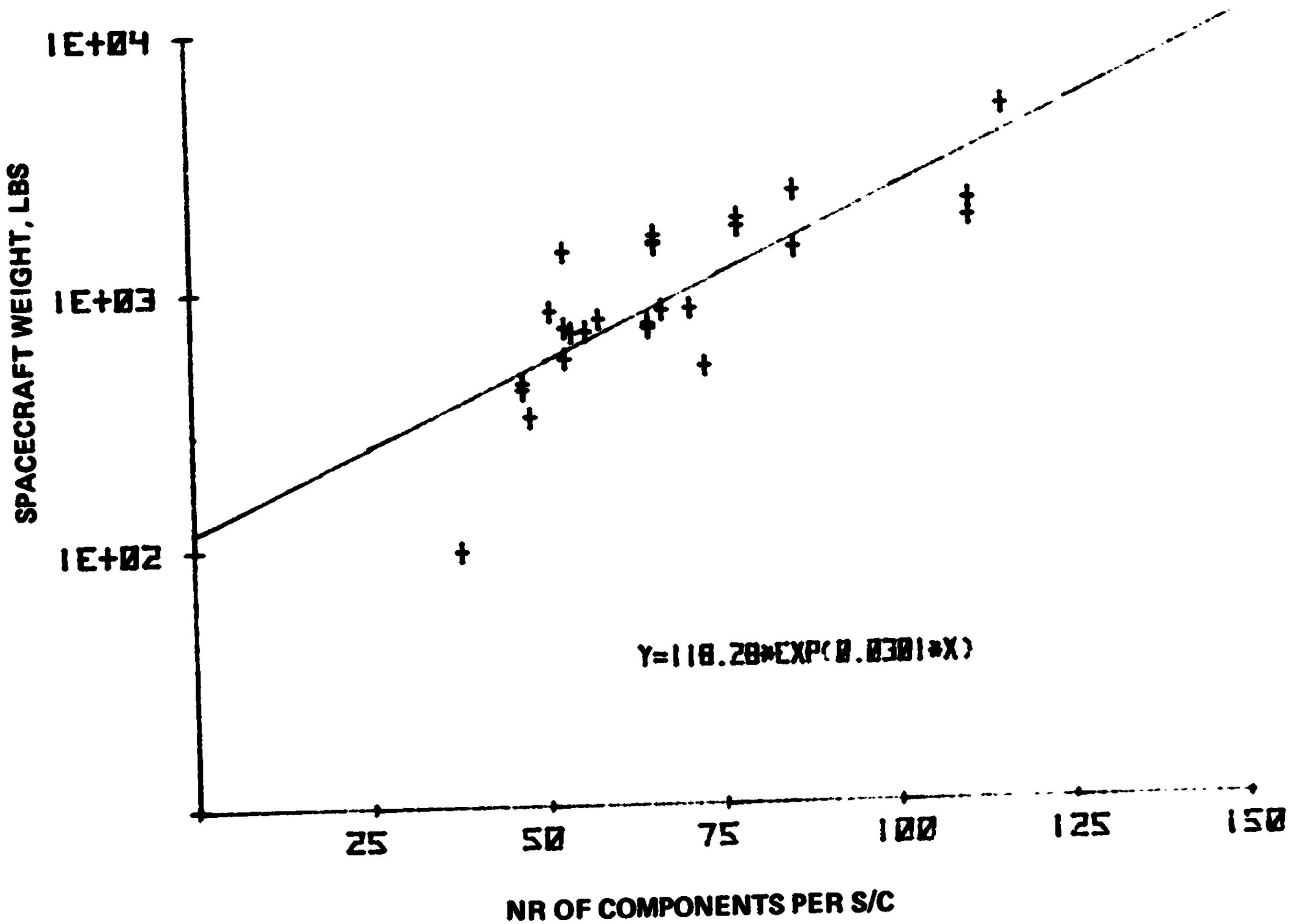


Figure F-2. Total Components per Spacecraft (1970-1975) vs. Spacecraft Weight

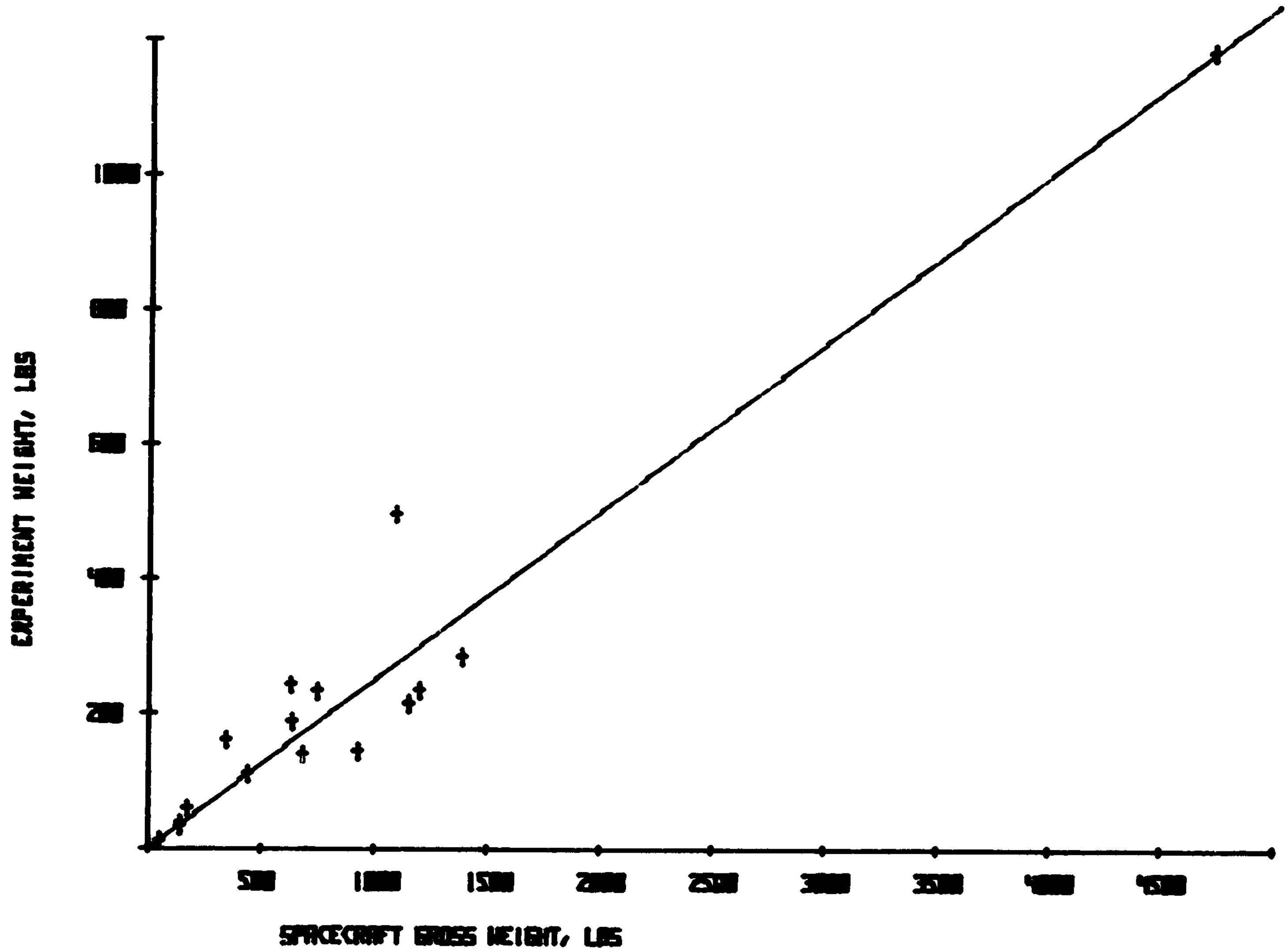


Figure F-3. Experiment vs. Spacecraft Gross Weight (Based on 17 GSFC Spacecraft)

APPENDIX G

ESTIMATION OF PAYLOAD RECURRING COSTS

APPENDIX G

ESTIMATION OF PAYLOAD RECURRING COSTS

The model requires an input of payload recurring costs. If the user is unable to provide this as an input, it is internally generated based on the payload weight, the type of instrument involved, and whether the payload is a free-flier or not.

If the payload is a free-flier, the payload weight is distributed as 3/4 to the platform and 1/4 to the instruments. The platform cost is then computed using the equation:

$$\text{Platform Cost, M\$} = 0.02498\ (\text{Platform Weight, lbs})^{0.81} \qquad \text{(G-1)}$$

This relationship is taken from the recurring cost estimating relationship for the first unit as found on page IV-29 of Ref. 10.

Exhibit 5-1 of Ref. 11 provides cost estimating relationships (for the first flight unit, less design, development, test and evaluation) for 18 types of instruments. 17 of these are based on weight and one on power. In order to simplify the program, the relationship based on power was omitted and the remaining 17 divided among three groups. The user of the program can compare his particular case to the three groups (which name the instrument types) and select the best fitting relationship. If none of the groups seem to fit as the instrument is unknown (as was the case in developing the program), the user is instructed to select the average case.

If the payload is attached to the STS or a Spacelab mission, the entire weight is considered as instrument and the cost computed accordingly.

The subroutine, steps 4430 to 4940, in File #2 performs the cost estimating portion of the program.

APPENDIX H

TEST COSTS

APPENDIX H

TEST COSTS

Table H-1 has been prepared based on data received from aerospace industry and government sources. Since the basic data provided by the contractors contains information on the internal company operations and since it was desired that this report be generally available, the data on which Table H-1 is based has not been made part of this report; it is contained in a separate document.

The nominal complexity of the payload indicated in the table is basically that of an earth-orbiting, scientific spacecraft with a one to three year projected lifetime. It would be similar to previous ones although requiring entirely new structure. However, very few, if any, entirely new housekeeping function designs would be needed. Experiment instrument requirements during test would be modest during test insofar as stimuli or test configuration constructions; for instance, no critical alignments or special movements are needed. The spacecraft would contain some 40 housekeeping components plus eight to ten instruments.

As a first approximation for simplicity, algorithms have been devised that base test costs on the maturity of the item (i.e., protoflight, first flight unit, or follow-on unit) and on the number of components contained in the item. Table H-1 is constructed from adjusted costs of nominal complexity tests in 50000 and 1500 cu. ft. facilities and average component test costs in a 50 cu. ft. facility, it presents the actual algorithms.

One cost that is included under test but is not immediately apparent is sometimes referred to as a "marching army" cost. This is a cost arising in other project areas due to a delay caused by the test program. The present algorithm contains only a rough estimate of this cost. It is based on $120,000 per week for a payload having 84 components or .120/(84 x 7) million dollars per component per day.

Table H-1

Test Cost Algorithms

I. Component Level Tests: (50 cu ft chamber)

1. Protoflight or Qualification Unit or Follow-On unit

   Cost, \$ = (N9 + F2) x (868 + 25.2 x T2) + F2 x Q1

2. First Flight Unit Costs = 2 x Qualification unit component test costs

II. System Level Tests:

A. Large Chamber (30,000 to 50,000 cu ft)

1. Protoflight or Qualification Unit:

   Cost, \$ = (N9 x 3,400 + 147,000) + T1 x (N9 x 177 + 17,000) + Q2 x (N9 x 158 + 6,160) + F1 x Q1 + Q3 x N9 (T1 - T1/1.34)

2. First Flight Unit:

   Cost, \$ = Cost for a qualification unit test (same times and failures) + (N9 x 861 + 40,300) + T1 x (N9 x 44.5 + 7,000) + Q2 x (N9 x 158 + 6,160) + F1 x Q1 + Q3 x N9 (T1 - T1/1.34)

3. Follow-On Unit:

   Cost, \$ = (N9 x 158 + 6,160) + T1 x (N9 x 44.5 + 7,000) + Q2 x (N9 x 158 + 6,160) + F1 x Q1 + Q3 x N9 (T1 - T1/1.34)

B. Medium Sized Chamber: (1,000 to 2,000 cu ft)

1. Protoflight or Qualification Unit:

   Cost, \$ = (N9 x 2,860 + 69,800) + T1 x (N9 x 96.4 + 1,240) + Q2 x (N9 x 133 + 2,920) + F1 x Q1 + Q3 x N9 (T1 - T1/1.34)

2. First Flight Unit:

   Cost, \$ = Cost for a qualification unit test (same times and failures) + (N9 x 679 + 19,100) + T1 x (N9 x 24.2 + 516) + Q2 x (N9 x 133 + 2,920) + F1 x Q1 + Q3 x N9 (T1 - T1/1.34)

3. Follow-On Unit:

   Cost, \$ = (N9 x 133 + 2,920) + T1 x (N9 x 24.2 + 516) + Q2 x (N9 x 133 + 2,920) + F1 x Q1 + Q3 x N9 (T1 - T1/1.34)

Legend:
- N9 = Number of Components
- T2 = Test duration, hours; F2 = Nr. of failures in component test
- T1 = Test duration, days; F1 = Nr. of failures in system test
- Q1 = Repair Costs/failure (\$5,300)
- Q2 = (Nr. of system tests with retests)/(Nr. of system tests with and without retest) = 27/39; based on GSFC data base
- Q3 = Estimated Marching Army cost, \$120K/84 component system/week = \$120/(84 x 7)

APPENDIX I

DETERMINATION OF AVAILABILITY

APPENDIX I

DETERMINATION OF AVAILABILITY

In Ref.2, the Planning Research Corporation developed a parameter that they termed "availability"* to describe the usefulness of a spacecraft system as the mission progresses. A, the instaneous availability immediately after the n^{th} anomaly, was defined in terms of the degradation due to the anomalies up to the point as

$$A = \prod_{i=1}^{n} (1 - D_i) \tag{I-1}$$

where Di was defined as the mission degradation that results from the anomaly when compared to a perfectly functioning system.

This approach allows for the continuing operation of a payload even with a number of degrading anomalies.

For simplification, each anomaly was assigned a mission effect code with a corresponding degradation as follows:

Mission Effect Code	Degradation (Per Cent)
1	2.5
2	20
3	50
4	80
5	97.5

Ref. 4 presents data based on a study of 57 spacecraft (all under GSFC cognizance). In Fig. 5 of Ref. 4, the author presents a chart indicating the criticality of the total space malfunctions (analogous to the PRC term "anomaly") of the 57 spacecraft in the form of bar graphs.

Note* This usage of the term "availability" is different than that generally found in standard reliability texts.

The criticality of each malfunction is divided as follows:

Criticality	Percentage Loss
1. Catastrophic	>90
2. Major Loss	50–90
3. Substantial Loss	10–50
4. Minor Loss	0–10

The data is presented in Ref. 4 considering the existing conditions i.e., with such redundancy as existed during the mission and without redundancy. In the case including redundancy, the values shown are:

Criticality	Percentage of Malfunctions
1	2.1
2	1.9
3	11.4
4	84.6

Addendum I–A presents data concerning the variation of the criticality of malfunctions with time; while a formal proof was not undertaken, it was felt that there was sufficient evidence to support the thesis that the criticality of a malfunction was invariant with time. With this hypotheses, one should be able to describe a single value of criticality, D*, that can be assigned to each malfunction of a particular spacecraft such that

$$(1-D^*)^n = \prod_{i=1}^{n} (1-D_i) \qquad \text{(I-2)}$$

where n is the number of malfunctions up to some time.

If D_i assumes m number of different values of which any one can occur w to z times, then Eq. (I–1) may be expanded and written as:

$$A = (1 - a)^w \times (1 - b)^x \times \ldots \times (1 - m)^z \, . \qquad \text{(I-3)}$$

Recognizing that $n = w + x + \ldots + z$, we may take the logarithms of Eq. I-3 and I-2 and by dividing one by the other and rearranging terms, we can find the value of the criticality, D*, based on actual data as

$$D^* = 1 - \exp\left[\frac{1}{n}\left(w \ln(1 - a) + x \ln(1 - b) + \ldots + z \ln(1 - m)\right)\right] \qquad \text{(I-4)}$$

Substituting this value into Eq. I-1 the availability can be expressed as

$$A = (1 - D^*)^n \qquad \text{(I-5)}$$

Ref. 1 provides the bridge needed to determine spacecraft availability as a function of time. Eq. 3 of Ref. 1 expresses a relationship (based on a study of 57 spacecraft programs having an average of some 65 components per spacecraft) that determines a cumulative failure rate as:

$$\lambda_\Sigma = \frac{F}{N(t + \gamma)} = K_0(t + \gamma)^{-\alpha} \text{ failures per day} \qquad \text{(I-6)}$$

where: F is the number of failures during time t, N is the average number of components per spacecraft, γ is a "location parameter" similar to that used to fit a Weibull distribution, and α is the slope of the line (a growth rate).

The negative sign in the exponent is based on a convention of referring to α as positive in sign. However, the sign of α in the reliability growth case is negative and so the sign in Eq. I-6 should actually be positive. To maintain the mathematical treatment correctly, Eq. I-7 which follows and the rest will consider the sign as positive. Therefore, rewriting Eq. I-6 we have,

$$\frac{F}{N(t + \gamma)} = K_0(t + \gamma)^{\alpha} \qquad \text{(I-7)}$$

Multiplying both sides by $N(t + \gamma)$,

$$F = NK_0(t + \gamma)^{1 + \alpha} \qquad \text{(I-8)}$$

Again remembering the change in the sign convention for α, Ref. 4 defines a term

$$\beta = 1 + \alpha \qquad \text{(I-9)}$$

and substituting this in Eq. I-8 yields

$$F = NK_0(t + \gamma)^{\beta} \quad \text{(I-10)}$$

This equation was derived for failures; however, it can be modified for malfunctions (i.e., any performance outside specified limits) by determining the ratio of malfunctions to failures. From Fig. 2 of Ref. 1 it appears that the ratio of malfunctions (M) to failures (F) is relatively constant with time. Since Ref. 4 indicates 438 malfunctions of which 239 were failures, one may define malfunctions in terms of failures for that group of spacecraft as,

$$M = \frac{438}{239} F = 1.833F \quad \text{(I-11)}$$

Also, Ref. 1 defines values for γ as 3 (using days as the unit of time) and β as 0.311. The value for K_0 in that report is given as 0.00918. This was based on an analysis considering an average of 65 components per spacecraft. More recent analysis indicates that a value of 67.34 components per spacecraft would better suit the data. Since K_0N is a constant, then the value for K_0, based on N = 67.34, is 0.00886.

Substitution of these values in Eq. I-10 yields, as the number of malfunctions at time T,

$$\begin{aligned} M &= 1.833 \times 0.00886\ N(t + 3)^{0.311} \\ &= 0.01624\ N(t + 3)^{0.311} \end{aligned} \quad \text{(I-12)}$$

The development of the factor γ in Ref. 1 stemmed from a need to account for a large number of early failures. Without this apparently high initial rate, the expression to describe the later failure parameter could exclude the γ. Since early failures can be expected to include the preponderance of failures due to the mechanical stresses of launch (vibration, shock, etc.) and the later failure can be considered as representative of the thermal vacuum environment, the γ factor is deleted in this study in order to characterize those failures arising from the thermal vacuum environment.

Addendum I-B provides additional information as to this assumption.

Combining Eq. I-5 and I-12 and deleting the γ factor, the instantaneous availability payloads can be described as

$$A = (1-D^*)^{0.01624N(t^{0.311})} \qquad \text{(I-13)}$$

One apparent problem with the model for availability described by Eq. I-13 is the fact that the availability is so directly tied to the number of components. One would intuitively believe that as the number of components increased, the apparent criticality of a failure would decrease.

In order to develop a model to describe this phenomenon, it was decided to use 31 of the 33 spacecraft contained in the PRC model; the two that were omitted failed shortly after launch and were felt to be not part of a family intended to describe thermal vacuum associated anomalies.

The data plotted in Fig. I-1 depicts the expected criticality of a failure for each of the 31 spacecraft as a function of the number of components in that spacecraft. Through that data was fitted an exponential curve and the best fit was found to be described by the equation

$$D^* = 0.273 \exp(-0.0086\, N) \qquad \text{(I-14)}$$

Substituting this function in place of the coefficient $(1 - D^*)$ in Eq. I-13 (determined as in Eq. I-5), the following equation is developed:

$$A = [1 - (0.273 \exp(-0.0086\, N))]^{0.01624N(t^{0.311})} \qquad \text{(I-15)}$$

Fig. I-2 presents a comparison between an average instantaneous spacecraft availability and the analytical expression shown as Eq. I-13. The plot indicated as "PRC data" was constructed from information obtained from PRC on 31 spacecraft that were contained in the GSFC data base. This permitted a common ground for comparison purposes. The plot was constructed by developing an instantaneous spacecraft availability for each of the 31 spacecraft and then averaging these individual instantaneous spacecraft availabilities. If a spacecraft fell below a 5% availability, it was maintained as part of the sample at whatever availability it had although it was

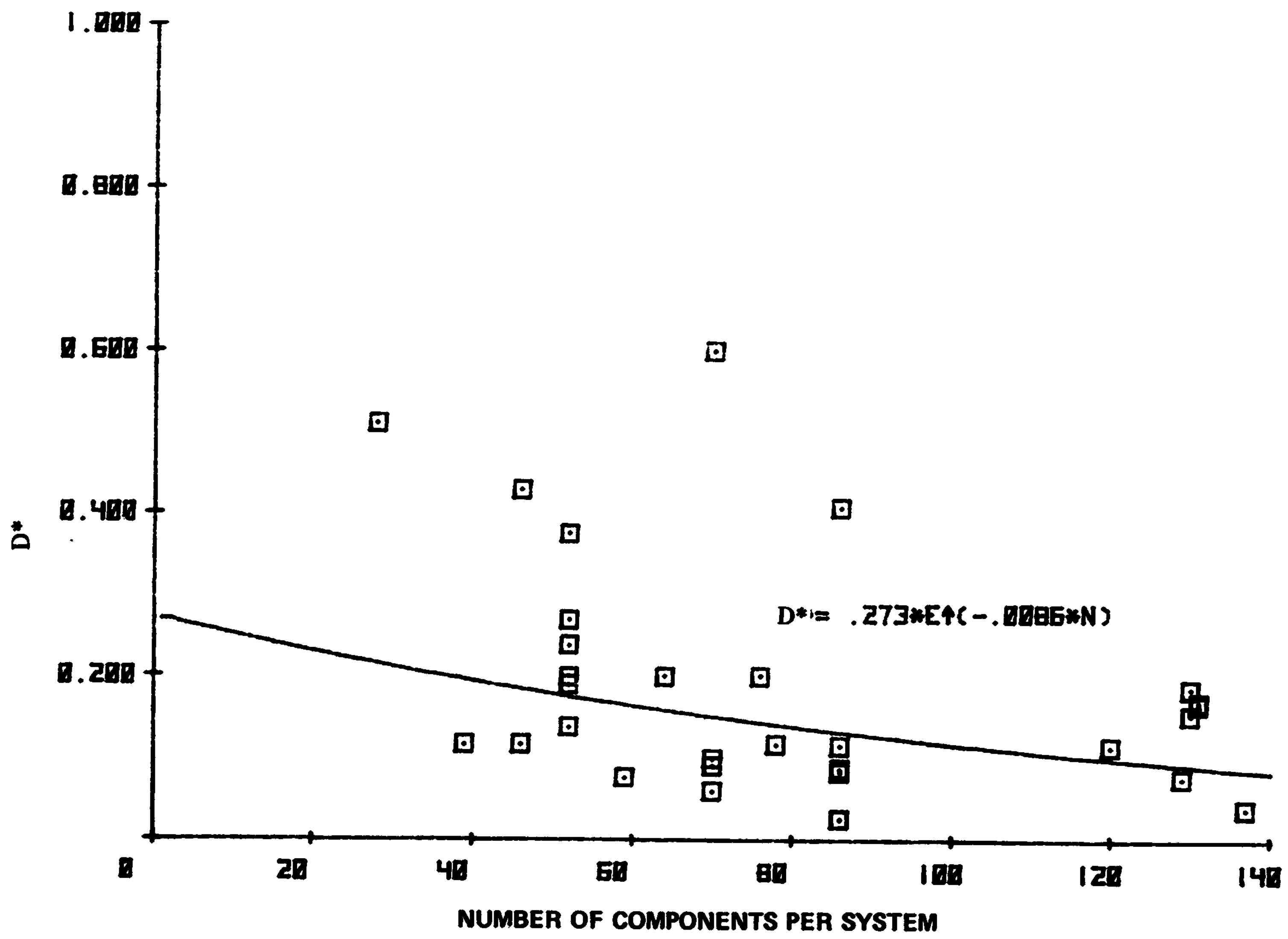


Figure I-1. $E(D_i)$ vs. Number of System Components Based on 31 PRC Spacecraft

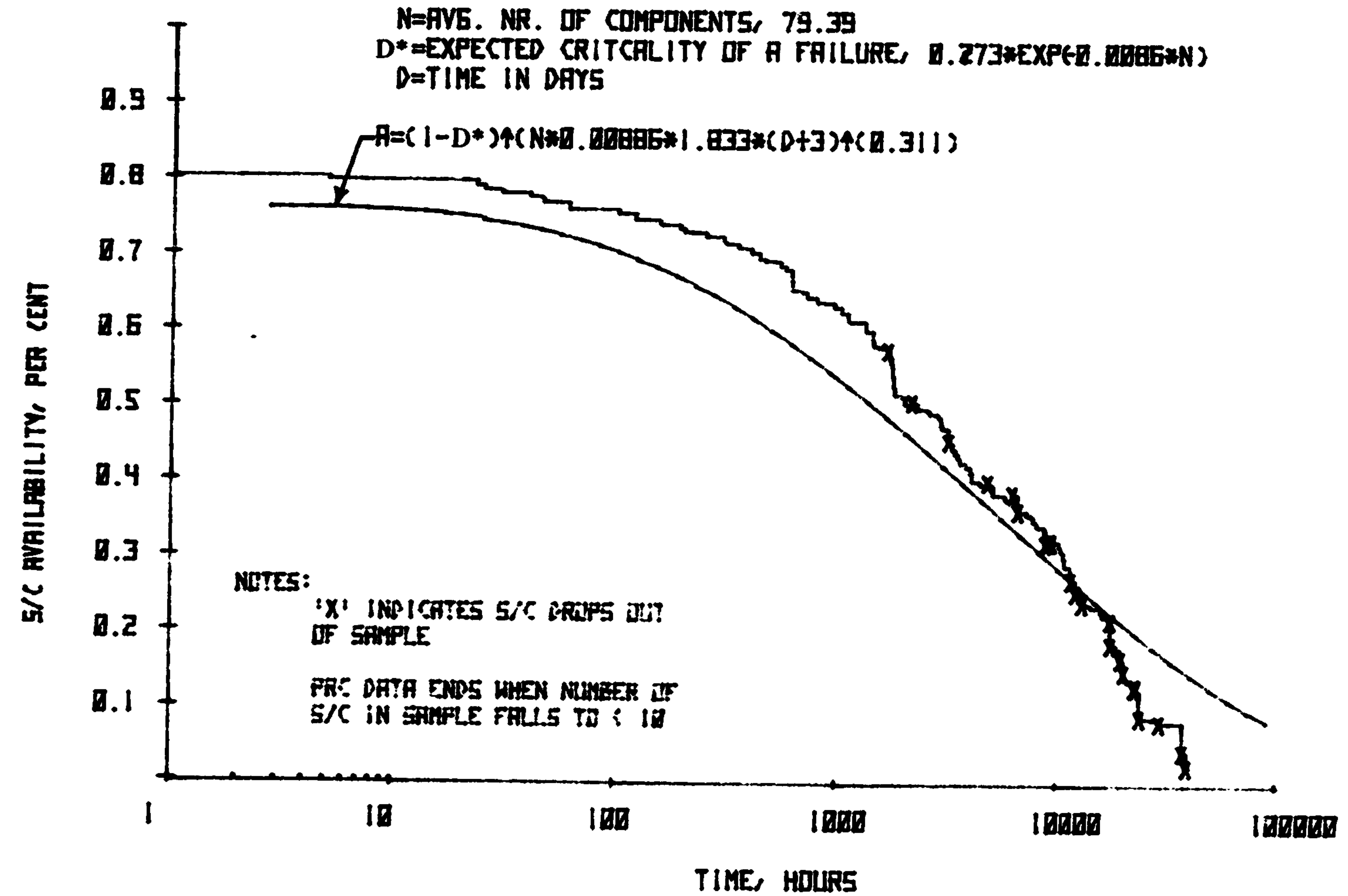


Figure I-2. Average Spacecraft Availability, PRC Data vs. Analytical Model considered as being basically "dead." In other cases, data was unavailable beyond some point in time. In these cases, the spacecraft was removed from the sample and a new average computed from that time forward; such a drop-out is indicated by an "x" plotted on the graph. The plot was terminated when the number of spacecraft fell below 10. Addendum I-C contains a listing of the program used to generate the plots and the data that was taken from the PRC data sheets.

It is felt that this comparison indicates a good correlation between the model which, except for the function defined in equation I-14, was derived independently from the anomaly criticality analysis performed by PRC.

One may describe a term A_0 based on Eq. I-14 as

$$A_0 = 1 - D^* \quad \text{(I-16)}$$

$$= 1 - 0.273 \exp(-0.0086\,N) \quad \text{(I-17)}$$

The instantaneous availability, A, at the end of some time T, in orbit can be expressed as:

$$A = A_0^{(1.833\,KEN)(t^B)} \quad \text{(I-18)}$$

where: K = cumulative failure rate at day one, E = environmental intensity of space*, N = number of components that comprise the system, and B = 1/3**.

If one were to define a desired instantaneous availability at some time t, then the value for K can be derived from Eq. I-16 and I-18 as

$$K = \ln A/(1.833\,E\,N \ln A_0 t^B) \quad \text{(I-19)}$$

*This is a factor (such as the factor π_E and π_T of Table 2-4 in Ref. 12) that relates the failure rate to the environment.

**A value of 1/3 is used rather than 0.311 as indicated in Eq. I-15 so that an integration can be performed. This error is not considered serious since it applies to all cases investigated and since comparisons are used for optimizations equivalent errors would be second order. Fig. I-3 shows the variation in availability with a change in B.

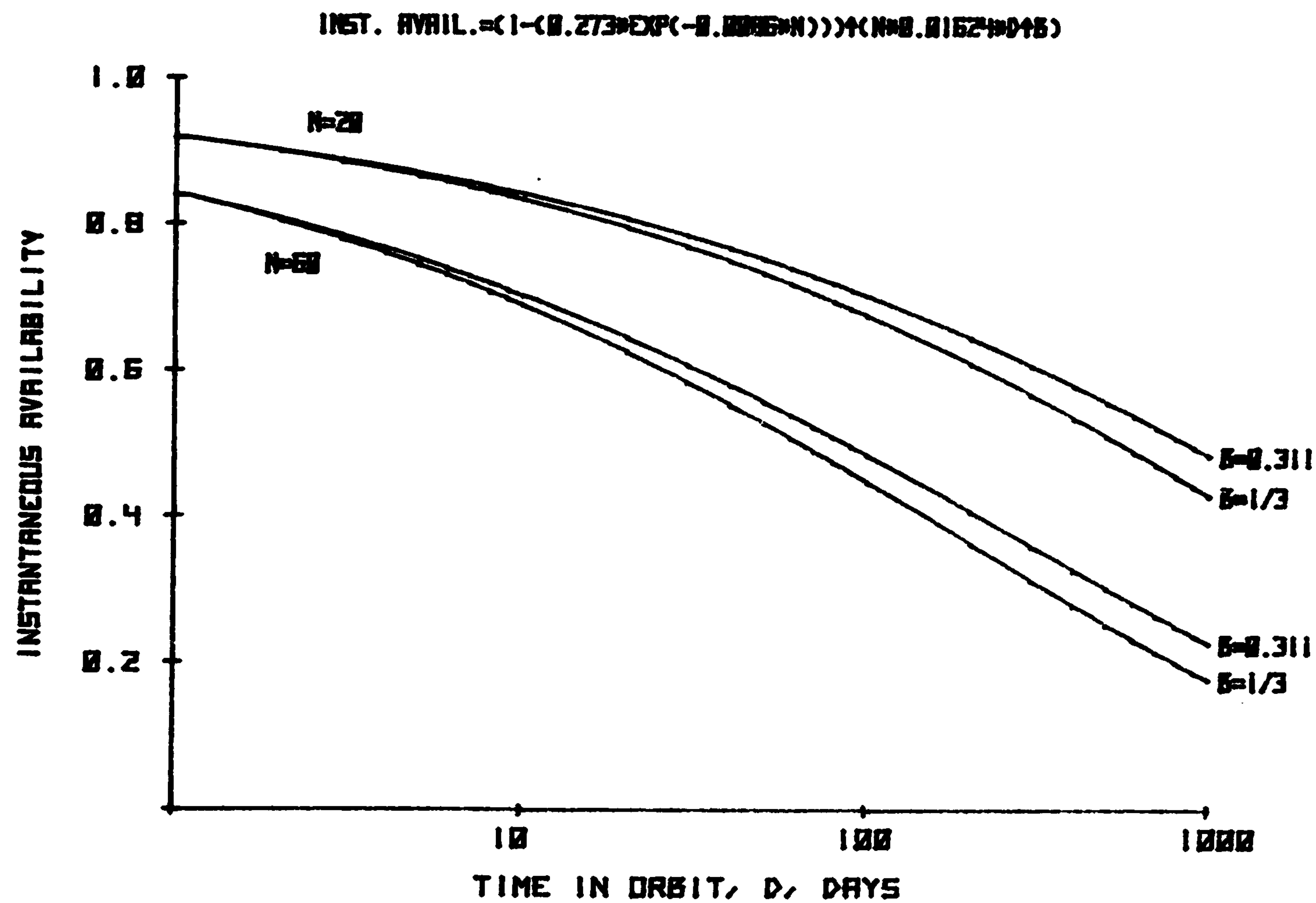


Figure I-3. Effect of Change in Exponent, B; (N = Number of Components)

The value of instantaneous availability, A, cannot be directly used in the optimization model. Moreover, it is a rather difficult concept to convey or to use in defining mission parameters. An average availability, A, is a much more useable form of the availability concept. It can be looked at as that portion of the information that is obtained by the payload as a function of that portion that would have been obtained had there been no malfunctions. This then is a parameter that can be used to define the effectiveness of a mission or its cost effectiveness if one can attribute costs in an acceptable manner. It is also more tractable as a concept as to the performance of an item during its mission.

The total availability, A_t, may be defined in terms of the instantaneous availability as:

$$A_t = \int_0^t A dt \tag{I-20}$$

where the limits of the integration go from launch (time = 0) to some time, t, considered the end of mission life.

The average availability, $\overline{A}$, would then be

$$\overline{A} = \frac{A_t}{t} \tag{I-21}$$

It can be seen then that if there were no failures $\overline{A}$ would equal 1; if the item failed completely at launch, $\overline{A}$ would equal 0. The average availability then can range between 0 and 1 and depends on the number of failures accumulated by time t and their significance. The development of the criticality of a failure, D*, from Eq. I-17 permits one to proceed without assigning differing effects to each failure.

Addendum I-D contains the integration indicated in Eq. I-23 and I-24. Fig. I-4 is a graph on which is plotted both average and instantaneous availabilities. Fig. I-5 is a graph of the instantaneous availability as expressed by the equation

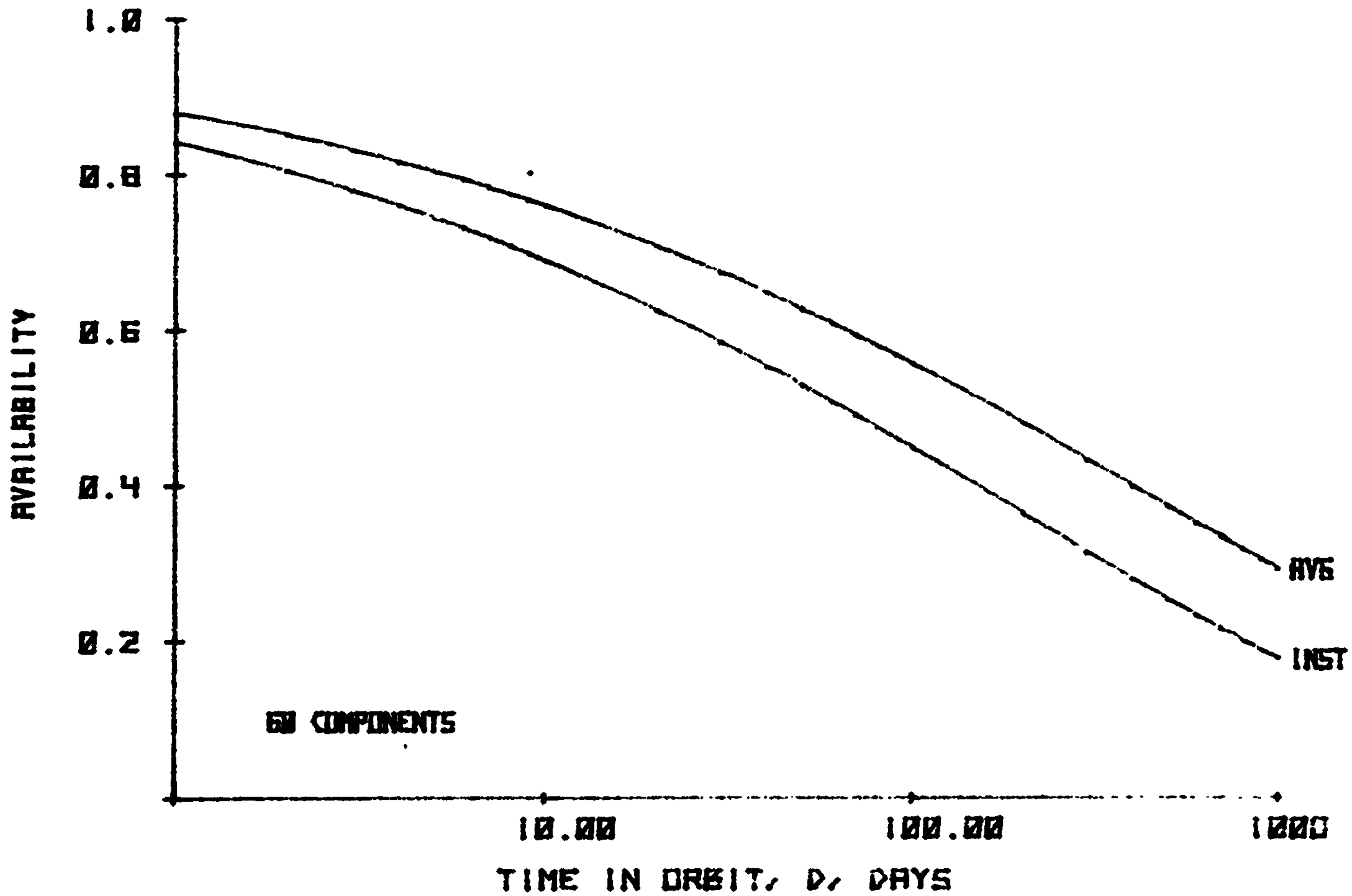


Figure I-4. Comparison of Average (Avg.) and Instantaneous (Inst.) Availability

$$A = [1 - (0.273 \exp(-0.0086\, N))]^{0.01624 N (t^{1/3})} \qquad \text{(I-22)}$$

showing its variability with the number of components.

Fig. I-6 is a graph of the corresponding average availability, $\overline{A}$, as derived in Addendum I-D. Since it is based on data from GSFC missions, it may be used as a point of reference for one who wishes to select a particular average availability for a mission.

Addendum I-E contains the results of a short study into the development of an approach for assigning an average availability for a mission in which the payload is operational for the entire length of the mission but opportunities for taking data are limited. Of those opportunities for obtaining data, only a portion is required in order to achieve mission objectives. For instance, the first case noted on Table I-E-2 is one in which the mission is 14 days long (such as on the STS). 42 opportunities for observation present themselves during this period with each opportunity 2h long; a total of 8h of successful observation is needed for mission success. The program for determining the average availability (Table I-E-1) depends on an iterative process and so the results are not exact but the closeness of the resulting solution (successful observing time = 7.979h) to the desired performance of 8h seems satisfactory. This addendum then presents a way of applying the availability concept.

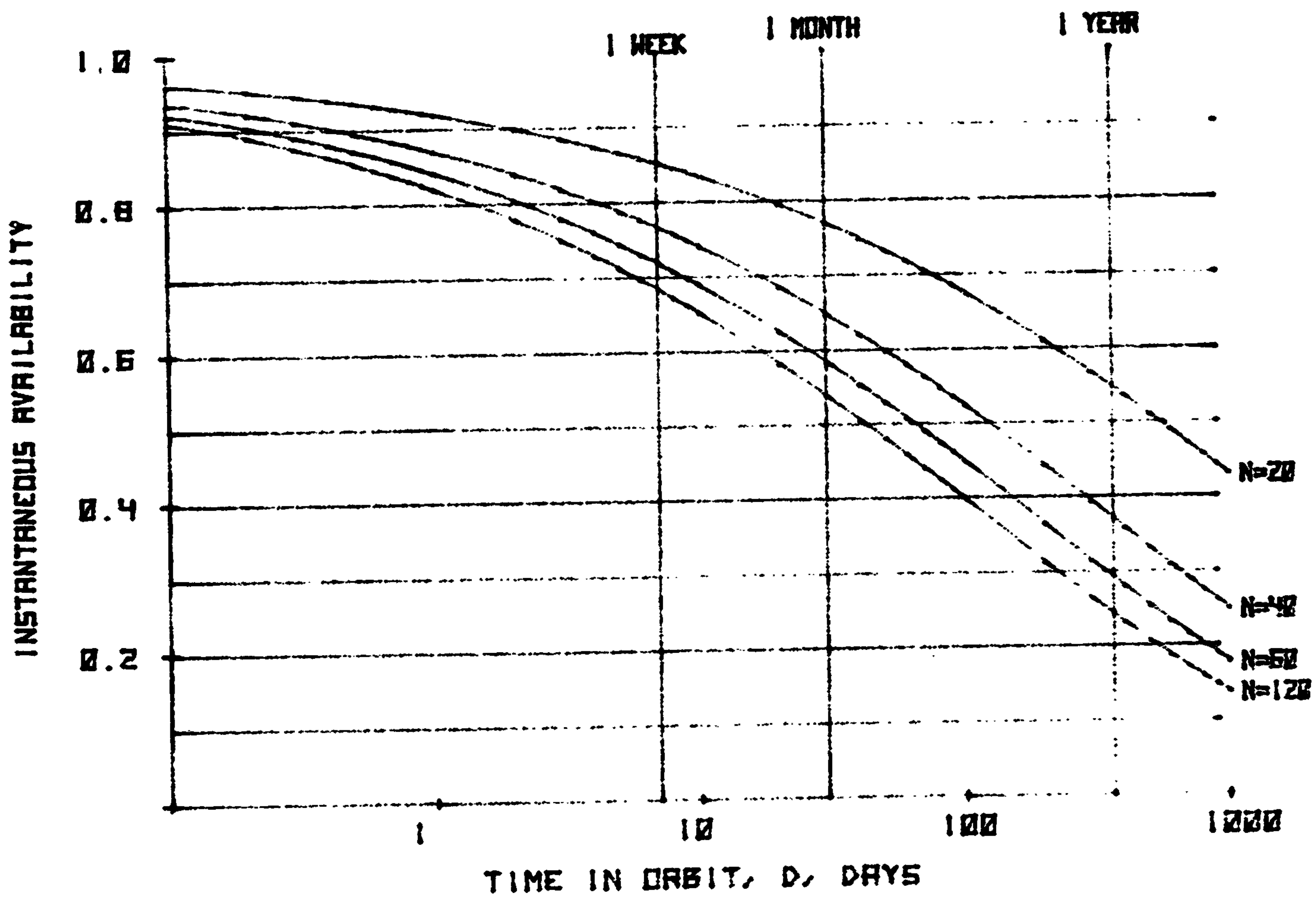


Figure I-5. Instantaneous Availability as a Function of Number of Components (N)

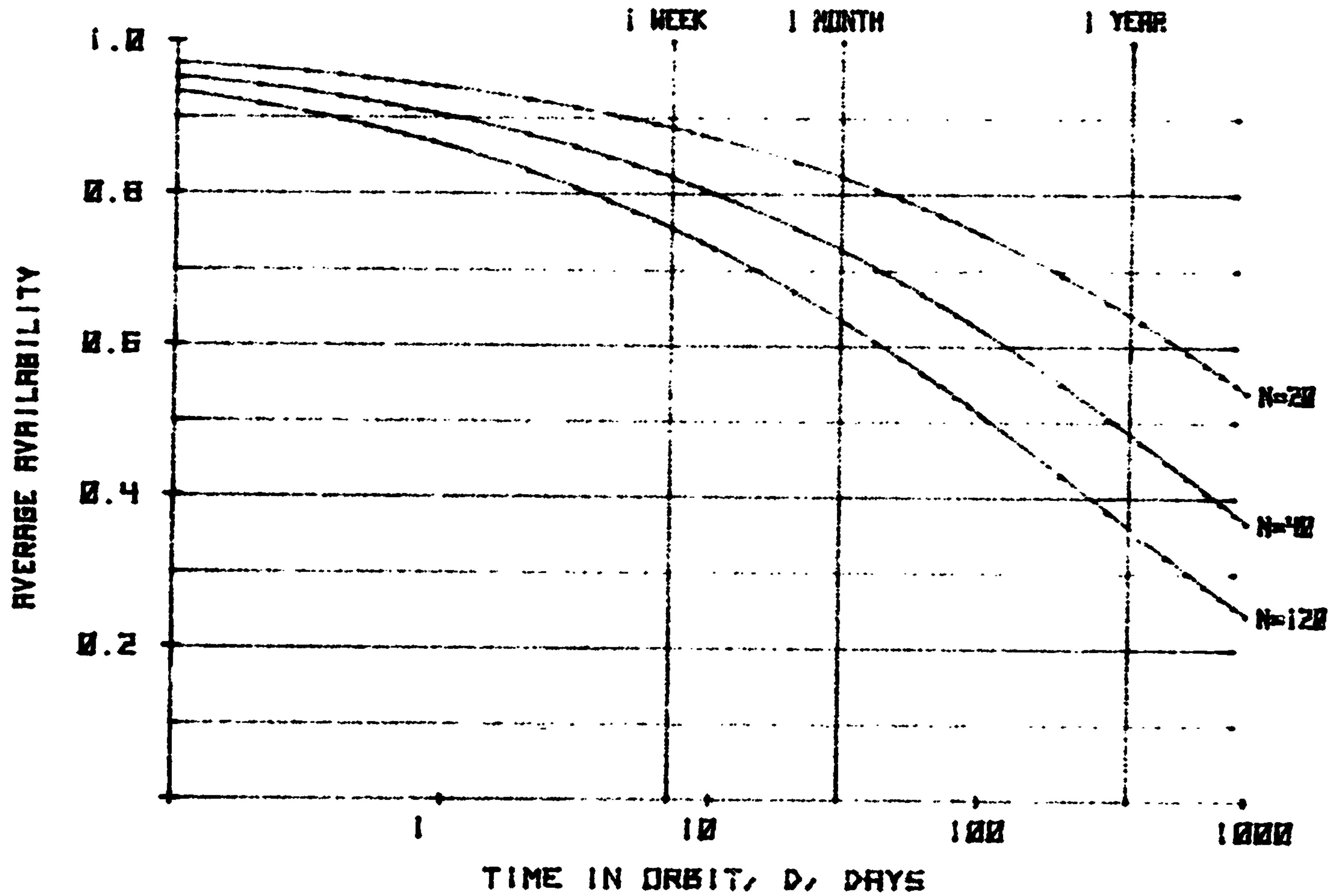


Figure I-6. Average Availability as a Function of Number of Components (N)

ADDENDUM I-A

VARIABILITY OF THE CRITICALITY OF A FAILURE

ADDENDUM I-A

VARIABILITY OF THE CRITICALITY OF A FAILURE

The following data was derived from information received from the Planning Research Corporation regarding 33 spacecraft that are part of the 57 that make up the GSFC sample.

While a formal statistical test has not been performed due to time limitations, the data does appear to demonstrate a consistency as to the distribution of the criticality of malfunctions based either on a function of time or on a count of malfunction. The two following tables provide some of the data.

Table I-A-1 was developed by counting the number of anomalies of the various classifications for 5,000 hour time increments and determining the percentages among them. Table I-A-2 was developed by counting up 10 anomalies for each category and determining what percentage they form of the total. In Table I-A-2 only categories 1, 2, and 3 are depicted since less than 10 category 4 or 5 anomalies exist in the sample.

Table I-A-1

Anomaly Distribution for 33 Spacecraft from PRC Data
(5000 hour increments from launch)

Time Interval (hours)	Anomaly Criticality Code									
	1		2		3		4		5	
	Number of Anomalies	Percent	Number of Anomalies	Percent	Number of Anomalies	Percent	Number of Anomalies	Percent	Number of Anomalies	Percent
0–5000	124	0.554	80	0.357	14	0.063	3	0.013	3	0.013
5000–10000	30	0.625	13	0.271	3	0.063	1	0.021	1	0.021
10000–15000	18	0.600	9	0.300	2	0.067	1	0.033	0	0.0
15000–20000	6	0.600	3	0.300	1	0.100	0	0.0	0	0.0
20000–25000	3	0.273	5	0.455	2	0.182	0	0.0	1	0.091
25000–30000	1	0.500	1	0.500	0	0.0	0	0.0	0	0.0

Table I-A-2

Percentage of the Total Number of Anomalies Encountered when Counting up to 10 of a Particular Criticality (PRC Data on 33 GSFC Spacecraft)

Time at Which 10 are Counted (hours)	Percentage of All Anomalies in the Interval
Category 1	
1	0.556
7	0.500
120	0.588
385	0.556
790	0.500
1150	0.714
1500	0.667
1800	0.476
2300	0.588
2880	0.556
3631	0.435
4380	0.769
7130	0.416
7934	0.769
8760	0.769
11520	0.455
14300	0.769
23040	0.476
Category 2	
1	0.345
100	0.417
462	0.417
1330	0.286
2000	0.250
2664	0.526
3400	0.400
4800	0.357
8700	0.263
13140	0.313
23400	0.370
Category 3	
1790	0.072
18650	0.058

ADDENDUM I-B

ADJUSTMENT OF ORBITAL MALFUNCTION PREDICTION TO ACCOUNT FOR NON-THERMAL VACUUM ASSOCIATED EFFECTS

ADDENDUM I-B

ADJUSTMENT OF ORBITAL MALFUNCTION PREDICTION TO ACCOUNT FOR NON-THERMAL VACUUM ASSOCIATED EFFECTS

Eq. I-12 of Appendix I has within it a term, "(t + 3)." The number 3 was found by the analysis in Ref. 1 to provide a reasonable fit to the empirical data used in the preparation of that document. This term is similar to the location parameter (generally designated by the Greek letter gamma and herein referred to as "G") of the Weibul distribution. Its use infers the start of a process at some time other than that indicated by the time function.

In the case of Ref. 1, the later period data seemed to be part of some common process: that is, it complied with a particular function of decreasing failure rate. However, the failure rates encountered during the early portion of the mission did not appear to follow this same function and seemed to be of a different family. In order to describe both of these phenomena with a common equation, a gamma of -3 was employed. (The form of the equation is generally given with the value as (D - G) and so a value of -3 would yield (D + 3).)

It would appear reasonable to take those early failures as some evidence of launch failure phenomena such as those arising from vibration or acceleration. They would be generally evidenced immediately after the equipment was activated. On the other hand, that class of failures that would occur after some period of time in orbit could be ascribed to the class of thermal vacuum failures (recognizing that there would be some residual number of failures due to the launch environment and due to non-thermal vacuum causes such as electromagnetic interference).

Failures due to the thermal vacuum space environment are taken as very broad in scope as are those failures uncovered during thermal vacuum testing. Many of these failures are due to neither the temperature nor vacuum environments nor to a combination of both, but many may be due to operating procedures, faulty parts, design error, or similar problems. However, since this type of problem forms a significant part of that group uncovered during thermal vacuum testing, they are considered as being detectable in that environment. It is possible that one might develop separate functions that separate failures due to the environmental stresses from those that are simply uncovered during environmental exposure; however, the data used in preparing this report did not permit such a differentiation.

In order, then, to describe failure rates in orbit that were ascribable to the thermal vacuum environment, the factor gamma, or G, was set to zero and in that way the function is believed to best describe those failures due to the thermal vacuum environment. Fig. 1 (based on 67.34 components) shows the effect of setting G = 0 when establishing spacecraft availability. It is interesting to note that the availability, although larger during the early periods with G = 0 as opposed to G = –3, does not go to 1.0 for the first day. Rather, the equation indicates some number of failures occuring during the first day. This appears quite reasonable since one would not expect that only the launch mechanical stress environments would cause early failures. One would expect other failures to be evidenced and the model exhibits this characteristic.

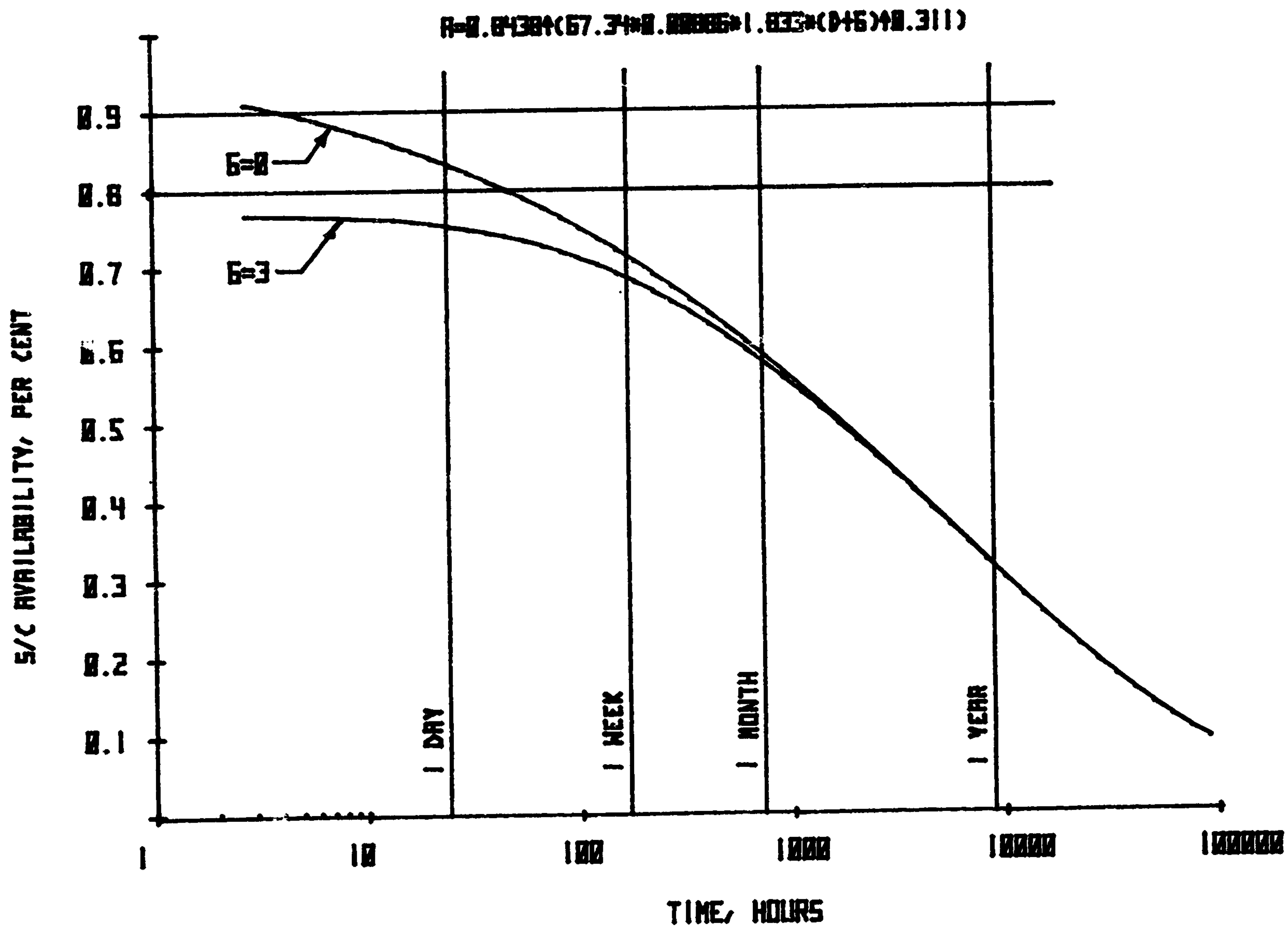


Figure I-B-1. Change in Spacecraft Availability to Account for Non-Thermal Vacuum Early Failures

ADDENDUM I-C

PROGRAM TO OPERATE ON PRC DATA AND DATA LISTING

Program used to operate on PRC data.

```
10 REM- Call up PRC data (stored in file15 as matrix B), compute data, and plot.
20 REM: Plot Routine, semi-log plot
30 DIM A$[32],B$[32],X$[32],Y$[32]
40 REM- Label statements set for 6 in. hi x 9 in. wide field.
50 DISP "Enter plot title, 32 space max.  ";
60 INPUT A$
70 DISP "Line 2? 32 max. Enter spa if no.";
80 INPUT B$
90 X$="                         TIME, HOURS"
100 Y$="      S/C AVAILABILITY, PER CENT"
110 Y1=-0.2
120 Y2=1.2
130 Y3=0
140 Y4=1
150 Y5=0
160 X1=0.1
170 X2=1000000
180 X3=1
190 X4=100000
200 X5=1
210 S1=10
220 S2=0.1
230 SCALE LOGX1,LOGX2,Y1,Y2
240 DISP "PLOT TITLES? Y-260, N-300"
250 STOP
260 PLOT LOGX5+LOGS1,Y4+S2,1
270 CPLOT 0,0
280 LABEL (*)A$
290 LABEL (*)B$
300 DISP "PLOT FOOTNOTES? Y-320, N-390
310 STOP
320 PLOT LOG2,0.25
330 LABEL (*,1.5,2,0,0.67)"NOTES:"
340 LABEL (*)"       'X' INDICATES S/C DROPS OUT"
350 LABEL (*)"       OF SAMPLE"
360 LABEL (*)"
370 LABEL (*)"       PRC DATA ENDS WHEN NUMBER OF"
380 LABEL (*)"       S/C IN SAMPLE FALLS TO < 10"
390 DISP "PLOT SCALES? Y-410, N-680          "
400 STOP
410 XAXIS Y5,LOGS1,LOGX3,LOGX4
420 FOR I=2 TO 10
430 PLOT LOG(I*X3),S2/20
440 PLOT LOG(I*X3),0,-1
450 NEXT I
460 YAXIS LOGX5,S2,Y3,Y4
470 LABEL (*,1.7,2,0,0.67)
480 FOR X=LOGX3 TO LOGX4 STEP LOGS1
490 PLOT X,Y5,1
500 CPLOT -2.5,-1.5
510 LABEL (*)EXPX
520 NEXT X
530 PLOT LOGX5+LOGS1,Y3,1
540 CPLOT 0,-3.5
550 LABEL (*)X$
560 FOR Y=(Y3+S2) TO (Y4-S2) STEP S2
570 PLOT LOGX5,Y,1
580 CPLOT -6,-0.3
590 LABEL (*)Y
600 NEXT Y
610 LABEL (*,1.5,2,PI/2,0.67)
620 PLOT LOGX5,Y5+S2,1
```

```
630 CPLOT 0,5
640 LABEL (*)Y$
650 LABEL (*,1.5,2,0,0.67)
660 DISP "TO COMP AND PLOT, CONT 680
670 STOP
680 REM- Analysis of PRC data; mean availability based on
690 REM- the average of all the S/C availability at a given time.
700 FORMAT "S/C:",F3.0,3X,"H:",F6.0,2X,"EC:",F2.0,3X,"E:",F8.5,3X,"COMP E:",F8.5
710 DIM BS[360,4]
720 MAT B=ZER[360,4]
730 J=0
740 LOAD  DATA 15,B
750 DISP "SORT #1: BY S/C, BY TIME";
760 SORT B,C,1,2
770 REM- Find highest S/C # (= nr. of S/C).
780 FOR I=1 TO 360
790 N=B[I,1]
800 DISP N
810 IF N <= J THEN 830
820 J=N
830 NEXT I
840 REM-   PRINT "MAX S/C # =";J,LIN1
850 REM- Determine individual S/C cumulative effectiveness
860 A=0
870 FOR I=2 TO 360
880 B[I,2]=B[I,2]+A
890 A=A+0.00001
900 IF B[I,1]#B[I-1,1] THEN 920
910 B[I,4]=B[I,4]*B[I-1,4]
920 NEXT I
930 REM- Compute average S/C availability as f(time) where
940 REM- D=sum of all availabilities, M=average availability=D/J
950 DISP "SORT #2, BY HOUR";
960 SORT B,C,2
970 CFLAG 0
980 D=J
990 REM- Compute avg effectiveness, EC:6 = still running, 7 = dead
1000 F=1
1010 FOR I=1 TO 360
1020 IF J<10 THEN 1340
1030 DISP I
1040 REM- Diminish divisor by 1 when B(I,3)=6
1050 IF B[I,3]=6 THEN 1070
1060 GOTO 1110
1070 J=J-1
1080 IF J<10 THEN 1340
1090 D=D-B[I,4]
1100 GOTO 1200
1110 REM- Find next prior time S/C # appears in the matrix
1120 FOR B=I-1 TO 0 STEP -1
1130 DISP I,B
1140 IF B=0 THEN 1180
1150 IF B[I,1]#B[B,1] THEN 1310
1160 C=B[B,4]
1170 GOTO 1190
1180 C=1
1190 D=D-C+B[I,4]
1200 M=D/J
1210 REM- PLOT:(this time, last avail.),(this time, this avail.)
1220 PLOT LOGB[I,2],F
1230 PLOT LOGB[I,2],M
1240 F=M
1250 IF B[I,3]#6 THEN 1320
1260 PRINT "S/C #";B[I,1];"drops out at";INTB[I,2];" hours."
1270 CPLOT -0.3,-0.3
1280 LABEL (*)"X"
```

```
1290 IPLOT 0,0
1300 GOTO 1320
1310 NEXT B
1320 NEXT I
1330 PRINT
1340 PEN
1350 END
1360 FOR I=1 TO 15 STEP 0.2
1370 T=EXPI
1380 D=T/24
1390 A=0.8438↑(67.34*0.00886*1.833*(D+3)↑0.311)
1400 IF A<0 THEN 1440
1410 IF T>100000 THEN 1440
1420 PLOT LOGT,A
1430 NEXT I
1440 PEN
1450 END
```

LISTING OF DATA TAKEN FROM PRC DATA SHEETS

Notes: EC = 1 indicates 0.025 loss of remaining S/C availability
EC = 2 indicates 0.200 loss of remaining S/C availability
EC = 3 indicates 0.500 loss of remaining S/C availability
EC = 4 indicates 0.800 loss of remaining S/C availability
EC = 5 indicates 0.975 loss of remaining S/C availability
EC = 6 indicates S/C still operating, no more info available
EC = 7 indicates S/C failed or availability < 5 per cent

Row	S/C #	Time, h	EC	(1-eff.)
1	1	1	1	0.975
2	1	1	2	0.800
3	1	1776	3	0.500
4	1	1968	2	0.800
5	1	2304	3	0.500
6	1	2305	2	0.800
7	1	2664	2	0.800
8	1	3048	2	0.800
9	1	3480	2	0.800
10	1	4512	2	0.800
11	1	5592	2	0.800
12	1	7488	2	0.800
13	1	8670	1	0.975
14	1	10469	4	0.200
15	1	21696	2	0.800
16	1	22727	5	0.025
17	1	22728	7	1.000
18	2	252	1	0.975
19	2	720	2	0.800
20	2	17592	6	1.000
21	3	3320	2	0.800
22	3	3530	2	0.800
23	3	3820	2	0.800
24	3	37671	6	1.000
25	4	1	2	0.800
26	4	5	2	0.800
27	4	1440	2	0.800
28	4	5040	2	0.800
29	4	5760	2	0.800
30	4	6570	2	0.800
31	4	13900	2	0.800
32	4	17500	2	0.800
33	4	20180	2	0.800
34	4	29510	6	1.000
35	5	1	1	0.975
36	5	1	1	0.975
37	5	1	2	0.800
38	5	1	1	0.975
39	5	10600	2	0.800
40	5	12134	6	1.000
41	6	46	2	0.800
42	6	190	2	0.800
43	6	2020	2	0.800
44	6	3220	2	0.800
45	6	4000	3	0.500
46	6	4760	2	0.800
47	6	5740	2	0.800
48	6	7220	5	0.025
49	6	7221	7	1.000
50	7	154	2	0.800

51	7	250	2	0.800
52	7	308	2	0.800
53	7	462	2	0.800
54	7	616	5	0.025
55	7	617	7	1.000
56	8	1	1	0.975
57	8	1	1	0.975
58	8	1	1	0.975
59	8	1	1	0.975
60	8	1	1	0.975
61	8	50	1	0.975
62	8	51	1	0.975
63	8	52	1	0.975
64	8	60	1	0.975
65	8	120	1	0.975
66	8	380	1	0.975
67	8	1120	1	0.975
68	8	1250	1	0.975
69	8	1430	1	0.975
70	8	1450	1	0.975
71	8	1640	1	0.975
72	8	1710	3	0.500
73	8	1770	2	0.800
74	8	1920	1	0.975
75	8	2110	2	0.800
76	8	2360	1	0.975
77	8	2460	2	0.800
78	8	2600	2	0.800
79	8	2870	1	0.975
80	8	3900	1	0.975
81	8	4420	2	0.800
82	8	6090	1	0.975
83	8	6340	1	0.975
84	8	7130	1	0.975
85	8	7800	1	0.975
86	8	7900	1	0.975
87	8	8100	1	0.975
88	8	9460	1	0.975
89	8	10600	2	0.800
90	8	11700	1	0.975
91	8	13140	1	0.975
92	8	15600	1	0.975
93	8	23400	2	0.800
94	8	23401	3	0.500
95	8	23402	7	1.000
96	9	1	1	0.975
97	9	1	2	0.800
98	9	1	2	0.800
99	9	20	1	0.975
100	9	30	1	0.975
101	9	45	1	0.975
102	9	120	1	0.975
103	9	195	1	0.975
104	9	200	2	0.800
105	9	600	1	0.975
106	9	683	2	0.800
107	9	700	1	0.975
108	9	790	1	0.975
109	9	930	1	0.975
110	9	1000	1	0.975
111	9	1366	1	0.975
112	9	1420	1	0.975
113	9	1470	1	0.975
114	9	1610	1	0.975
115	9	1790	1	0.975
116	9	1970	1	0.975

117	9	2050	1	0.975
118	9	2160	6	1.000
119	10	1	2	0.800
120	10	400	1	0.975
121	10	1440	2	0.800
122	10	1500	1	0.975
123	10	1670	6	1.000
124	11	1	1	0.975
125	11	7	1	0.975
126	11	130	1	0.975
127	11	158	1	0.975
128	11	216	1	0.975
129	11	520	1	0.975
130	11	940	1	0.975
131	11	956	2	0.800
132	11	1330	2	0.800
133	11	1800	2	0.800
134	11	1850	1	0.975
135	11	1912	1	0.975
136	11	2150	2	0.800
137	11	2170	2	0.800
138	11	2868	1	0.975
139	11	2920	1	0.975
140	11	3320	1	0.975
141	11	3824	1	0.975
142	11	4230	1	0.975
143	11	4670	2	0.800
144	11	4750	1	0.975
145	11	4780	1	0.975
146	11	4781	6	1.000
147	12	1	4	0.200
148	12	1	2	0.800
149	12	890	1	0.975
150	12	2350	1	0.975
151	12	2800	1	0.975
152	12	3767	1	0.975
153	12	7151	1	0.975
154	12	8600	1	0.975
155	12	8760	1	0.975
156	12	11300	1	0.975
157	12	13520	1	0.975
158	12	27040	2	0.800
159	12	32700	1	0.975
160	12	40560	1	0.975
161	12	40561	6	1.000
162	13	1	4	0.200
163	13	1	2	0.800
164	13	660	2	0.800
165	13	1136	1	0.975
166	13	1210	1	0.975
167	13	1775	1	0.975
168	13	1777	1	0.975
169	13	1786	2	0.800
170	13	1790	3	0.500
171	13	1800	1	0.975
172	13	1801	1	0.975
173	13	2200	1	0.975
174	13	2524	2	0.800
175	13	2754	1	0.975
176	13	2880	1	0.975
177	13	2881	1	0.975
178	13	3391	1	0.975
179	13	3393	1	0.975
180	13	3631	1	0.975
181	13	3650	1	0.975

182	13	3790	1	0.975
183	13	4510	1	0.975
184	13	5600	3	0.500
185	13	6580	1	0.975
186	13	8330	2	0.800
187	13	9500	2	0.800
188	13	9800	2	0.800
189	13	10600	2	0.800
190	13	13140	2	0.800
191	13	13150	1	0.975
192	13	14144	6	1.000
193	14	25	2	0.800
194	14	1100	3	0.500
195	14	4300	1	0.975
196	14	4400	2	0.800
197	14	7660	1	0.975
198	14	21300	2	0.800
199	14	27200	1	0.975
200	14	39300	6	1.000
201	15	1	1	0.975
202	15	40	2	0.800
203	15	100	2	0.800
204	15	7650	1	0.975
205	15	10300	1	0.975
206	15	10530	1	0.975
207	15	11520	1	0.975
208	15	11870	1	0.975
209	15	12960	3	0.500
210	15	14300	2	0.800
211	15	16200	1	0.975
212	15	18650	3	0.500
213	15	22920	6	1.000
214	16	60	2	0.800
215	16	101	1	0.975
216	16	720	1	0.975
217	16	1320	1	0.975
218	16	7600	1	0.975
219	16	7970	1	0.975
220	16	10600	1	0.975
221	16	11000	1	0.975
222	16	12860	1	0.975
223	16	14300	1	0.975
224	16	17060	1	0.975
225	16	20200	1	0.975
226	16	23040	1	0.975
227	16	23900	1	0.975
228	16	24000	6	1.000
229	17	1	1	0.975
230	17	120	1	0.975
231	17	300	2	0.800
232	17	600	1	0.975
233	17	2830	1	0.975
234	17	4060	1	0.975
235	17	4360	1	0.975
236	17	7320	1	0.975
237	17	8050	1	0.975
238	17	10340	2	0.800
239	17	10800	3	0.500
240	17	13000	6	1.000
241	18	546	2	0.800
242	18	612	3	0.500
243	18	760	1	0.975
244	18	1430	4	0.200
245	18	1520	3	0.500
246	18	1660	3	0.500
247	18	2280	1	0.975

248	18	3040	2	0.800
249	18	3041	7	1.000
250	19	23	2	0.800
251	19	120	1	0.975
252	19	800	2	0.800
253	19	1690	1	0.975
254	19	2940	1	0.975
255	19	3380	1	0.975
256	19	11520	6	1.000
257	20	120	2	0.800
258	20	950	1	0.975
259	20	1700	1	0.975
260	20	5000	1	0.975
261	20	7350	1	0.975
262	20	8100	1	0.975
263	20	9800	1	0.975
264	20	10125	2	0.800
265	20	11500	2	0.800
266	20	14950	1	0.975
267	20	15000	1	0.975
268	20	18200	1	0.975
269	20	20250	2	0.800
270	20	20251	6	1.000
271	21	720	1	0.975
272	21	865	1	0.975
273	21	1030	2	0.800
274	21	1150	1	0.975
275	21	3000	1	0.975
276	21	3400	2	0.800
277	21	5090	3	0.500
278	21	6000	1	0.975
279	21	7270	1	0.975
280	21	9000	1	0.975
281	21	12000	1	0.975
282	21	22630	6	1.000
283	22	998	1	0.975
284	22	1800	1	3.975
285	22	1896	1	0.975
286	22	6576	6	1.000
287	23	48	1	0.975
288	23	2304	1	0.975
289	23	3160	1	0.975
290	23	3161	6	1.000
291	24	1	1	0.975
292	24	1	1	0.975
293	24	1	2	0.800
294	24	1464	1	0.975
295	24	1750	2	0.800
296	24	2300	1	0.975
297	24	7934	1	0.975
298	24	7958	1	0.975
299	24	8150	1	0.975
300	24	15120	1	0.975
301	24	16300	2	0.800
302	24	19518	6	1.000
303	25	1	2	0.800
304	25	1728	2	0.800
305	25	2930	2	0.800
306	25	2973	2	0.800
307	25	4800	2	0.800
308	25	5800	2	0.800
309	25	8800	2	0.800
310	25	9000	6	1.000
311	26	1	2	0.800
312	26	8760	1	0.975
313	26	8761	6	1.000

314	27	1	1	0.975
315	27	1	1	0.975
316	27	400	2	0.800
317	27	1800	1	0.975
318	27	1801	2	0.800
319	27	2000	2	0.800
320	27	2600	2	0.800
321	27	2850	2	0.800
322	27	2900	2	0.800
323	27	3600	3	0.500
324	27	6200	6	1.000
325	28	1	3	0.500
326	28	30	2	0.800
327	28	385	1	0.975
328	28	436	3	0.500
329	28	2600	1	0.975
330	28	3850	1	0.975
331	28	7700	4	0.200
332	28	8600	7	1.000
333	29	1	1	0.975
334	29	1330	2	0.800
335	29	1760	3	0.500
336	29	4650	1	0.975
337	29	8700	2	0.800
338	29	9300	3	0.500
339	29	9301	6	1.000
340	30	576	2	0.800
341	30	2930	2	0.800
342	30	4080	3	0.500
343	30	8760	1	0.975
344	30	12240	1	0.975
345	30	16320	1	0.975
346	30	20400	3	0.500
347	30	23000	6	1.000
348	31	1	1	0.975
349	31	1	2	0.800
350	31	350	2	0.800
351	31	543	1	0.975
352	31	3600	2	0.800
353	31	8000	2	0.800
354	31	13150	1	0.975
355	31	16000	2	0.800
356	31	17500	6	1.000
357	32	1	5	0.025
358	32	2	7	1.000
359	33	1	5	0.025
360	33	2	7	1.000

ADDENDUM I-D

INTEGRATION OF INSTANTANEOUS AVAILABILITY TO DETERMINE

THE AVERAGE AVAILABILITY

ADDENDUM I-D

INTEGRATION OF INSTANTANEOUS AVAILABILITY TO DETERMINE THE AVERAGE AVAILABILITY

The initial program contained a value for B (see Appendix I) of 0.311. In order to determine the average availability, $\overline{A}$, a numerical integration method was introduced. Because of the relatively long integration time that it required, it was decided to accept the error introduced by setting B = 1/3 so that a closed form solution could be developed. The following analysis provides that solution.

From Eq. I-20 of Appendix I,

$$A_t = \int_0^t A dt \qquad \text{(I-C-1)}$$

From Eq. I-18 of Appendix I,

$$A = A_0^{(1.833\ KEN)(t^B)} \qquad \text{(I-C-2)}$$

or,

$$\ell n\ A = 1.833\ KEN(t^B)\ \ell n\ A_0 \qquad \text{(I-C-3)}$$

Let

$$C = 1.833\ KEN\ \ell n\ A_0 \qquad \text{(I-C-4)}$$

then,

$$A = e^{Ct^B} \qquad \text{(I-C-5)}$$

and

$$A_t = \int_0^t e^{Ct^B} dt \qquad \text{(I-C-6)}$$

If one lets $u = t^B$, then

$$du = \frac{Bt^B}{t} dt \qquad \text{(I-C-7)}$$

but $t = u^{1/B}$,

then Eq. I-C-7 can be rewritten as:

$$du = \frac{Bu}{u^{1/B}}\, dt$$

$$= Bu^{(1-1/B)}\, dt \qquad \text{(I-C-8)}$$

and

$$dt = \frac{1}{Bu^{(1-1/B)}}\, du$$

$$= \frac{u^{(1/B-1)}}{B}\, du \qquad \text{(I-C-9)}$$

If now $B = 1/3$, then

$$dt = \frac{u^2}{B}\, du \qquad \text{(I-C-9)}$$

Substituting this value for dt into I-C-6, one obtains:

$$A_t = \frac{1}{B} \int_{u(0)}^{u(t)} u^2 e^{Cu}\, du \qquad \text{(I-C-10)}$$

Integrating,

$$A_t = \frac{1}{B}\left\{\frac{u^2 e^{Cu}}{C} - \frac{2}{C}\int_{u(0)}^{u(t)} u e^{Cu}\, du\right\}$$

$$= \frac{1}{B}\left\{\frac{u^2 e^{Cu}}{C} - \frac{2}{C}\left(\frac{e^{Cu}}{C^2}(Cu-1)\right)\right\}\Bigg]_{u(0)}^{u(t)} \qquad \text{(I-C-11)}$$

Substituting for u, cu, and e^{cu},

$$A_t = \frac{1}{B}\left\{\frac{t^{2B} A}{C} - \frac{2A}{C^3}(\ell n\, A - 1)\right\}\Bigg]_0^t \qquad \text{(I-C-12)}$$

Since, from Eq. I-C-5,

$$\ell n\, A = ct^B \qquad \text{(I-C-13)}$$

Eq. I-C-12 may be rewritten as:

$$A_T = \frac{1}{B}\left\{\frac{t^{2B}}{C} - \frac{2}{C^3}(Ct^B - 1)\right\} e^{Ct^B}\Bigg]_0^t \qquad \text{(I-C-13)}$$

$$= \frac{1}{B}\left\{\left[\frac{t^{2B}}{C} - \frac{2}{C^3}(Ct^B - 1)\right] e^{Ct^B} - \frac{2}{C^3}\right\} \qquad \text{(I-C-14)}$$

From Eq. I-21 of App. I,

$$\overline{A} = \frac{A_t}{t} = \frac{1}{Bt}\left\{\left[\frac{t^{2B}}{C} - \frac{2}{C^3}(Ct^B - 1)\right] e^{Ct^B} - \frac{2}{C^3}\right\} \qquad \text{(I-C-15)}$$

For an initial number of failures, F_0,

$$\overline{A} = \frac{A_0^{F_0}}{Bt}\left\{\left[\frac{t^{2B}}{C} - \frac{2}{C^3}(Ct^B - 1)\right] e^{Ct^B} - \frac{2}{C^3}\right\} \qquad \text{(I-C-16)}$$

If $\overline{A}$ is given and C is known, Eq. I-C-15 may be rewritten as:

$$A = (Bt\overline{A} + 2/C^3)/\left((t^{2B}/C) - \frac{2}{C^3}(Ct^B - 1)\right) \qquad \text{(I-C-17)}$$

If C is unknown, we may let $C = \ell n\ A/t^B$ Therefore, the average availability may be solved as:

$$\overline{A} = \frac{1}{B}\left[\left(\frac{1}{\ell n\ A} - \frac{2}{(\ell n\ A)^2} + \frac{2}{(\ell n\ A)^3}\right)A - \frac{2}{(\ell n\ A)^3}\right] \qquad \text{(I-C-18)}$$

$$= \frac{A}{B(\ell n\ A)^3}\left[(\ell n\ A)^2 - 2\ell n\ A + 2 - \frac{2}{A}\right] \qquad \text{(I-C-19)}$$

ADDENDUM I-E

DETERMINATION OF INSTANTANEOUS AVAILABILITY BASED ON INTERMITTANT OPERATION DURING MISSION LIFE

Table I-E-1

Program for Computing Instantaneous Availability for Intermittant Operations During Mission Life

```
10 FORMAT F10.0,2F10.3
20 DISP "ENTER NR COMPONENTS";
30 INPUT N9
40 DISP "ENTER MISSION DURATION,DAYS";
50 INPUT O9
60 DISP "ENTER TOTAL NR OBSERVATIONS.";
70 INPUT M
80 DISP "ENTER TOTAL OBSERV.HRS AVAIL";
90 INPUT O
100 T=O/M
110 P=O9/M
120 DISP "ENTER OBSERV. HRS REQUIRED";
130 INPUT R
135 PRINT "NR OF COMPONENTS=";N9
140 PRINT "MISSION DURATION=";O9;" DAYS"
150 PRINT "NR OF OBSERV. IS=";M
160 PRINT "DUR. OF EA.OBSERV=";T;"HRS."
170 PRINT "TOTAL HRS OBSERV.AVAIL=";O;"HRS."
180 PRINT "TIME BETWEEN OBSERV.IS=";P*24
190 PRINT "OBSERVATION HOURS REQD=";R
200 E=14.26
210 K=(8850/E)
220 B=0.314
230 C8=1-0.273*EXP(-0.0086*N9)
240 K5=1.833*N9*E*K*10↑(-6)
250 D=0
260 FOR I=1 TO M
270 A=T*C8↑(K5*(P*I)↑B)
280 D=D+A
290 NEXT I
300 FIXED 3
310 DISP A;D;INT(K)
320 IF D>0.998*R AND D<1.008*R THEN 360
325 D=D+(R-D)/2
330 Y=LOG(R/D)/(K5*LOG(C8))+1
340 K=Y*K
350 GOTO 240
360 PRINT LIN1
365 PRINT TAB7,"K";TAB15,"AVAIL.";TAB25,"TOT.H"
366 PRINT TAB7,"-";TAB15,"------";TAB25,"-----"
370 WRITE (2,10)K,A,D
380 PRINT LIN2
390 END
```

Table I-E-2

Typical Outputs for Program of Table I-E-1

```
MISSION DURATION= 14    DAYS
NR OF OBSERV. IS= 42
DUR. OF EA.OBSERV= 2    HRS.
TOTAL HRS OBSERV.AVAIL= 84    HRS.
TIME BETWEEN OBSERV.IS= 8.000000000
OBSERVATION HOURS REQD= 8

      K         AVAIL.    TOT.H
      -         ------    -----
    10578       0.073     7.979


MISSION DURATION= 14    DAYS
NR OF OBSERV. IS= 20
DUR. OF EA.OBSERV= 4.2  HRS.
TOTAL HRS OBSERV.AVAIL= 84    HRS.
TIME BETWEEN OBSERV.IS= 16.8
OBSERVATION HOURS REQD= 8

      K         AVAIL.    TOT.H
      -         ------    -----
    10325       0.166     7.984


MISSION DURATION= 14    DAYS
NR OF OBSERV. IS= 10
DUR. OF EA.OBSERV= 8.4  HRS.
TOTAL HRS OBSERV.AVAIL= 84    HRS.
TIME BETWEEN OBSERV.IS= 33.6
OBSERVATION HOURS REQD= 8

      K         AVAIL.    TOT.H
      -         ------    -----
     9957       0.373     7.989
```

APPENDIX J

THERMAL VACUUM TEST OPTIMIZATION COMPUTER PROGRAM

(PHASE I VERSION, 1979) AND EXAMPLES

APPENDIX J

THERMAL VACUUM TEST OPTIMIZATION COMPUTER PROGRAM (PHASE I VERSION, 1979) AND EXAMPLES

The program is written in an expanded form of BASIC devised by the Hewlett-Packard Company. The calculator used is a Hewlett-Packard 9831A with an attached 9866B printer. An expanded memory (7677 word nominal capacity) is needed. The plotting routines use a Hewlett-Packard 9862A Calculator Platter (which requires a 98223 Matrix-Platter ROM). The program is stored on magnetic tape (Hewlett-Packard 9162-0061 Data Cartridge) which is also used for storing the data developed by the program. The programs are stored in four files on track #0 of the tape; track #1 is marked for a minimum of 21 files of 350 words each for matrix storage. Table J-1 is a listing of data as stored on the tape.

Addenda J-A through J-D contain listings of the four files that together make up the Thermal Vacuum Test Optimization (TVTO) computer program. Addendum J-E provides the format of the matrix in which the data is stored.

The program is written to be user interactive; certain information is provided the user, questions are posed, and answers are requested from the user. The user inputs may be the answers yes or no (which are input to the program as a one or a zero) or a numerical data input. When questions are not applicable, the user is requested to enter a zero; a zero entry also indicates a need for the computer to develop a result (such as payload weight) internally.

The program automatically proceeds from one file to the next under internal control (LINK statements). Fig. J-1 provides a general flow diagram indicating the major portions within each segment of the overall model.

Table J-2 contains a list of questions options that are presented to the user as he proceeds through the program. Not all options are available in all cases (for instance, the user may not add an upper stage to a Spacelab mission); the program selects the appropriate questions.

Table J-1

Listing of Files

File No.	File Type	File Size: Abs Wrds	File Size: Current Words	Line Numbers: 1st	Line Numbers: Last
TLIST#0					
0	3	2000	13	10	20
1	3	3000	2020	10	1020
2	3	6500	5925	10	9680
3	3	6000	5185	10	5600
4	3	4000	2836	10	6230
5	0	0	0	0	0
TLIST#1					
0	0	350	0	0	0
1	2	350	336	1	0
2	2	350	336	1	0
3	2	350	336	1	0
4	2	350	336	1	0
5	2	350	336	1	0
6	2	350	336	1	0
7	2	350	336	1	0
8	2	350	336	1	0

(Continued for 100 files for storage)

Legend:
File Type 0: Unused
File Type 2: Data
File Type 3: Program

Addendum J-F is the output of a typical run. The calculator has been placed in the PRINT ALL mode; this results in statements that are normally only displayed being printed. This is seen as a statement or question followed by a question mark and followed again by the user input. This PRINT ALL mode was retained until a point in file #3 where it would have resulted in a lengthy (but not informative) output; this is noted by an asterisked statement. The pages are in the order in which they are printed by the printer. Page J-F-4 is the summary output of the first run; page J-F-6 the summary of a variation.

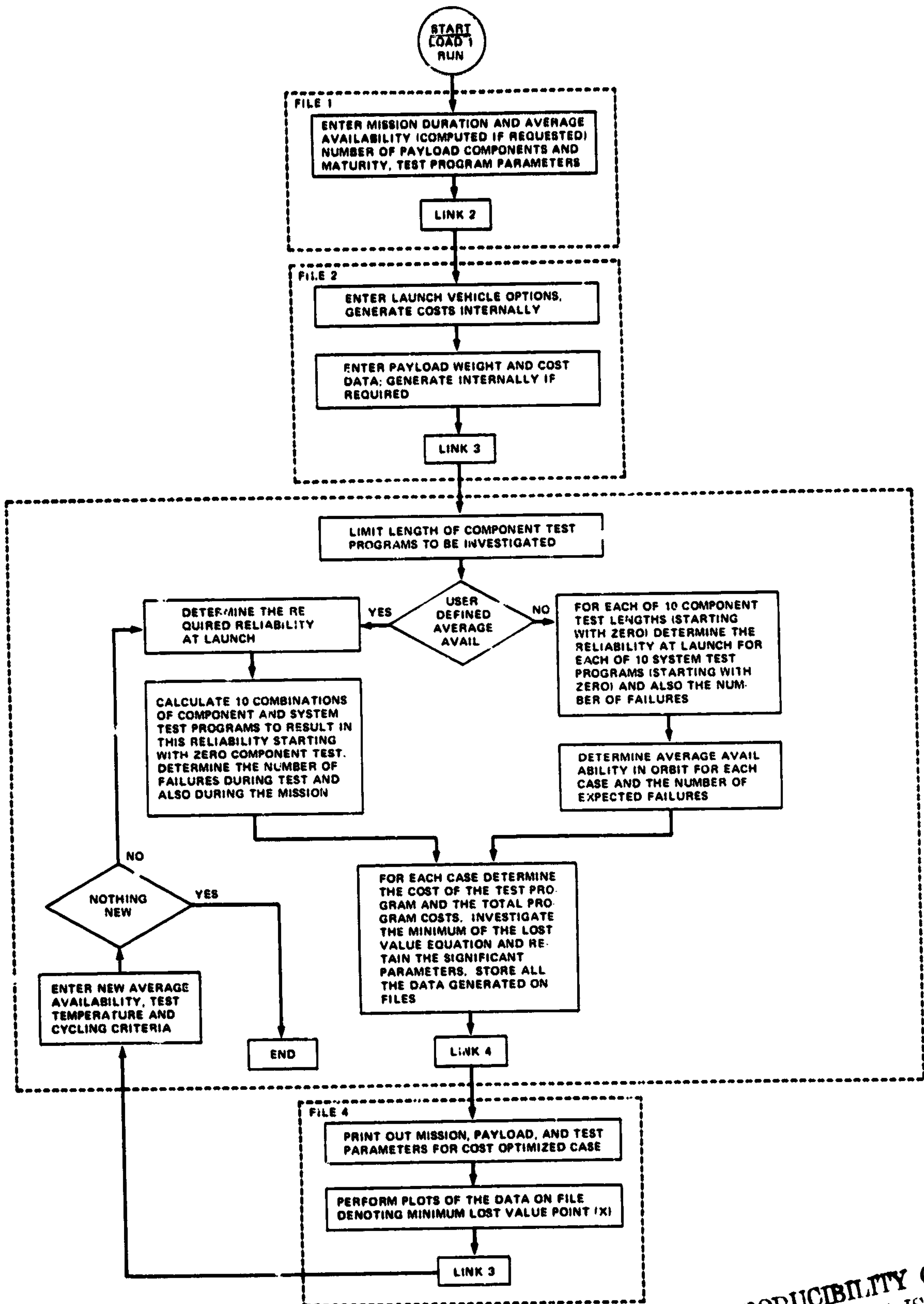


Figure J-1. General Flow Diagram

Table J-2

Questions Presented and Options Available to the User
(The numbers opposite the statement indicate the appropriate program line number)

File #1:	
90	Additional information needed to execute the program?
360	Number of components in the payload?
400	Minimum acceptable average availability (zero to be entered if no minimum is defined).
440	Mission duration
520	Component test transition time and dwell time at temperature?
650	System test transition time and dwell time at temperature?
850	System level minimum and maximum test temperatures?
920	System level test chamber size?
950	Maturity of the payload (protoflight, first flight unit, or follow-on unit)?
File #2:	
70	An STS or an expendable launch vehicle mission?
–	(If an expendable launch vehicle is selected, only question from line 9560 is posed regarding launch)
9560	Scout, 2900 series Delta, or 3900 series Delta vehicle?
–	(If an STS mission is selected, the applicable of lines 290 to 8310 (below) are posed)
290	Free-flier, an attached payload or a Spacelab payload?
301	Will the payload be reflown?
306	How many reflights?
340	Is the mission shared or dedicated?
420	The percentage of the payload weight on the pallets?
470	Are Spacelab elements dedicated or shared?
706, 900	Number of pallets if a long, pressurized module is involved?
800, 950	Number of pallets with no pressurized module?
8030	Is upper stage required?
8070	SSUS-D?
8100	SSUS-A?
8130	IUS two stage?
8160	IUS twin stage?
8190	IUS twin stage plus spinner?
8310	How many OMS kits are needed?
4090	Payload length?
4150	Payload weight?
4350	Payload cost (1978 millions of dollars)?
–	(If payload cost is unknown, the following additional question is posed; line 4600)
4600	Instrument class (based on data presented in the program)?

Table J-2 (Continued)

File #3:	
130	Date?
190	Maximum number of component test hours to be investigated?
210	First file number into which data will be stored?
250	Is a reliability data printout desired?
300	Is a cost data printout desired?
–	(If File #3 has been accessed from File #4, questions from lines 2162 to 2400 are posed)
2162	Try a new average availability?
2168	Input a new desired average availability (must be greater than 0.04).
2178	Try new test temperature conditions?
2210	Enter new system minimum and maximum test temperature conditions.
2260	Enter a new increment difference between component and system test temperatures.
2280	Change test transition or dwell times?
2360	Enter new component test transition and dwell times.
2400	Enter new system test transition and dwell times.
File #4:	
5800	Input the starting and ending file numbers to be plotted.
6170	Further plots desired?

Figure J-F-1 is typical of the plot that results when zero is entered in response to the first question as to the desired average availability. The ordinate (lost value in millions of dollars) is scaled so as to maximize resolution and the abcissa length is set equal to the maximum number of component test hours to be investigated. The abcissa is divided into 24 or 48 hour periods. Two curves are automatically plotted. The first is the one that results from having no system level test; this is indicated by the "0.0" following the curve under the heading "PLANNED SYS TEST DAYS." The "X" indicates the minimum computed point on the curve (recognizing that the curve is based on 10 computed points).

The second curve is drawn from the files and is the one that contains the minimum value of all the values that were computed. This point too is indicated by an "X" on the curve labeled "58.3" days planned for the system test. Page J-F-4 indicates that this data is located on File # 26.

Figure J-F-2 contains the same data but has, in addition, plotted data from other files. These files contained system tests of 2.3, 4.7, [illegible].7, and 93.3 days. The minimum points of these combinations are all greater than the one on File #26. It can be seen that as the system test length is increased, the lost value decreases until a length of 58.3 days is reached; after that point, costs increase with increased test time more quickly than any gain due to increased average availability. In general then, as the test program length increases, the average availability in orbit increases; however, overall costs reach a minimum at some point during this continual availability increase.

The plot on Fig. J-F-3 results from the user's having input a desired average availability. Whereas on Fig. J-F-2, availability is constantly varying, in Fig. J-F-3, availability is fixed. In Fig. J-F-3, individual points are plotted against an abcissa of component test hours. Each point has associated with it a number that indicates the number of planned test days; the combination of system test days and component test hours results in the desired average availability. The optimum point is again marked with an "X" plotted over the "+" mark used to designate the point. The data that is plotted is contained on page J-F-5 and the corresponding parameters for the optimum program are contained on page J-F-6.

If the optimum program is listed in the last file, it is an indication that longer test times may be needed. This may be done by entering a longer maximum component test length or increasing the system test transition or dwell times.

If one operates the program so that the average availability is initially entered as zero and then subsequently changed to some trial value, the points as plotted in Fig. J-F-3 may be overlaid on the curves as plotted in Fig. J-F-2.

This overlay format can be seen in Addendum J-G. In that addendum, the payload parameters have been held constant except for length. A variation in length results in varying the STS launch costs. The lengths have been entered as 10 feet, 5 feet, and 0 feet (the latter resulting in a launch cost based on payload weight). The resulting data may be seen on pages J-G-1, J-G-2, and Fig. J-G-1, pages J-G-4, J-G-5, and Fig. J-G-2, and pages J-G-7, J-G-8, and Fig. J-G-3 respectively. The average availability required for optimization can be seen to decrease with the launch cost as does the minimum lost value. In the foregoing cases, a medium sized chamber was selected for the system test; pages J-G-10 and J-G-11, and Fig. J-G-4 show a case with a large chamber for a 10ft. long payload.

Addendum J-H presents a case where the average availability is varied. Fig. J-H-1 shows the case of an average availability of 0.75 as compared to the case where the overall optimum was sought; no system level test is found to be required for the 0.75 average availability. In Fig. J-H-2, average availabilities of 0.75 and 0.85 are compared. It is interesting to note that by increasing the required availability, a system level test was found needed to achieve optimization. The apparent discontinuity in going to the no-system-test option is due to the deletion of start-up costs for the system level test.

One of the test parameters accounted for within the analytical model is the test cycle, that is the time the unit takes to go from one temperature extreme to the other (the transition time) and the time spent at temperature (the dwell time). These may be entered in any combination by the user. If the user enters "0,0", indicating no particular choice, the program with automatically enter a 3 hour transition and a 6 hour dwell time for the component test and an 8 hour transition and a 12 hour dwell for the system level test. There is no apparent "best choice" to input based on inspection of the algorithm inasmuch as temperature levels enter into the consideration. Addendum J-1 contains a comparison of three combinations, all summing to the same period.

Addendum J-J presents data for a case in which the ratio of transition to dwell time is constant but the period is different. As indicated elsewhere (Ref. 14 et al.), one would expect the shorter period (resulting in a greater number of cycles over a given time) to result in a more effective program and this is indicated by the data in Addendum J-J.

Inspection of the algorithm would indicate that savings could be accomplished by increasing the range over which the test temperature is cycled. This is evidenced in Addendum J-K. It should be recognized that the model assumes that no new failure modes are introduced by increasing the temperature (in fact, by any test program parameter change). In practice, one would have to make sure that this is in fact true.

This Appendix can be extended indefinitely because of the infinite number of variations that the model can accomodate. However, it is considered that the foregoing data provides an insight as to the way in which the analytical model operates and depicts some trends indicated by the model.

ADDENDUM J-A

PROGRAM LISTING, FILE #1

```
LOAD1
LIST

10 REM: #1 FILE FOR TVTO PROGRAM, PHASE-I VERSION (1979)
15 DIM A$[19],TS[12,14]
20 FIXED 0
30 REM: FLAG 0 affects print-out of information
40 CFLAG 0
50 REM: FLAG 1 set when P/L length =0; deletes comparisons based on length
60 CFLAG 1
70 A=A9=B9=C5=D7=D8=N9=O9=T3=T4=T7=T8=0
90 DISP "If you need gen'l info, enter 1 ";
100 INPUT A
110 IF A=1 THEN 130
120 SFLAG 0
130 PRINT LIN1
140 IF FLAG0 THEN 360
150 PRINT "In order to use this program, the user must know or estimate a "
160 PRINT "number of items to be used \s program inputs."LIN1
180 PRINT "As a minimum, the user must know:"
190 PRINT "a) the number of components in the payload (P/L)"
210 PRINT "b) the mission time in orbit"
220 PRINT "c) the type of item; protoflight, first flight item, or follow-on"
230 PRINT "d) whether an expendable launch vehicle (ELV) or Shuttle (STS)"
240 PRINT "   is involved; if the latter, whether its a Free-Flier or a"
250 PRINT "   Spacelab mission."
260 PRINT "e) the minimun and maximum test temperatures.";LIN1
270 PRINT "The user will also be asked to input various other data.  If the"
280 PRINT "answers are unknow, the user should input 0; in this case the"
290 PRINT "program will provide average value estimates or will skip over"
300 PRINT "that item."LIN1
310 PRINT
320 PRINT "Questions should be answered with 1 for yes and 0 for no.",LIN1
330 PRINT "For questions that are not applicable, enter 0.",LIN1
340 PRINT "When two values are requested, enter them with a comma inbetween"LIN1
350 PRINT TAB25,"* * * * * * * * * * * * ",LIN2
360 DISP "Nr. of components in the P/L";
370 INPUT N9
380 PRINT "The P/L has";N9;"components."LIN1
390 PRINT "Input minimum acceptable P/L average availability as a decimal;"
395 PRINT "input 0 if unknown or full optimization run desired."LIN1
400 DISP "Minimum acceptable avg. avail.";
402 INPUT A9
404 IF A9=0 THEN 430
406 IF A9>0.07 THEN 412
408 A4=A9/2
410 GOTO 414
412 A4=A9-0.05
414 A3=LOGA4
416 D3=(3*A4/A3↑3)*(A3↑2-2*A3+2-2/A4)
418 IF ABS(D3-A9) <= 0.0004 THEN 424
420 A4=A4-(D3-A9)/2
422 GOTO 414
424 B7=A9
426 PRINT "The minimum acceptable availability input as";A9*100;"%"LIN1
428 A9=A4
429 GOTO 440
430 PRINT "The minimum acceptable availability input as";A9*100;"%"LIN1
435 B7=A9
440 PRINT "Input mission time in orbit."LIN1
450 DISP "Mission time in orbit (days)";
460 INPUT O9
470 PRINT O9;"days required in orbit."LIN1
490 PRINT "Input the estimated minimum time an average component will take to"
500 PRINT "get from one temperature extreme to the other during test and the"
510 PRINT "minimum dwell time at temperature. Enter 0's where unknown."LIN1
```

```
520 DISP "Comp:Trans time, Dwell time (h)";
530 INPUT T7,D7
540 IF T7=0 THEN 560
550 GOTO 570
560 T7=3
570 IF D7=0 THEN 590
580 GOTO 600
590 D7=6
600 PRINT "Component test profile contains";T7;" hour transition times"
610 PRINT "and";D7;"hour long dwell times."LIN1
620 PRINT "Input the estimated minimum time it will take the P/L system to"
630 PRINT "get from one temperature extreme to the other during test and the"
640 PRINT "minimum dwell time at temperature. Enter 0's where unknown."LIN1
650 DISP "Sys: Trans time, Dwell time (h)";
660 INPUT T8,D8
670 IF T8=0 THEN 690
680 GOTO 700
690 T8=8
700 IF D8=0 THEN 720
710 GOTO 730
720 D8=12
730 PRINT "System level test profile contains";T8;"hour transition"
740 PRINT "times and";D8;"hour long dwell times."LIN1
830 PRINT "Input the general minimum and maximum system level test"
840 PRINT "temperatures in deg C."LIN1
850 DISP "Sys lvl test Tmin,Tmax (deg C)";
860 INPUT T3,T4
870 IF T3>T4 THEN 890
880 GOTO 910
890 PRINT "Tmin must not exceed Tmax."LIN2
900 GOTO 830
910 PRINT "System test temp. levels: Tmin=";T3;", Tmax=";T4;"deg C"LIN1
912 GOTO 916
914 PRINT "A 1 OR A 2 MUST BE ENTERED."LIN2
916 PRINT "System level tests can be conducted in a large chamber"
917 PRINT "(in the order of 30 ft in diameter and 60 ft high), enter a 1,"
918 PRINT "or in a medium sized chamber"
919 PRINT "(in the order of 12 ft in diameter and 15 ft high), enter a 2."LIN1
920 DISP "Large (1) or medium (2) chamber";
922 INPUT C5
924 PRINT C5;"has been entered."LIN1
926 IF C5#1 AND C5#2 THEN 914
930 PRINT "The P/L may be a protoflight (enter 1), a first flight"
940 PRINT "unit (enter 2), or a follow-on unit (enter3)."LIN1
950 DISP "Pflt (1), Flt#1 (2), or F-O (3)";
960 INPUT B9
970 IF B9=1 OR B9=2 OR B9=3 THEN 1000
980 PRINT "YOU MUST SELECT EITHER 1,2, OR 3."LIN2
990 GOTO 950
1000 PRINT B9;"has been selected."LIN1
1010 LINK 2
1020 END
```

XREF

A$	15										
TS[ ]	15										
A	70	100	110								
A9	70 430	402 435	404	406	408	412	418	420	424	426	428

B9	70	960	970	970	970	1000		
C5	70	922	924	926	926			
D7	70	530	570	590	610			
D8	70	660	700	720	740			
N9	70	370	380					
O9	70	460	470					
T3	70	860	870	910				
T4	70	860	870	910				
T7	70	530	540	560	600			
T8	70	660	670	690	730			
A4	408	412	414	416	416	420	420	428
A3	414	416	416	416				
D3	416	418	420					
B7	424	435						

ADDENDUM J-B

PROGRAM LISTING. FILE #2

```
LOAD2
LIST

10 REM: #2 FILE FOR TVTO PROGRAM, PHASE-I VERSION (1979)
20 REM: This portion develops P/L and launch costs
30 REM: Decision as to type of launch vehicle
35 CFLAG 7
37 CFLAG 8
40 A=C3=C9=D1=D5=D6=E8=E9=I5=I9=K8=K9=L=L1=L2=L3=L4=L5=L9=M=N=0
41 N9=N9
42 P=R=R5=S=T=U7=U8=U9=V=V9=W=W1=W2=W3=W4=W5=W7=W9=0
45 I5=1.302
50 PRINT LIN1,"The following questions pertain to the launch vehicle,"
60 PRINT "Shuttle (STS) or an expendable launch vehicle (ELV)."LIN1
70 DISP "STS (enter 1) or ELV (enter 2)";
80 INPUT V9
90 IF V9=1 OR V9=2 THEN 120
100 PRINT "YOU MAY ENTER ONLY 1 OR 2"LIN2
110 GOTO 70
120 IF V9=2 THEN 1090
130 GOTO 150
140 PRINT "YOU MAY ONLY ENTER 1, 2, OR 3"LIN2
150 PRINT "This is an STS mission."LIN1
160 PRINT LIN1
170 IF FLAG0 THEN 260
180 PRINT "This program considers only payload weight and length.  Full"
190 PRINT "computation of STS launch costs includes consideration of payload"
200 PRINT "volume; this has been omitted to simplify the effort. If length"
210 PRINT "was entered as 0, only weight will be considered."LIN1
220 PRINT "OMS kits are only considered for Free-Flier and attached"
230 PRINT "non-S/L payloads in this model."LIN1
240 REM: Dimensions should be: weight-lbs, length-ft
250 REM: W4= OMS kit wt, W5= upper stg wt, L5= upper stg lngth
260 PRINT "This may be a Free-Flier P/L (F-F), enter 1,"
270 PRINT "an attached but not Spacelab P/L (Att), enter 2,"
280 PRINT "or a Spacelab P/L (S/L), enter 3."LIN1
290 DISP "F-F (1), Att (2), or S/L (3)";
300 INPUT C9
301 DISP "Will P/L be reflown";
302 INPUT R5
303 R5=R5+1
304 IF R5=1 THEN 310
305 PRINT "If the number of reflights is unknown, enter 1."LIN1
306 DISP "How many reflights";
307 INPUT A
308 R5=R5+A-1
309 PRINT (R5-1);"reflights are expected."LIN1
310 IF C9#1 AND C9#2 AND C9#3 THEN 140
320 PRINT "The flight may be dedicated to this P/L (enter 1),"
330 PRINT "or shared with other P/L's (enter 2)."LIN1
340 DISP "Dedicated (1) or shared (2)";
350 INPUT D1
360 IF C9#3 THEN 1000
370 REM: Spacelab computations
380 REM: Foll subroutine to develop P/L wt, lngth, and cost
390 GOSUB 4000
400 PRINT "This model makes decisions on pallet and pressurized module factors"
402 PRINT "based on weight distributions.  If there is no pressurized module,"
404 PRINT "assume all the weight is on the pallets even thought some may"
406 PRINT "be in the aft flight deck. Enter fraction of weight on the pallet"
410 PRINT "plus the aft flight deck as 0.XX (or 1.00 if appropriate)."LIN1
420 DISP "% wt on pallet(s), enter as X.XX";
430 INPUT P
440 IF D1=1 THEN 850
450 PRINT "S/L elements (pallets or press. mod.) can be"
460 PRINT "dedicated to the P/L (enter 1) or shared with others (enter 2)"LIN1
```

```
470 DISP "Dedicated (1) or shared (2)";
480 INPUT E9
490 IF E9=1 THEN 650
500 IF P>0 THEN 540
510 GOSUB 6200
520 C3=((L3*22)+(L4*1.67))*I5
530 GOTO 2000
540 IF P=1 THEN 620
550 GOSUB 6000
560 GOSUB 6200
570 IF L1+L3>1 THEN 600
580 C3=((L1+L2)*22+(L4*1.67)+(L2*0.33))*I5
590 GOTO 2000
600 C3=(22+(L4*1.67)+(L2*0.33))*I5
610 GOTO 2000
620 GOSUB 6000
630 C3=((L1*20.3)+(L2*0.33))*I5
640 GOTO 2000
650 IF P>0 THEN 690
660 GOSUB 6600
670 C3=(L2*22+1.67)*I5
680 GOTO 2000
690 IF P=1 THEN 790
700 PRINT "S/L missions with the long pressurized module may have"
703 PRINT "no more than 2 pallets."LIN1
706 DISP "Number of pallets (<=2)";
710 INPUT N
720 GOSUB 6400
730 GOSUB 6600
740 IF (L1+L2)>1 THEN 770
750 C3=((L1+L2)*22+1.67+(N*0.33))*I5
760 GOTO 2000
770 C3=(22+1.67+(N*0.33))*I5
780 GOTO 2000
790 PRINT "S/L without pressirised module may have no more than 5 pallets."LIN1
800 DISP "Number of pallets (<=5)";
810 INPUT N
820 GOSUB 6400
830 C3=((L1*20.3)+(N*0.33))*I5
840 GOTO 2000
850 IF P>0 THEN 880
860 C3=(22+1.67)*I5
870 GOTO 2000
880 IF P=1 THEN 940
890 PRINT "S/L with long pressurized module may have"
895 PRINT "no more than 2 pallets."LIN1
900 DISP "Number of pallets (<=2)";
910 INPUT N
920 C3=(22+1.67+(N*0.33))*I5
930 GOTO 2000
940 PRINT "S/L without pressurized module may have no more than 5 pallets"LIN1
950 DISP "Number of pallets (<=5)";
960 INPUT N
970 C3=(20.3+(N*0.33))*I5
980 GOTO 2000
990 REM: Free-Fliers or attached P/L's
1000 GOSUB 8000
1010 GOSUB 4000
1020 IF D1=2 THEN 1050
1030 C3=18*I5
1040 GOTO 2000
1050 GOSUB 7000
1060 C3=A*18*I5
1070 GOTO 2000
1080 REM: ELV operations
1090 GOSUB 9500
```

```
1100 GOSUB 4000
1110 GOTO 2000
2000 REM: Output mission costs
2010 FIXED 3
2015 IF V9=2 THEN 2100
2020 PRINT LIN1
2025 T=C3+S+R+K8
2030 PRINT "STS LAUNCH COST IS";T;" MILLION (1978) DOLLARS";LIN1
2040 IF C9=3 THEN 2090
2045 IF S=0 THEN 2055
2050 PRINT "Upper stage portion =";S
2055 IF K9=0 THEN 2070
2060 PRINT K9;"OMS kits; total cost =";K8
2070 IF R=0 THEN 2116
2080 PRINT "Revisit cost is included at";R;"million (1978) dollars."LIN1
2090 GOTO 2120
2100 PRINT LIN1
2110 PRINT "ELV LAUNCH COST IS";T;" MILLION (1978) DOLLARS"LIN1
2113 GOTO 2120
2116 PRINT LIN1
2120 PRINT "PAYLOAD COST IS";U9;"MILLION (1978) DOLLARS."LIN1
2130 IF C9=2 OR C9=3 THEN 2160
2135 IF FLAG2 THEN 2160
2140 PRINT "Instrument cost =";U7
2150 PRINT "Platform cost =";U8
2160 PRINT LIN2
2210 LINK 3
2220 END
4000 REM: Subroutine for determining P/L dimensions and costs ******************
4010 FIXED 0
4020 PRINT "P/L dimensions are to be determined."LIN1
4030 IF V9=2 OR C9=3 THEN 4130
4040 PRINT "Program internally adds OMS kit and upper stage data; payload"
4050 PRINT "weight or length inputs should not include these factors."LIN1
4060 PRINT "Enter P/L length (in feet); if unknown, enter 0.  This model does"
4070 PRINT "not estimate P/L length when 0 is entered; all subsequent STS"
4080 PRINT "computations are based on weight alone."LIN1
4090 DISP "P/L length (feet)";
4100 INPUT L9
4110 PRINT "P/L length (feet) entered as";L9,LIN1
4120 GOTO 4140
4130 L9=0
4140 PRINT "Enter P/L weight (lbs); enter 0 if unknown."LIN1
4150 DISP "P/L weight (lbs)";
4160 INPUT W9
4170 IF W9#0 THEN 4300
4180 REM: Develop P/L wt from component count based on
4190 REM: regression of 26 S/C from the period 1970-1975 whose
4200 REM: component count is established.
4210 W9=118.28*EXP(0.0301*N9)
4220 IF C9=2 OR C9=3 THEN 4270
4230 PRINT "Estimated platform weight (lbs):";W9*3/4
4240 PRINT "Estimated instrument weight (lbs) :";W9/4
4250 PRINT "Estimated total P/L weight (lbs) :";W9,LIN1
4260 GOTO 4310
4270 W9=W9/4
4280 PRINT "Estimated P/L weight (lbs) :";W9,LIN1
4290 GOTO 4310
4300 PRINT "P/L weight (lbs) input as";W9
4310 REM: Foll determines P/L costs
4320 FIXED 3
4330 PRINT "Enter P/L cost in millions of 1978 dollars; if the amount is"
4340 PRINT "unknown, enter 0.";LIN1
4350 DISP "P/L cost (1978 M$)";
4360 INPUT U9
4370 IF U9#0 THEN 4390
```

```
4380 GOTO 4420
4390 SFLAG 2
4400 PRINT "P/L cost (1978 M$) input as";U9,LIN1
4410 GOTO 4940
4420 REM: Generate the P/L cost
4425 IF FLAG0 THEN 4600
4430 REM: Recurring Platform costs (ie, less instruments) per SAMSO model
4440 REM: "Unmanned Spacecraft Cost Model", TR-78-61, Feb 1978
4450 REM: Data adjusted to 1978 costs
4460 REM: Instrument costs based on Planning Research Corp. Tech Brief No. 40
4470 REM: "Scientific instrument Cost Model", PRC D-2136, Dec. 15,1978
4480 REM: Data from GSFC X-213-73-66, Feb 1973 indicates instrument weight
4490 REM: is roughly 1/4 of the P/L weight
4500 PRINT LIN1,"Instrument costs may be estimated based on the type"
4510 PRINT "and weight of the instrument."
4520 PRINT "The following classes apply:"
4530 PRINT "     class 1: Interferometers"
4540 PRINT "     class 2: Telescope, Spectroheliograph, Passive Microwave"
4550 PRINT "              Radiometer, Photometer, Spectrometer, T-V Camera,"
4560 PRINT "              Magnetometer"
4570 PRINT "     class 3: Active Microwave, Mass Measurement, Plasma Probe"
4580 PRINT "              Charge Detector, Film Camera"LIN1
4590 PRINT "If type is unknown, use class 2 as an average."LIN1
4600 DISP "Instrument class, 1, 2, or 3";
4610 INPUT I9
4620 IF I9=1 OR I9=2 OR I9=3 THEN 4650
4630 PRINT "ONLY THE NUMBERS 1, 2, OR 3 MAY BE SELECTED"LIN2
4640 GOTO 4600
4650 FIXED 0
4660 PRINT "Instrument class";I9;"is selected."LIN1
4670 FIXED 3
4680 REM: If attached or S/L P/L, branch over
4690 IF C9=2 OR C9=3 THEN 4790
4700 W7=W9/4
4710 GOSUB I9 OF 4850,4890,4920
4720 PRINT "Estimated instrument cost (1978 M$) :";U7
4730 REM: SAMSO model, U8= platform cost, wt= P/L*3/4
4740 U8=(0.02498*(W9*3/4)↑0.81)*1.558/1.307
4750 PRINT "Estimated platform cost (1978 M$) :";U8
4760 U9=U8+U7
4770 PRINT "Estimated total P/L cost (1978 M$) :";U9,LIN1
4780 GOTO 4940
4790 REM: Compute costs for attached or S/L P/L
4800 W7=W9
4810 GOSUB I9 OF 4850,4890,4920
4820 PRINT "Estimated P/L cost (1978 M$) :";U7,LIN1
4830 U9=U7
4840 RETURN
4850 REM: Compute cost of an instrument based on class
4860 REM: class 1
4870 U7=0.027*W7↑0.953
4880 RETURN
4890 REM: class 2
4900 U7=0.03*W7↑0.776
4910 RETURN
4920 REM: class 3
4930 U7=0.037*W7↑0.652
4940 RETURN
4950 END
5990 REM: Subroutines for Load Factors & Load Fractions ************************
6000 REM: Pallet, Shared Element, Load Factor & Load Fraction
6010 W=W1/(19559*0.75)
6020 M=0.01
6030 A=W
6040 GOSUB 6800
6050 L1=A
```

```
6060 W=W1/(4890*0.75)
6070 M=0.04
6080 A=W
6090 GOSUB 6800
6100 L2=A
6110 A=0
6120 RETURN
6130 END
6200 REM: Pressurized Module, Shared Element, Load Factor & Load Fraction
6210 W=W2/(14065*0.75)
6220 M=0.01
6230 A=W
6240 GOSUB 6800
6250 L3=A
6260 W=W2/(14065*0.75)
6270 M=0.04
6280 A=W
6290 GOSUB 6800
6300 L4=A
6310 A=0
6320 RETURN
6330 END
6400 REM: Pallet(s), Dedicated Element, Load Factor
6410 W=(W1+(2747*N))/(32000*0.75)
6420 M=0.01
6430 A=W
6440 GOSUB 6800
6450 L1=A
6460 W=0.2*N/0.75
6470 M=0.01
6480 A=W
6490 GOSUB 6800
6500 IF L>A THEN 6520
6510 L1=A
6520 A=0
6530 RETURN
6540 END
6600 REM: Pressurized Module, Dedicated Element, Load Factor
6610 W=(W2+17934)/(32000*0.75)
6620 M=0.01
6630 A=W
6640 GOSUB 6800
6650 L2=A
6660 IF L2>0.62/0.75 THEN 6680
6670 L2=0.62/0.75
6680 A=0
6690 RETURN
6700 END
6800 REM: Subroutine to det'm'n if 1<=A<=M and adjust as required
6810 IF A>1 THEN 6840
6820 IF A<M THEN 6860
6830 GOTO 6870
6840 A=1
6850 GOTO 6870
6860 A=M
6870 RETURN
6880 END
7000 REM: Subroutine to develop F-F and Att. P.L Load Factors ******************
7010 REM: Compute total P/L chargeable weight
7020 IF L9#0 THEN 7050
7030 L=0
7040 GOTO 7060
7050 L=L9+K9*9+L5
7060 W3=W9+W4+W5
7070 REM: Load Factors
7080 W=W3/(60000*0.75)
```

```
7090 IF L9=0 THEN 7110
7100 V=(L+0.5)/((720/12)*0.75)
7110 M=0.067
7120 REM: Det'm'n larger of W or V
7130 IF W=0 THEN 7220
7140 IF L9=0 THEN 7190
7150 IF W>V THEN 7190
7160 A=V
7170 GOSUB 6800
7180 GOTO 7230
7190 A=W
7200 GOSUB 6800
7210 GOTO 7230
7220 !
7230 RETURN
7240 END
8000 REM: Subroutine for STS extras: upper stages  (P/L revisit), OMS kits *****
8010 IF C9=2 THEN 8250
8020 REM: SSUS-D, SSUS-A, IUS
8030 DISP "Is upper stage required";
8040 S=0
8050 INPUT S
8060 IF S=0 THEN 8240
8070 DISP "SSUS-D";
8080 INPUT A
8090 IF A=1 THEN 8490
8100 DISP "SSUS-A";
8110 INPUT A
8120 IF A=1 THEN 8540
8130 DISP "IUS two stage";
8140 INPUT A
8150 IF A=1 THEN 8600
8160 DISP "IUS twin stage";
8170 INPUT A
8180 IF A=1 THEN 8660
8190 DISP "IUS twin stage +spinner";
8200 INPUT A
8210 IF A=1 THEN 8720
8220 PRINT LIN1,"THERE ARE NO OTHER CHOICES IN THIS MODEL";LIN2
8230 GOTO 8030
8240 PRINT "No upper stage is used.";LIN1
8250 REM: P/L revisit
8260 REM: DISP "Does mission need P/L revisit";
8270 REM: INPUT R
8280 REM: IF R=0 THEN 8310
8290 REM: PRINT "There is a P/L revisit planned for this mission.";LIN1
8300 REM: R=0.35*I5
8310 DISP "How many OMS kits (up to 3)";
8320 INPUT K9
8330 IF K9=0 THEN 8450
8340 REM: OMS kits weight: 1) 16302, 2) 29468, 3) 43033
8350 REM: They are each 9 feet long
8360 GOTO K9 OF 8370,8390,8410
8370 W4=16302
8380 GOTO 8420
8390 W4=29468
8400 GOTO 8420
8410 W4=43033
8420 PRINT K9;"OMS kits are used in this mission.";LIN1
8430 REM: Kit + installation time costs
8440 K8=K9*0.22*I5+((K9*44)-24)*(0.01375*I5)
8450 RETURN
8460 END
8470 REM: Routine for upper stage information ---------------------------------
8480 PRINT "Mission uses SSUS-D",LIN1
8490 REM: SSUS-D cost in 1980 $'s; length=7.5 ft., wt approx 7500
```

```
8495 D6=1
8500 S=(2.5+1.5)*1.078/1.338
8510 W5=7500
8520 L5=7.5
8530 GOTO 8250
8540 REM: SSUS A cost in 1976 $'s; length=8 ft; wt=8200+4000 for cradle
8550 PRINT "Mission uses SSUS-A",LIN1
8555 D6=2
8560 S=3*1.302/1.092
8570 W5=12200
8580 L5=8
8590 GOTO 8250
8600 REM: IUS two stage, 1980 $'s, length approximated
8610 PRINT "Mission uses IUS two stage,",LIN1
8615 D6=3
8620 S=(9.4+6)*1.078/1.338
8630 W5=32000
8640 L5=16.4
9650 GOTO 8250
8660 REM: IUS twin stage, 1980 $'s, length approximated
8670 PRINT "Mission uses IUS twin stage",LIN1
8675 D6=4
8680 S=(12+6)*1.078/1.338
8690 W5=48700
8700 L5=21.8
8710 GOTO 8250
8720 REM: IUS twin stage + spinner, 1980 $'s, length approximated
8730 PRINT "Mission uses IUS twin stage + spinner",LIN1
8735 D6=5
8740 S=(13+6)*1.078/1.338
8750 W5=55900
8760 L5=27.2
8770 GOTO 8250
8780 END
9500 REM: Subroutine for development of expendable launch vehicle (ELV) costs **
9510 FIXED 3
9515 R5=1
9520 PRINT "This mission uses an expendable launch vehicle."LIN1
9530 PRINT "Only three vehicles are included in this model; enter a"
9540 PRINT "1 for a Scout, a 2 for a 2900 series Delta,"
9550 PRINT "and a 3 for a 3900 series Delta."LIN1
9560 DISP "Expendable launch vehicle code";
9570 INPUT D5
9580 GOTO D5 OF 9590,9620,9650
9590 REM: Scout is approx 2.2M + .2M for support services
9600 T=2.4
9605 PRINT "A Scout launch vehicle has been selected."LIN1
9610 GOTO 9670
9620 REM: 2900 series Delta (Castor II), includes support services
9630 T=15.4
9635 PRINT "A 2900 series Delta launch vehicle has been selected."LIN1
9640 GOTO 9670
9650 REM: 3900 series Delta (Castor IV), includes support services
9660 T=19
9665 PRINT "A 3900 series Delta launch vehicle has been selected."LIN1
9670 RETURN
9680 END
```


XREF

A	40	307	308	1060	6030	6050	6080	6100	6110	6230	6250
	6280	6300	6310	6430	6450	6480	6500	6510	6520	6630	6650
	6680	6810	6820	6840	6860	7160	7190	7220	8080	8090	8110
	8120	8140	8150	8170	8180	8200	8210				

C3	40 970	520 1030	580 1060	600 2025	630	670	750	770	830	860	920
C9	40 4220	300 4690	310 4690	310 8010	310	360	2340	2130	2130	4030	4220
D1	40	350	440	1020							
D5	40	9570	9580								
D6	40	8495	8555	8615	8675	8735					
E8	40										
E9	40	480	490								
I5	40 920	45 970	520 1030	580 1060	600 8440	630 8440	670	750	770	830	860
I9	40	4610	4620	4620	4620	4660	4710	4810			
K8	40	2025	2060	8440							
K9	40	2055	2060	7050	8320	8330	8360	8420	8440	8440	
L	40	6500	7030	7050	7100						
L1	40	570	580	630	740	750	830	6050	6450	6510	
L2	40 6670	580	580	600	630	670	740	750	6100	6650	6660
L3	40	520	570	6250							
L4	40	520	580	600	6300						
L5	40	7050	8520	8580	8640	8700	8760				
L9	40	4100	4110	4130	7020	7050	7090	7140			
M	40	6020	6070	6220	6270	6420	6470	6620	6820	6860	7110
N	40 6460	710	750	770	810	830	910	920	960	970	6410
N9	41	41	4210								
P	42	430	500	540	650	690	850	880			
R	42	2025	2070	2080							
R5	42	302	303	303	304	308	308	309	9515		
S	42 8740	2025	2045	2050	8040	8050	8060	8500	8560	8620	8680
T	42	2025	2030	2110	9600	9630	9660				
U7	42	2140	4720	4760	4820	4830	4870	4900	4930		
U8	42	2150	4740	4750	4760						
U9	42	2120	4360	4370	4400	4760	4770	4830			
V	42	7100	7150	7160							

V9	42	80	90	90	120	2015	4030				
W	42	6010	6030	6060	6080	6210	6230	6260	6280	6410	6430
	6460	6480	6610	6630	7080	7130	7150	7190			
W1	42	6010	6060	6410							
W2	42	6210	6260	6610							
W3	42	7060	7080								
W4	42	7060	8370	8390	8410						
W5	42	7060	8510	8570	8630	8690	8750				
W7	42	4700	4800	4870	4900	4930					
W9	42	4160	4170	4210	4230	4240	4250	4270	4270	4280	4300
	4700	4740	4800	7060							

ADDENDUM J-C

PROGRAM LISTING, FILE #3

```
LOAD3
LIST

10 REM: #3 FILE FOR TVTO PROGRAM, PHASE-I VERSION (1979)
20 REM: Program computes number of component test failures vs. time and system
30 REM: test time and failures for either a fixed launch failure rate or for
40 REM: a failure rate based on a given instantaneous availability
50 A2=A5=A6=F5=M1=M2=M3=M4=M5=M6=R6=0
60 D4=5
70 CFLAG 1
80 CFLAG 2
90 X7=0
100 X8=Z9=10↑9
110 X9=0
120 IF FLAG7 THEN 2160
130 DISP "DATE";
140 INPUT A$
150 PRINT LIN2
160 PRINT TAB55,A$,LIN2
170 PRINT "Enter maximum number of component test hours to be investigated."
180 PRINT
190 DISP "MAXIMUM NR COMP TEST HOURS";
200 INPUT T5
210 DISP "FILE NR. FOR 1ST DATA ARRAY";
220 INPUT F9
225 REM: F9 IS A FILE NUMBER COUNTER FOR STORING  EACH ARRAY
230 F8=F9
240 A1=A9
250 DISP "WANT RELIABILITY DATA PRINTOUT";
260 INPUT Z
270 IF Z=1 THEN 290
280 SFLAG 1
290 Y2=D7/(T7+D7)
300 DISP "WANT COST/PROJ. DATA PRINTOUT";
310 INPUT Z
320 IF Z=1 THEN 340
330 SFLAG 2
340 MAT T=ZER
350 C2=T4+D4
360 C1=T3-D4
370 E2=EXP(0.0306*(C2+32))+EXP(0.0306*(62-C2))
380 E1=EXP(0.0306*(C1+32))+EXP(0.0306*(62-C1))
390 E2=E1+E2
400 B2=0.7
410 E2=E2*(Y2/2)↑B2+3*(1-Y2)↑B2*((C2-C1)/((1-Y2)*(T7+D7)))↑0.5
420 K2=424*10↑(-6)
430 H2=K2*B2*E2
440 REM: K2= EXPECTED VALUE OF INITIAL CUMULATIVE FAILURE RATE  FOR UNTESTED"
450 REM: COMPONENTS.
460 FIXED 1
470 REM: PROGRAM INITIALLY SETS COMPONENT TEST TEMPERATURES TO SYSTEM TEST
480 REM:TEMPERATURES +/- 5 deg C
490 T[1,1]=C1
500 T[1,2]=C2
510 T[1,3]=T3
520 T[1,4]=T4
530 T[1,5]=T7
540 T[1,6]=D7
550 T[1,7]=T8
560 T[1,8]=D8
570 T[1,9]=A9
580 T[1,10]=H2
590 T[1,11]=E2
595 T[1,13]=B7
600 Y1=D8/(T8+D8)
610 E4=EXP(0.0306*(T4+32))+EXP(0.0306*(62-T4))
```

```
620 E3=EXP(0.0306*(T3+32))+EXP(0.0306*(62-T3))
630 E1=E3+E4
640 B1=0.6
650 E1=E1*(Y1/2)↑B1+3*(1-Y1)↑B1*((T4-T3)/((1-Y1)*(T8+D8 ))↑0.5
660 T[1,12]=E1
670 E=14.26
680 K=(8850*10↑(-6))/E
690 B=0.314
700 C8=1-0.273*EXP(-0.0086*N9)
710 REM: PROGRAM NOW COMPUTES COMP. TEST FAILURES VS. # OF CYCLES, AND INITIAL"
720 REM: SYSTEM TEST K(DAYS)
730 FORMAT F6.1,2F9.0,F8.1,F9.1,F10.1,F10.2,F7.3
740 IF FLAG1 THEN 790
742 FIXED 2
743 PRINT "E(COMP)=";E2;TAB20,"E(SYS)=";E1;TAB40,"E(SPA E)=";E
745 PRINT
750 PRINT "C.TEST      (HRS)   PLANNED (DAYS)                           MISSION END"
760 PRINT "NO.OF 1/2   COMP.   SYSTEM  SYS.T   COMPONENT SYSTEM         AVAIL/FACTOR"
770 PRINT "PERIODS     TEST T  CYCLES  E(T)    TEST FAIL TEST FAIL      ----- ------"
780 PRINT "-------     ------  ------  ------  --------- ---------
790 N1=0
800 Y=P9=1
810 CFLAG 9
820 IF T8+D8>24 THEN 850
830 P9=2
850 FOR J=0 TO 40 STEP P9
870 N1=0
910 FOR A=0 TO T5 STEP (T5/10)
915 K4=(24↑B2)*K2*(B2/B1)*(E2/E)↑((B2-1)/B2)
920 IF A#0 THEN 990
930 T2=I=F2=0
950 F3=0.02*N9
960 K1=K4
980 GOTO 1110
990 T2=A-10
1000 F2=0.02*N9
1010 F3=0
1030 IF T2 <= 0.4 THEN 1060
1032 F2=F2+N9*K2*E2*(T2-0.4)↑B2
1034 I=T2/(T7+D7)
1040 IF T2>1.4 THEN 1090
1060 I=0
1070 K1=K4
1080 GOTO 1100
1090 K4=K4*(T2-0.4)↑(B2-1)
1095 K1=K4
1100 T2=T2+10
1110 IF A9=0 THEN 1690
1112 K=(E*LOG(C8)*1.833*N9*(O9)↑B)
1114 K5=(LOG(A9)-0.02*N9*LOG(C8))/K
1115 A7=A9
1120 K=LOG(A9)/K
1122 IF K*B >= (K1*B1) THEN 1140
1124 IF Y>1 THEN 1270
1126 IF (K5*B)<(K1*B1*(E1/E)↑((B1-1)/B1)) THEN 1270
1128 T1=1
1130 P5=F4=0
1132 SFLAG 9
1134 F1=F3
1136 GOTO 1370
1140 SFLAG 9
1150 T1=F1=P5=0
1152 IF A=0 THEN 1220
1153 F4=0
1154 IF (T2-10) >= 1.4 THEN 1160
1156 T2=10
```

```
1157 F2=0.02*N9
1158 I=0
1159 GOTO 1370
1160 T2=(K*B/(K2*B2*(24↑B2)))↑(1/(B2-1))
1170 T2=((E/E2)↑(1/B2))*T2+0.4
1180 I=T2/(T7+D7)
1190 T2=T2+10
1195 IF T2<10.4 THEN 1157
1200 F2=0.02*N9+N9*K2*E2*(T2-10.4)↑B2
1210 GOTO 1370
1220 F4=0.02*N9
1240 GOTO 1370
1270 T1=(K*B/(K1*B1))↑(1/(B1-1))
1280 T1=((E/E1)↑(1/B1))*T1
1290 T1=T1+0.8
1300 T1=T1/1.34
1310 P5=INT(T1*24/(T8+D8))
1320 IF P5=T1*24/(T8+D8) THEN 1340
1330 P5=P5+1
1340 T1=T1*1.34
1350 F1=F3+N9*K1*E1*(T1-0.8)↑B1
1360 F4=0
1370 GOSUB 1390
1380 GOTO 1870
1390 H1=K1*E1*B1
1400 H=K*E*B
1410 F=F4+N9*K*E*(O9)↑B
1420 R3=1-K*E*(O9)↑B
1430 E6=LOGA7
1440 D=(3*A7/E6↑3)*(E6↑2-2*E6+2-2/A7)
1450 D=1-D
1470 DISP I;J;D;F9
1480 A1=C8↑(F4+1.833*K*E*N9*O9↑B)
1490 Y=Y+1
1500 T[Y,1]=I/2
1502 IF  NOT FLAG9 THEN 1510
1506 T[Y,2]=T2
1509 GOTO 1520
1510 T[Y,2]=A
1520 T[Y,3]=F2
1530 T[Y,13]=D
1540 T[Y,5]=P5/2
1550 T[Y,6]=T1
1560 T[Y,7]=F1
1570 T[Y,8]=H1
1580 T[Y,10]=H
1590 T[Y,11]=A1
1600 T[Y,12]=F
1610 IF FLAG1 THEN 1660
1620 WRITE (2,730)I,T[Y,2],P5,T1,F2,F1,A1,D
1630 N1=N1+1
1640 IF N1<5 THEN 1670
1650 PRINT
1660 N1=0
1670 RETURN
1680 END
1690 T1=1.34*J*(T8+D8)/24
1700 P5=J
1710 IF J#0 THEN 1760
1720 K=(K1*B1/B)*(E1/E)↑((B1-1)/B1)
1730 F1=0
1740 F4=F3
1750 GOTO 1850
1760 IF T1>1.8 THEN 1810
1770 F1=F3
1780 F4=0
```

```
1790 K=(K1*B1/B)*(E1/E)↑((B1-1)/B1)
1800 GOTO 1850
1810 F4=0
1820 K=(K1*B1/B)*(E1/E)↑((B1-1)/B1)
1830 K=K*(T1-0.8)↑(B1-1)
1840 F1=F3+N9*K1*E1*(T1-0.8)↑B1
1850 A7=C8↑(1.833*(F4+K*E*N9*O9↑B))
1855 GOSUB 1390
1870 NEXT A
1880 Y=1
1885 CFLAG 9
1890 GOSUB 4000
1900 GOSUB 5000
1910 STORE  DATA #1,F9,T
1920 FOR I=2 TO 12
1930 FOR I1=1 TO 14
1940 D[I,I1]=0
1950 NEXT I1
1960 NEXT I
1970 F9=F9+1
1980 IF FLAG1 THEN 2000
1990 PRINT LIN1
2000 IF A9#0 THEN 2100
2010 IF FLAG1 THEN 2070
2012 FIXED 2
2015 PRINT "E(COMP)=";E2;TAB20,"E(SYS)=";E1;TAB40,"E(SPACE)=";E
2017 PRINT
2020 PRINT "C.TEST      (HRS)   PLANNED (DAYS)
2030 PRINT "NO.OF 1/2   COMP.   SYSTEM  SYS.T    COMPONENT SYSTEM     MISSION END"
2040 PRINT "PERIODS     TEST T  CYCLES  E(T)     TEST FAIL TEST FAIL  AVAIL/FACTOR
2050 PRINT "-------     ------  ------  ------   --------- ---------  ----- ------
2070 NEXT J
2080 PRINT LIN1
2100 FIXED 0
2110 PRINT "RUN(S) COMPLETE.",LIN2
2120 PRINT "LAST DATA ARRAY IS STORED ON TRACK#1,FILE # ";(F9-1),LIN2
2130 LINK #0,4
2140 CFLAG 1
2150 CFLAG 2
2160 PRINT
2162 DISP "CHANGE AVG. AVAILABILITY";
2164 INPUT A3
2166 IF A3=0 THEN 2178
2168 DISP "NEW AVG. AVAIL.(must be >0.04) ";
2170 INPUT A9
2175 GOSUB 2470
2178 DISP "Try new temperature conditions";
2180 INPUT Z
2190 IF Z=0 THEN 2280
2200 PRINT "Current min, max system test temperatures, deg. C:";T3;",";T4,LIN1
2210 DISP "Enter new system test Tmin, Tmax ";
2220 INPUT T3,T4
2230 PRINT
2240 PRINT "Component test temps are now incremented";D4;"deg. C higher/lower"
2250 PRINT "than the system test temperatures.  Input new temp. increment"LIN1
2260 DISP "Enter new comp. temp. increment ";
2270 INPUT D4
2280 DISP "Change transit'n or dwell times";
2290 INPUT A
2300 IF A=1 THEN 2330
2310 IF Z=0 AND A3=0 AND A=0 THEN 2430
2320 GOTO 210
2330 FIXED 0
2340 PRINT LIN1,"Current component test transition and dwell times (hours) are";
2350 PRINT T7;",";D7,LIN1
2360 DISP "Comp test trans, dwell times, h";
```

```
2370 INPUT T7,D7
2380 PRINT LIN1"Current system test transition and dwell times (hours) are";
2390 PRINT T8;",";D8,LIN1
2400 DISP "Sys test trans, dwell times, h";
2410 INPUT T8,D8
2420 GOTO 210
2430 PRINT "END",LIN2
2440 CFLAG 7
2450 CFLAG 8
2460 END
2470 Z=A3
2475 IF A9>0.07 THEN 2500
2480 A4=A9/2
2490 GOTO 2510
2500 A4=A9-0.05
2510 A3=LOGA4
2520 D3=(3*A4/A3↑3)*(A3↑2-2*A3+2-2/A4)
2530 IF ABS(D3-A9) <= 0.0004 THEN 2560
2540 A4=A4-(D3-A9)/2
2550 GOTO 2510
2560 B7=A9
2570 A9=A4
2575 A3=Z
2580 RETURN
4000 REM: Subroutine for developing test costs
4010 REM: Q1= repair costs/failure; Q2, based on historical data,=
4020 REM: (sys tests with retests)/(sys tests with and without retests)
4030 REM: Q3 is estimate for marching-army costs of 120K per week for 84 comp.
4040 Q1=5300
4050 Q2=27/39
4060 Q3=120000/(84*7)
4070 FOR I=2 TO 12
4080 REM: Comp level test costs; 1.78 comp/test already included
4090 IF T[I,2]#0 THEN 4120
4100 T[I,4]=0
4110 GOTO 4150
4120 T[I,4]=((N9+T[I,3])*(T[I,2]*25.2+868)+(T[I,3]*Q1))/10↑6
4130 IF B9#2 THEN 4150
4140 T[I,4]=2*T[I,4]
4150 REM: Sys level test costs
4160 IF T[I,6]#0 THEN 4190
4170 T[I,9]=0
4180 GOTO 4510
4190 IF C5=2 THEN 4220
4200 GOTO B9 OF 4230,4270,4330
4210 REM
4220 GOTO B9 OF 4370,4410,4470
4230 REM: Large chamber, Protoflight unit
4240 T[I,9]=N9*3400+147000+T[I,6]*(N9*177+17000)+Q2*(N9*158+6160)+T[I,7]*Q1
4250 T[I,9]=(T[I,9]+Q3*N9*(T[I,6]*0.34/1.34))/10↑6
4260 GOTO 4510
4270 REM: Large chamber, Qual tests + Flt unit #1
4280 T[I,9]=N9*3400+147000+T[I,6]*(N9*177+17000)+Q2*(N9*158+6160)+T[I,7]*Q1
4290 T[I,9]=(T[I,9]+Q3*N9*(T[I,6]*0.34/1.34))
4300 T[I,9]=T[I,9]+N9*861+40300+T[I,6]*(N9*44.5+7000)
4310 T[I,9]=(T[I,9]+Q2*(N9*158+6160)+Q1*T[I,7]+Q3*N9*(T[I,6]*0.34/1.34))/10↑6
4320 GOTO 4510
4330 REM: Large chamber, Follow-on unit
4340 T[I,9]=((1+Q2)*(N9*158+6160)+T[I,6]*(N9*44.5+7000)+T[I,7]*Q1)
4350 T[I,9]=(T[I,9]+Q3*N9*(T[I,6]*0.34/1.34))/10↑6
4360 GOTO 4510
4370 REM: Medium chamber, Protoflight unit
4380 T[I,9]=N9*2860+69800+T[I,6]*(N9*[illegible])+Q2*(N9*[illegible]33+2920)+T[I,7]*Q1
4390 T[I,9]=(T[I,9]+Q3*N9*(T[I,6]*0.34/1.34))/10↑6
4400 GOTO 4510
4410 REM: Medium chamber, Qual + Flt unit #1
```

```
4420 T[I,9]=N9*2860+69800+T[I,6]*(N9*96.4+1240)+Q2*(N9* 33+2920)
4430 T[I,9]=(T[I,9]+Q3*N9*(T[I,6]*0.34/1.34))
4440 T[I,9]=T[I,9]+N9*697+19100+T[I,6]*(N9*24.2+516)+Q2*(N9*133+2920)+T[I,7]*Q1
4450 T[I,9]=(T[I,9]+Q3*N9*(T[I,6]*0.34/1.34))/10↑6
4460 GOTO 4510
4470 REM: Medium chamber, Follow-on unit
4480 T[I,9]=(1+Q2)*(N9*133+2920)+T[I,6]*(N9*24.2+516)+T[I,7]*Q1
4490 T[I,9]=(T[I,9]+Q3*N9*(T[I,6]*0.34/1.34))/10↑6
4500 REM: Total flight costs, M$
4510 A2=0
4520 IF R5=1 THEN 4540
4530 A2=1
4540 T[I,14]=T+U9/R5+A2*T[I,12]*Q1/10↑6
4550 NEXT I
4560 RETURN
4570 END
5000 REM: Subroutine for data printout
5010 IF FLAG2 THEN 5260
5020 PRINT LIN2
5030 PRINT "DATA ON TRACK#1, FILE#";F9
5040 PRINT LIN1
5050 FORMAT "Tmin, deg C: ",F4.0,12X,"Tmin, deg C: ",F4 0
5060 FORMAT "Tmax, deg C: ",F4.0,12X,"Tmax, deg C: ",F4 0
5070 FORMAT "Transition time, h:",F4.0,6X,"Transition t me, h:",F4.0
5080 FORMAT "Dwell time,      h:",F4.0,6X,"Dwell time,      h:",F4.0
5090 FORMAT "       Programmatic"
5100 FORMAT F4.0,F5.0,"/",F4.0,F5.0,F8.3,F6.1,"/",F3.0,F6.1,F4.0,F8.3,F8.2,F9.3
5110 PRINT "Component Test Program"SPA7"System Test Program"
5120 WRITE (2,5050)T[1,1],T[1,3]
5130 WRITE (2,5060)T[1,2],T[1,4]
5140 WRITE (2,5070)T[1,5],T[1,7]
5150 WRITE (2,5080)T[1,6],T[1,8];
5160 WRITE (2,5090)
5170 PRINT "-------------------------   ---------------------------    --";
5180 PRINT "------------"
5190 PRINT
5200 PRINT "Test   Nr of     Nr"SPA10"Planned  Actual  Nr"SPA19"Lost"
5210 PRINT "Dur.   tests     of    Cost  Dur/Cyc   Dur.   of    Cost     Avg";
5220 PRINT "     Value"
5230 PRINT " h    plan/act  Fail    M$   days      days  Fail   M$     Avail.  ";
5240 PRINT "  M$"
5250 PRINT
5260 FOR I=2 TO 12
5265 IF T[I,13]=0 THEN 5566
5270 IF X7>T[I,2] THEN 5290
5280 X7=T[I,2]
5282 IF T[I,2]#0 THEN 5290
5284 Z=Z1=0
5286 GOTO 5310
5290 Z=N9/1.78
5300 Z1=(N9+T[I,3])/1.78
5310 Z2=T[I,6]/1.34
5320 Z3=1-T[I,13]
5330 Z4=T[I,13]*T[I,14]+T[I,4]+T[I,9]
5370 IF Z9<Z4 THEN 5470
5373 A5=T[I,11]
5376 A6=T[I,13]
5380 Z9=Z4
5390 M3=Z2
5400 M4=T[I,4]
5410 M6=(Q3*N9*T[I,6]*0.34/1.34)/10↑6
5420 M7=T[I,12]*1.833
5430 M5=T[I,9]-M6
5440 F5=F9
5450 M2=T[I,2]
5460 R6=I
```

```
5470 IF M1>Z2 THEN 5490
5480 M1=Z2
5490 IF X9>Z4 THEN 5510
5500 X9=Z4
5510 IF X8<Z4 THEN 5530
5520 X8=Z4
5530 Z5=T[I,9]
5540 IF FLAG2 THEN 5560
5550 WRITE (2,5100)T[I,2],Z,Z1,T[I,3],T[I,4],Z2,T[I,5], [I,6],T[I,7],Z5,Z3,Z4
5560 NEXT I
5563 GOTO 5570
5566 PRINT LIN1,"ROW";I;", COL 13 =0"LIN1
5570 IF FLAG2 THEN 5590
5580 PRINT LIN1
5590 RETURN
5600 END
```

XREF

A2	50	4510	4530	4540						
A5	50	5373								
A6	50	5376								
F5	50	5440								
M1	50	5470	5480							
M2	50	5450								
M3	50	5390								
M4	50	5400								
M5	50	5430								
M6	50	5410	5430							
R6	50	5460								
D4	60	350	360	2240	2270					
X7	90	5270	5280							
X8	100	5510	5520							
Z9	100	5370	5380							
X9	110	5490	5500							
A$	140	160								
T5	200	910	910							
F9	220	230	1470	1910	1970	1970	2120	5030	5440	
F8	230									
A1	240	1480	1590	1620						
A9	240	570	1110	1114	1115	1120	2000	2170	2475	2480
	2500	2530	2540	2560	2570					

Z	260	270	310	320	2180	2190	2310	2470	2575	5284	5290
	5550										
Y2	290	410	410	410							
D7	290	290	410	540	1034	1180	2350	2370			
T7	290	410	530	1034	1180	2350	2370				
T[ ]	340	490	500	510	520	530	540	550	560	570	[illegible]
	590	595	660	1500	1506	1510	1520	1530	1540	1550	1560
	1570	1580	1590	1600	1620	1910	1940	4090	4100	[illegible]	4120
	4120	4120	4140	4140	4160	4170	4240	4240	4240	4250	4250
	4250	4280	4280	4280	4290	4290	4290	4300	4300	4300	4310
	4310	4310	4310	4340	4340	4340	4350	4350	4350	4380	4380
	4380	4390	4390	4390	4420	4420	4420	4430	4430	4430	4440
	4440	4440	4440	4450	4450	4450	4480	4480	4480	4490	4490
	4490	4540	4540	5120	5120	5130	5130	5140	5140	5150	5150
	5265	5270	5280	5282	5300	5310	5320	5330	5330	5330	5330
	5373	5376	5400	5410	5420	5430	5450	5530	5550	5550	5550
	5550	5550	5550								
C2	350	370	370	410	500						
T4	350	520	610	610	650	2200	2220				
C1	360	380	380	410	490						
T3	360	510	620	620	650	2200	2220				
E2	370	390	390	410	410	430	590	743	915	1032	1170
	1200	2015									
E1	380	390	630	650	650	660	743	1126	1280	1350	1390
	1720	1790	1820	1840	2015						
B2	400	410	410	430	915	915	915	915	1032	1090	1160
	1160	1160	1170	1200							
K2	420	430	915	1032	1160	1200					
H2	430	580									
T8	550	600	650	820	1310	1320	1690	2390	2410		
D8	560	600	600	650	820	1310	1320	1690	2390	2410	
B7	590	2560									
Y1	600	650	650	650							
E4	610	630									
E3	620	630									
B1	640	650	650	915	1122	1126	1126	1126	1270	1270	1280
	[illegible]	1390	1720	1720	1720	1790	1790	1790	1820	1820	1820
	[illegible]	1840									
E	670	680	743	915	1112	1126	1170	1280	1400	1410	1420
	[illegible]	1720	1790	1820	1850	2015					
K	680	1112	1114	1120	1120	1122	1160	1270	1400	1410	1420
	[illegible]	1720	1790	1820	1830	1830	1850				
B	690	1112	1122	1126	1160	1270	1400	1410	1420	1480	1720
	[illegible]	1820	1850								

C8	700	1112	1114	1480	1850						
N9	700	950	1000	1032	1112	1114	1157	1200	1200	1220	1350
	14[illegible]0	1480	1840	1850	4120	4240	4240	4240	4250	4280	4280
	42[illegible]0	4290	4300	4300	4310	4310	4340	4340	4350	4380	4380
	43[illegible]0	4390	4420	4420	4420	4430	4440	4440	4440	4450	4480
	44[illegible]0	4490	5290	5300	5410						
N1	790	870	1630	1630	1640	1660					
Y	800	1124	1490	1490	1500	1506	1510	1520	1530	1540	1550
	15[illegible]0	1570	1580	1590	1600	1620	1880				
P9	800	830	850								
J	850	1470	1690	1700	1710	2070					
A	910	920	990	1152	1510	1870	2290	2300	2310		
K4	91[illegible]	960	1070	1090	1090	1095					
T2	930	990	1030	1032	1034	1040	1090	1100	1100	1154	1156
	11[illegible]0	1170	1170	1180	1190	1190	1195	1200	1506		
I	930	1034	1060	1156	1180	1470	1500	1620	1920	1940	1960
	40[illegible]0	4090	4100	4120	4120	4120	4120	4140	4140	4160	4170
	42[illegible]0	4240	4240	4250	4250	4250	4280	4280	4280	4290	4290
	42[illegible]0	4300	4300	4300	4310	4310	4310	4310	4340	4340	4340
	43[illegible]0	4350	4350	4380	4380	4380	4390	4390	4390	4420	4420
	44[illegible]0	4430	4430	4430	4440	4440	4440	4440	4450	4450	4450
	44[illegible]0	4480	4480	4490	4490	4490	4540	4540	4550	5260	5265
	52[illegible]0	5280	5282	5300	5310	5320	5330	5330	5330	5330	5373
	53[illegible]6	5400	5410	5420	5430	5450	5460	5530	5550	5550	5550
	55[illegible]0	5550	5550	5560	5566						
F2	930	1000	1032	1032	1157	1200	1520	1620			
F3	950	1010	1134	1350	1740	1770	1840				
K1	960	1070	1095	1122	1126	1270	1350	1390	1720	1790	1820
	18[illegible]0										
O9	11[illegible]2	1410	1420	1480	1850						
K5	11[illegible]4	1126									
A7	11[illegible]5	1430	1440	1440	1850						
T1	11[illegible]8	1150	1270	1280	1280	1290	1290	1300	1300	1310	1320
	13[illegible]0	1340	1350	1550	1620	1690	1760	1830	1840		
P5	11[illegible]0	1150	1310	1320	1330	1330	1540	1620	1700		
F4	11[illegible]0	1153	1220	1360	1410	1480	1740	1780	1810	1850	
F1	11[illegible]4	1150	1350	1560	1620	1730	1770	1840			
H1	13[illegible]0	1570									
H	14[illegible]0	1580									
F	14[illegible]0	1600									
R3	14[illegible]0										
E6	14[illegible]0	1440	1440	1440							

D	14[illegible]0	1450	1450	1470	1530	1620					
I1	1[illegible]0	1940	1950								
A3	21[illegible]4	2166	2310	2470	2510	2520	2520	2520	2570		
A4	24[illegible]0	2500	2510	2520	2520	2540	2540	2570			
D3	25[illegible]0	2530	2540								
O1	40[illegible]0	4120	4240	4280	4310	4340	4380	4420	4460	4480	4540
O2	40[illegible]0	4240	4280	4310	4340	4380	4420	4440	4480		
O3	40[illegible]0	4250	4290	4310	4350	4390	4430	4450	4490	5410	
B9	41[illegible]0	4200	4220								
C5	41[illegible]0										
R5	45[illegible]0	4540									
T	45[illegible]0										
U9	45[illegible]0										
Z1	52[illegible]4	5300	5550								
Z2	53[illegible]0	5390	5470	5480	5550						
Z3	53[illegible]0	5550									
Z4	53[illegible]0	5370	5380	5490	5500	5510	5520	5550			
M7	54[illegible]0										
Z5	55[illegible]0	5550									

ADDENDUM J-D

PROGRAM LISTING, FILE #4

```
LOAD4
LIST

10 REM: #4 FILE FOR TVTO PROGRAM, PHASE-I VERSION (1979)
12 REM: LISTING OF PROGRAM PARAMETERS AND PLOT ROUTINE
15 CFLAG 7
20 PRINT A$,LIN1
30 PRINT "PROGRAM PARAMETERS:",LIN2
40 FIXED 0
50 PRINT "PAYLOAD:",LIN1
60 GOSUB B9 OF 780,800,820
70 PRINT "Number of components:";N9
80 PRINT "Payload weight, lbs:";W9
90 FIXED 3
100 PRINT "Payload cost, M$:";U9
102 FIXED 0
104 IF R5=1 THEN 108
106 PRINT (R5-1);"reflights are planned in addition to this flight."
108 PRINT
110 PRINT "MISSION PARAMETERS:",LIN1
130 PRINT "Mission length, days:";O9
140 FIXED 2
150 IF T[1,13]=0 THEN 180
160 PRINT "Desired average availability:";T[1,13]
170 GOTO 190
180 PRINT "Average availability not specified."
190 PRINT "Expected number of malfunctions over the mission duration:";M2,LIN1
200 PRINT "LAUNCH VEHICLE INFORMATION:",LIN1
210 GOSUB V9 OF 850,890
220 PRINT
230 PRINT "TEST PARAMETERS:",LIN1
240 FIXED 0
250 PRINT "Component test transition time , dwell time, hours:";T7;",";D7
260 PRINT "System test transition , dwell time, hours:";T8;",";D8
262 PRINT "Component test min, max temperatures, deg C:";C1;",";C2
264 PRINT "System test min, max temperatures; deg C:";T3;",";T4,LIN1
268 GOSUB C5 OF 1300,1320
270 PRINT "Maximum component test length investigated, hours:";T5
280 FIXED 1
290 PRINT "Maximum planned system test length investigated, days:";M1,LIN1
293 PRINT "OPTIMIZED PARAMETERS:"LIN1
296 FIXED 0
300 PRINT "Minimum cost program, other than zero test, on file";F5
302 FIXED 1
305 PRINT "Component test length, hours:";M2
310 FIXED 1
315 PRINT "Planned system test length, days:"M3
320 FIXED 3
325 PRINT "Component test program cost, M$:";M4
330 PRINT "System test program cost, M$:";M5
335 PRINT "Marching army cost, M$:";M6
340 PRINT "Mission average availabiliy:";(1-A6)
345 PRINT "Mission end instantaneous availabilbiy:";A5
350 PRINT "Minimum lost value, M$:";Z9,LIN2
380 GOTO 5000
390 FIXED 3
400 PRINT "This is an attached (non-Spacelab) payload."
410 IF D1=2 THEN 450
420 PRINT "This is a dedicated mission; cost, M$:";T
430 GOSUB 1070
440 GOTO 470
450 PRINT "This is a shared mission; cost, M$:";T
460 GOSUB 1070
470 RETURN
480 PRINT "This is a Spacelab mission."
490 GOSUB D1 OF 520,570
```

```
500 RETURN
510 END
520 FIXED 3
530 PRINT "This is a dedicated payload mission; STS cost, M$:";T
540 FIXED 0
550 GOSUB 620
560 GOTO 600
570 FIXED 3
580 PRINT "This is a shared mission; STS cost, M$:";T
590 GOSUB 620
600 RETURN
610 END
620 IF P=0 AND N=0 THEN 670
630 FIXED 0
640 IF E9=1 THEN 660
650 N=1
660 PRINT N;"pallet(s) are used with";P*100;"% of the payload weight on them."
670 IF P=1 THEN 690
680 PRINT (1-P)*100;"% of the payload weight is in the pressurized module."
690 RETURN
700 END
710 PRINT "The payload uses a dedicated element.
720 GOSUB 620
730 GOTO 760
740 PRINT "The payload shares an element."
750 GOSUB 620
760 RETURN
770 END
780 PRINT "Protoflight Unit"
790 RETURN
800 PRINT "First flight unit"
810 RETURN
820 PRINT "Follow-on unit"
830 RETURN
840 END
850 PRINT "Shuttle launch"
860 GOSUB C9 OF 990,390,480
870 RETURN
880 END
890 GOSUB D5 OF 920,940,960
900 GOTO 220
910 END
920 PRINT "Mission uses a Scout launch vehicle, cost, M$:";T
930 RETURN
940 PRINT "Mission uses a 2900 series Delta, cost, M$:";T
950 RETURN
960 PRINT "Mission uses a 3900 series Delta, cost, M$:";T
970 RETURN
980 END
990 PRINT "This is a Free-flier payload."
1000 GOSUB D1 OF 1030,1240
1010 RETURN
1020 END
1030 FIXED 3
1040 PRINT "This mission is dedicated to this payload; STS cost, M$:";T
1050 GOSUB 1070
1060 GOTO 1120
1070 IF D6=0 THEN 1080
1075 GOSUB D6 OF 1130,1150,1170,1190,1210
1080 IF K9=0 THEN 1100
1090 PRINT K9;"OMS kits are used; cost, M$:";K8
1100 IF R=0 THEN 1120
1110 PRINT "A revisit cost is included; cost, M$:";R
1115 RETURN
1120 RETURN
1125 END
```

```
1130 PRINT "Mission uses a SSUS-D upper stage; cost, M$:";S
1140 RETURN
1150 PRINT "Mission uses a SSUS-A upper stage; cost, M$:";S
1160 RETURN
1170 PRINT "Mission uses an IUS two stage; cost, M$:";S
1180 RETURN
1190 PRINT "Mission uses an IUS twin stage; cost, M$:";S
1200 RETURN
1210 PRINT "Mission uses an IUS twin stage + spinner; cost, M$:";S
1220 RETURN
1230 END
1240 FIXED 3
1250 PRINT "This mission is shared with other payloads; STS cost, M$:";T
1260 GOSUB 1070
1270 RETURN
1280 END
1300 PRINT "System test is conducted in a large (e.g. 30ft 60ft) facility."
1310 RETURN
1320 PRINT "System test is conducted in a medium (e.g. 12ft 15ft) facility."
1330 RETURN
1340 END
5000 REM: PLOT ROUTINE
5010 FIXED 0
5020 FORMAT 13X,"       ",F4.0,F7.0,F10.0,F11.0
5030 FORMAT 13X,"       ",F4.0,F7.0,F10.0,F11.0
5040 FORMAT F6.1
5045 IF FLAG8 THEN 5370
5050 X4=X7
5060 Y3=INTX8-1
5070 Y4=INTX9+2
5080 X1=-0.2*X4
5090 X2=1.3*X4
5100 X3=0
5110 X5=0
5120 Y6=Y3-0.2*(Y4-Y3)
5130 Y7=Y4+0.3*(Y4-Y3)
5140 Y5=Y3
5150 IF X4>240 THEN 5180
5160 S4=24
5170 GOTO 5190
5180 S4=48
5190 A=Y4-Y3
5200 IF A<1 THEN 5260
5210 IF A<2 THEN 5280
5220 IF A<5 THEN 5300
5230 IF A<10 THEN 5320
5240 IF A<20 THEN 5340
5250 GOTO 5360
5260 S5=0.1
5270 GOTO 5370
5280 S5=0.2
5290 GOTO 5370
5300 S5=0.5
5310 GOTO 5370
5320 S5=1
5330 GOTO 5370
5340 S5=2
5350 GOTO 5370
5360 S5=5
5370 SCALE X1,X2,Y6,Y7
5375 IF FLAG8 THEN 5750
5380 XAXIS Y5,S4,X3,X4
5390 YAXIS X5,S5,Y3,Y4
5400 LABEL (*,1.5,1.7,0,0.7)
5530 FOR X6=(X3+S4) TO (X4-S4) STEP S4
5540 PLOT X6,Y5,1
```

```
5550 CPLOT -2.5,-1.5
5560 LABEL (*)X6
5570 NEXT X6
5580 PLOT X5,Y5,1
5590 CPLOT 20,-3.5
5600 LABEL (*)"COMPONENT TEST DURATION, H"
5601 IF A9#0 THEN 5610
5602 PLOT X4,Y4,1
5604 CPLOT 3,3
5606 LABEL (*)"PLANNED"
5607 LABEL (*)"SYS TEST"
5608 LABEL (*)"  DAYS"
5610 PLOT X2,Y6,1
5620 CPLOT -20,1
5630 LABEL (*)A$
5640 FOR Y8=Y3+S5 TO Y4-S5 STEP S5
5650 PLOT X5,Y8,1
5660 CPLOT -5.5,-0.3
5670 IF S5>1 THEN 5690
5680 FIXED 1
5690 LABEL (*)Y8
5700 NEXT Y8
5710 PLOT X5,Y5,1
5720 CPLOT -7,8
5730 LABEL (*,1.5,1.7,PI/2,0.7)
5740 LABEL (*)"LOST VALUE,  M$"
5750 LABEL (*,1.5,1.7,0,0.7)
5752 CFLAG 5
5753 SFLAG 8
5755 REM: Plot only zero test file and min test file
5760 FOR B6=F8 TO F5 STEP (F5-F8)
5780 GOTO 5820
5790 REM: Plot any file
5800 DISP "Starting, ending file numbers";
5810 INPUT B6,E6
5815 IF B6=0 THEN 6210
5820 LOAD  DATA #1,B6,T
5830 Z1=10↑9
5840 FOR I=2 TO 12
5850 A=T[I,13]+T[I,14]+T[I,4]+T[I,9]
5860 IF T[I,2]>X4 OR A>Y4 THEN 6000
5870 IF A9=0 THEN 5960
5872 IF T[I-1,2]=T[I,2] THEN 6000
5880 PLOT T[I,2],A,1
5885 CPLOT -0.3,-0.3
5890 LABEL (*)"+"
5900 IF I#2 THEN 5930
5910 CPLOT 0,2
5920 GOTO 5940
5930 CPLOT -4,2
5940 LABEL (5040)T[I,6]/1.34
5950 GOTO 5965
5960 PLOT T[I,2],A
5965 REM: Find coordinates of min point
5970 IF Z1<A THEN 6000
5980 Z1=A
5990 Z2=T[I,2]
6000 NEXT I
6010 PEN
6020 PLOT X4,A,1
6030 CPLOT 2,-0.3
6040 IF A>Y4 THEN 6130
6050 IF A9#0 THEN 6070
6060 LABEL (5040)(T[I-1,6]/1.34)
6070 PLOT Z2,Z1,1
6080 CPLOT -0.3,-0.3
```

```
6090 LABEL (*)"X"
6100 IF FLAG5 THEN 6130
6105 IF A9#0 THEN 6210
6110 NEXT B6
6115 SFLAG 5
6120 GOTO 6170
6130 B6=B6+1
6140 IF B6=E6+1 THEN 6160
6150 GOTO 5820
6160 PLOT X2,Y3,1
6170 DISP "Further plots";
6180 INPUT A
6190 IF A=0 THEN 6210
6200 GOTO 5800
6210 SFLAG 7
6220 LINK 3
6230 END
```

XREF

```
A$     20     5630

B9     60

N9     70

W9     80

U9     100

R5     104    106

O9     130

T[ ]   150    160    5820   5850   5850   5850   5850   5860   5872   5872   5880
       5940   5960   5990   6060

M7     190

V9     210

T7     250

D7     250

T8     260

D8     260

C1     262

C2     262

T3     264

T4     264

C5     268

T5     270

M1     290

F5     300    5760   5760
```

M2	305									
M3	315									
M4	325									
M5	330									
M6	335									
A6	340									
A5	345									
Z9	350									
D1	410	490	1000							
T	420	450	530	580	920	940	960	1040	1250	
P	620	660	670	680						
N	620	650	660							
E9	640									
C9	860									
D5	890									
D6	1070	1075								
F9	1080	1090								
F8	1090									
F	1100	1110								
S	1130	1150	1170	1190	1210					
X4	5050	5080	5090	5150	5380	5530	5602	5860	6020	
X7	5050									
Y3	5060	5120	5120	5130	5140	5190	5390	5640	6100	
X8	5060									
Y4	5070	5120	5130	5130	5190	5390	5602	5640	5860	6040
X9	5070									
X1	5080	5370								
X2	5090	5370	5610	6160						
X3	5100	5380	5530							
X5	5110	5390	5580	5650	5710					
Y6	5120	5370	5610							
Y7	5130	5370								
Y5	5140	5380	5540	5580	5710					

S4	5160	5180	5380	5530	5530	5530					
A.	5190	5200	5210	5220	5230	5240	5850	5860	5880	5960	5970
	5980	6020	6040	6180	6190						
S5	5260	5280	5300	5320	[illegible]	[illegible]	5390	5640	[illegible]	5640	[illegible]
X6	5530	5540	5560	5570							
A9	5601	5870	6050	6105							
Y8	5640	5650	5690	5700							
B6	5760	5810	5815	5820	6110	[illegible]	6130	6140			
F8	5760	5760									
E6	5810	6140									
Z1	5830	5970	5980	6070							
I	5840	5850	5850	5850	5850	5860	5872	5872	[illegible]	5900	5940
	5960	5990	6000	6060							
Z2	5990	6070									

ADDENDUM J-E

MATRIX TS [12, 14]

Matrix TS [12, 14]

Row \ Col.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	C1 Comp. Test Tmin	C2 Comp. Test Tmax	T3 System Test Tmin	T4 System Test Tmax	T7 Comp. Test Transition (h)	D7 Comp. Test Dwell (h)	T8 System Test Transition (h)	D8 System Test Dwell (h)	A9 Input End Inst. Availability	H2 Initial Comp. Test Hazard Rate	E2 Comp. Test Intens. Factor	E1 System Test Intens. Factor	B7 User Defined Average Availability	0
2 → 12	1/2 Full Comp. Test Cycles	T2 Comp. Test Duration (h)	F2 Comp. Test Failures	Comp. Test Cost	P5/2 System Test Planned Full Cycles	T1 System Test Actual Test Length Days	F1 System Test Failures	H1 Initial System Test Hazard Rate	System Test Cost	H Initial Space Hazard Rate	A1 Computed End Avail.	F Space Failures	D Average Non-Avail.	Launch & Payload Cost

ADDENDUM J-F

EXAMPLE OF PROGRAM RUN

```
LOAD1
RUN
If you need gen'l info, enter 1 ?1
```

In order to use this program, the user must know or estimate a number of items to be used as program inputs.

As a minimum, the user must know:
a) the number of components in the payload (P/L)
b) the mission time in orbit
c) the type of item: protoflight, first flight item, or follow-on
d) whether an expendable launch vehicle (ELV) or Shuttle (STS) is involved; if the latter, whether its a Free-Flier or a Spacelab mission.
e) the minimum and maximum test temperatures.

The user will also be asked to input various other data. If the answers are unknown, the user should input 0; in this case the program will provide average value estimates or will skip over that item.

Questions should be answered with 1 for yes and 0 for no.

For questions that are not applicable, enter 0.

When two values are requested, enter them with a comma inbetween

* * * * * * * * * * * *

```
Nr. of components in the P/L?30
The P/L has 30   components.

Input minimum acceptable P/L average availability as a decimal;
input 0 if unknown or full optimization run desired.

Minimum acceptable avg. avail.?0
The minimum acceptable availability input as 0    %

Input mission time in orbit.

Mission time in orbit (days)?365
 365  days required in orbit.

Input the estimated minimum time an average component will take to
get from one temperature extreme to the other during test and the
minimum dwell time at temperature. Enter 0's where unknown.

Comp:Trans time, Dwell time (h)?0,0
Component test profile contains 3     hour transition times
and 6    hour long dwell times.

Input the estimated minimum time it will take the P/L system to
get from one temperature extreme to the other during test and the
minimum dwell time at temperature. Enter 0's where unknown.

Sys: Trans time, Dwell time (h)?8,48
System level test profile contains 8    hour transition
times and 48   hour long dwell times.

Input the general minimum and maximum system level test
temperatures in deg C.
```

```
Sys lvl test Tmin,Tmax (deg C)?0,40
System test temp. levels: Tmin= 0    , Tmax= 40   deg C

System level tests can be conducted in a large chamber
(in the order of 30 ft in diameter and 60 ft high), enter a 1,
or in a medium sized chamber
(in the order of 12 ft in diameter and 15 ft high), enter a 2.

Large (1) or medium (2) chamber?2
 2    has been entered.

The P/L may be a protoflight (enter 1), a first flight
unit (enter 2), or a follow-on unit (enter3).

Pflt (1), Flt#1 (2), or F-O (3)?1
 1    has been selected.


The following questions pertain to the launch vehicle,
Shuttle (STS) or an expendable launch vehicle (ELV).

STS (enter 1) or ELV (enter 2)?2
This mission uses an expendable launch vehicle.

Only three vehicles are included in this model: enter a
1 for a Scout, a 2 for a 2900 series Delta,
and a 3 for a 3900 series Delta.

Expendable launch vehicle code?1
A Scout launch vehicle has been selected.

P/L dimensions are to be determined.

Enter P/L weight (lbs): enter 0 if unknown.

P/L weight (lbs)?337
P/L weight (lbs) input as 337

Enter P/L cost in millions of 1978 dollars: if the amount is
unknown, enter 0.

P/L cost (1978 M$)?0

Instrument costs may be estimated based on the type
and weight of the instrument.
The following classes apply:
     class 1: Interferometers
     class 2: Telescope, Spectroheliograph, Passive Microwave
              Radiometer, Photometer, Spectrometer, T-V Camera,
              Magnetometer
     class 3: Active Microwave, Mass Measurement, Plasma Probe
              Charge Detector, Film Camera

If type is unknown, use class 2 as an average.

Instrument class, 1, 2, or 3?2
Instrument class 2    is selected.

Estimated instrument cost (1978 M$) : 0.936
Estimated platform cost (1978 M$) : 2.631
Estimated total P/L cost (1978 M$) : 3.567
```

ELV LAUNCH COST IS 2.400   MILLION (1978) DOLLARS

PAYLOAD COST IS 3.567   MILLION (1978) DOLLARS.

DATE?1-1-79

1 1 79

Enter maximum number of component test hours to be investigated.

MAXIMUM NR COMP TEST HOURS?480
FILE NR. FOR 1ST DATA ARRAY?1
WANT RELIABILITY DATA PRINTOUT?0
WANT COST PROJ. DATA PRINTOUT?

**** Calculator taken out of PRINT ALL mode. ****

RUN(S) COMPLETE.

LAST DATA ARRAY IS STORED ON TRACK#1,FILE # 41

1 1 79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 30
Payload weight, lb.: 337
Payload cost, M$: 3.567

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 1.35

LAUNCH VEHICLE INFORMATION:

Mission uses a Scout launch vehicle, cost, M$: 2.40

TEST PARAMETERS:

Component test transition time + dwell time, hours: 3 , 6
System test transition + dwell time, hours: 8 , 48
Component test min. and max. temperatures, deg C: -5 , 45
System test min. and max. temperatures, deg F: 0 , 40

System test is conducted in a medium (e.g. 12ft-15ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 9[illegible].3

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 26
Component test length, hours: 288.0
Planned system test length, days: 58.3
Component test program cost, M$: 0.392
System test program cost, M$: 0.508
Marching army cost, M$: 0.121
Mission average availability: 0.789
Mission end instantaneous availability: 0.721
Minimum lost value, M$: 2.283

E(COMP)= 16.01   E(SYS)= 14.32   E(SPACE)= 14.26

C.TEST NO.OF 1/2 PERIODS	(HRS) COMP. TEST T	PLANNED SYSTEM CYCLES	(DAYS) SYS.T E(T)	COMPONENT TEST FAIL	SYSTEM TEST FAIL	MISSION END AVAIL	FACTOR
0.0	0	27	83.4	0.0	27.0	0.19	0.700
4.2	48	2	6.2	3.2	1.7	0.19	0.700
9.6	96	2	3.7	5.2	0.9	0.19	0.700
14.9	144	1	2.9	6.9	0.7	0.19	0.700
20.2	192	1	2.5	8.4	0.5	0.19	0.700
25.6	240	1	2.2	9.8	0.4	0.19	0.700
30.9	288	1	2.0	11.1	0.4	0.19	0.700
36.2	336	1	1.9	12.3	0.3	0.19	0.700
40.4	374	0	0.0	13.2	0.0	0.19	0.700
40.4	374	0	0.0	13.2	0.0	0.19	0.700
40.4	374	0	0.0	13.2	0.0	0.19	0.700

DATA ON TRACK#1, FILE# 42.00

Component Test Program
Tmin, deg C: -5
Tmax, deg C: 45
Transition time, h: 3
Dwell time, h: 6

System Test Program
Tmin, deg C: 0
Tmax, deg C: 40
Transition time, h: 8
Dwell time, h: 48

Programmatic

Test Dur. h	Nr of tests plan/act	Nr of Fail	Cost M$	Planned Dur/Cyc days	Actual Dur. days	Nr of Fail	Cost M$	Avg Avail.	Lost Value M$
0	0/ 0	0	0.000	62.2/ 14	83.4	27	0.778	0.30	4.953
48	17/ 19	3	0.086	4.7/ 1	6.2	2	0.205	0.30	4.466
96	17/ 20	5	0.143	2.8/ 1	3.7	1	0.187	0.30	4.505
144	17/ 21	7	0.202	2.2/ 1	2.9	1	0.180	0.30	4.558
192	17/ 22	8	0.263	1.8/ 1	2.5	1	0.177	0.30	4.616
240	17/ 22	10	0.327	1.6/ 1	2.2	0	0.175	0.30	4.677
288	17/ 23	11	0.392	1.5/ 1	2.0	0	0.174	0.30	4.741
336	17/ 24	12	0.460	1.4/ 1	1.9	0	0.173	0.30	4.808
374	17/ 24	13	0.515	0.0/ 0	0.0	0	0.000	0.30	4.690
374	17/ 24	13	0.515	0.0/ 0	0.0	0	0.000	0.30	4.690
374	17/ 24	13	0.515	0.0/ 0	0.0	0	0.000	0.30	4.690

. (S) COMPLETE.

LAST DATA ARRAY IS STORED ON TRACK#1,FILE # 42

C-3

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 30
Payload weight, lbs: 337
Payload cost, M$: 3.567

MISSION PARAMETERS:

Mission length, days: 365
Desired average availability: 0.30
Expected number of malfunctions over the mission duration: 7.10

LAUNCH VEHICLE INFORMATION:

Mission uses a Scout launch vehicle, cost, M$: 2.40

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 48
Component test min, max temperatures, deg C:-5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 62.2

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 42
Component test length, hours: 48.0
Planned system test length, days: 4.7
Component test program cost, M$: 0.086
System test program cost, M$: 0.195
Marching army cost, M$: 0.010
Mission average availability: 0.300
Mission end instantaneous availability: 0.186
Minimum lost value, M$: 4.466

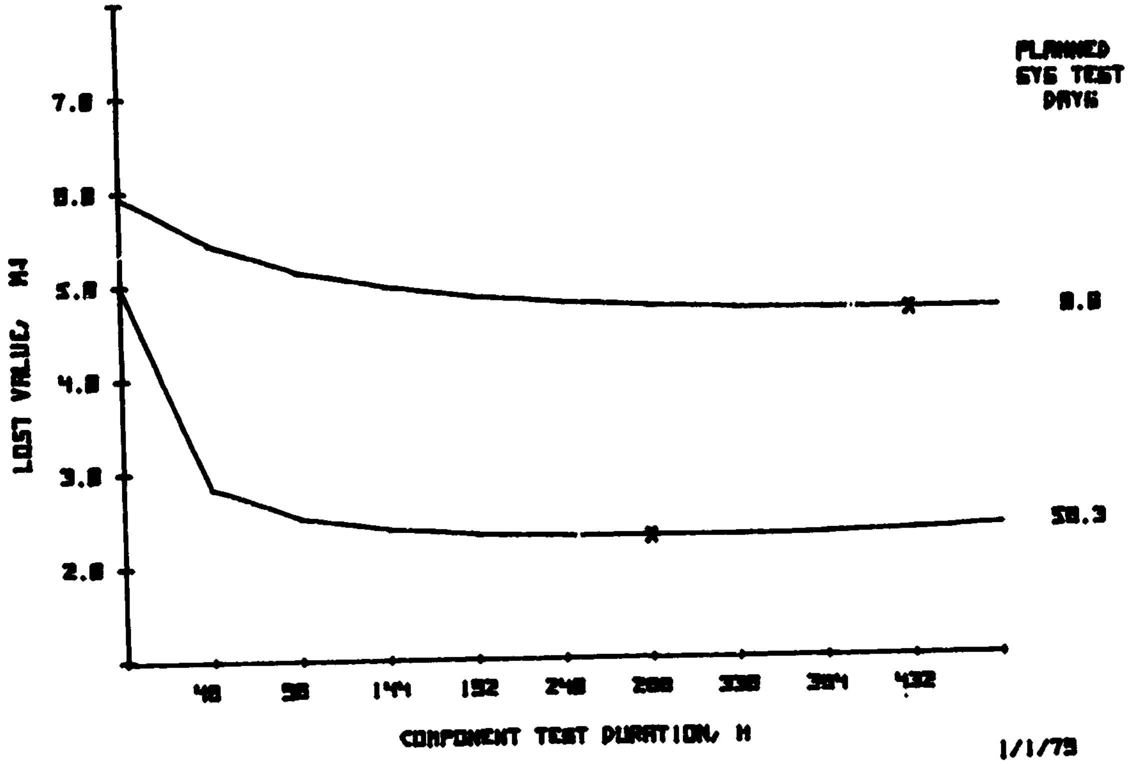


Figure J-F-1. Typical Plot; Desired Average Availability Entered as 0

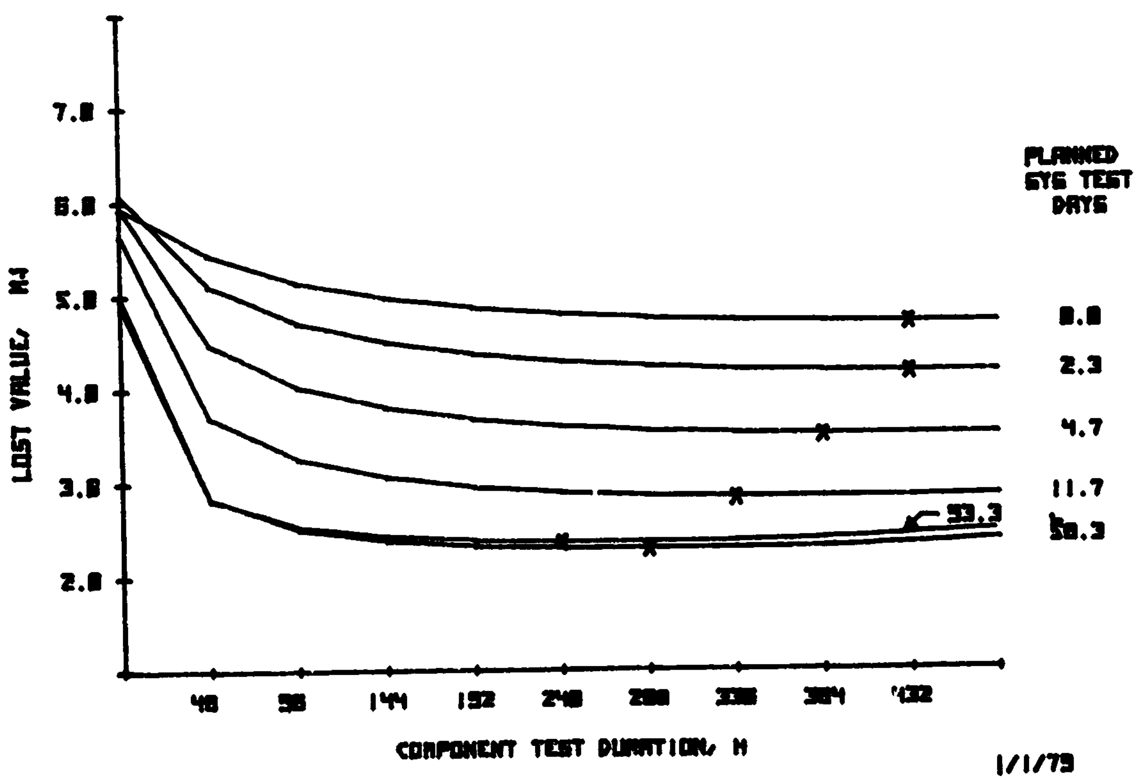


Figure J-F-2. Effect of Change in System Test Duration

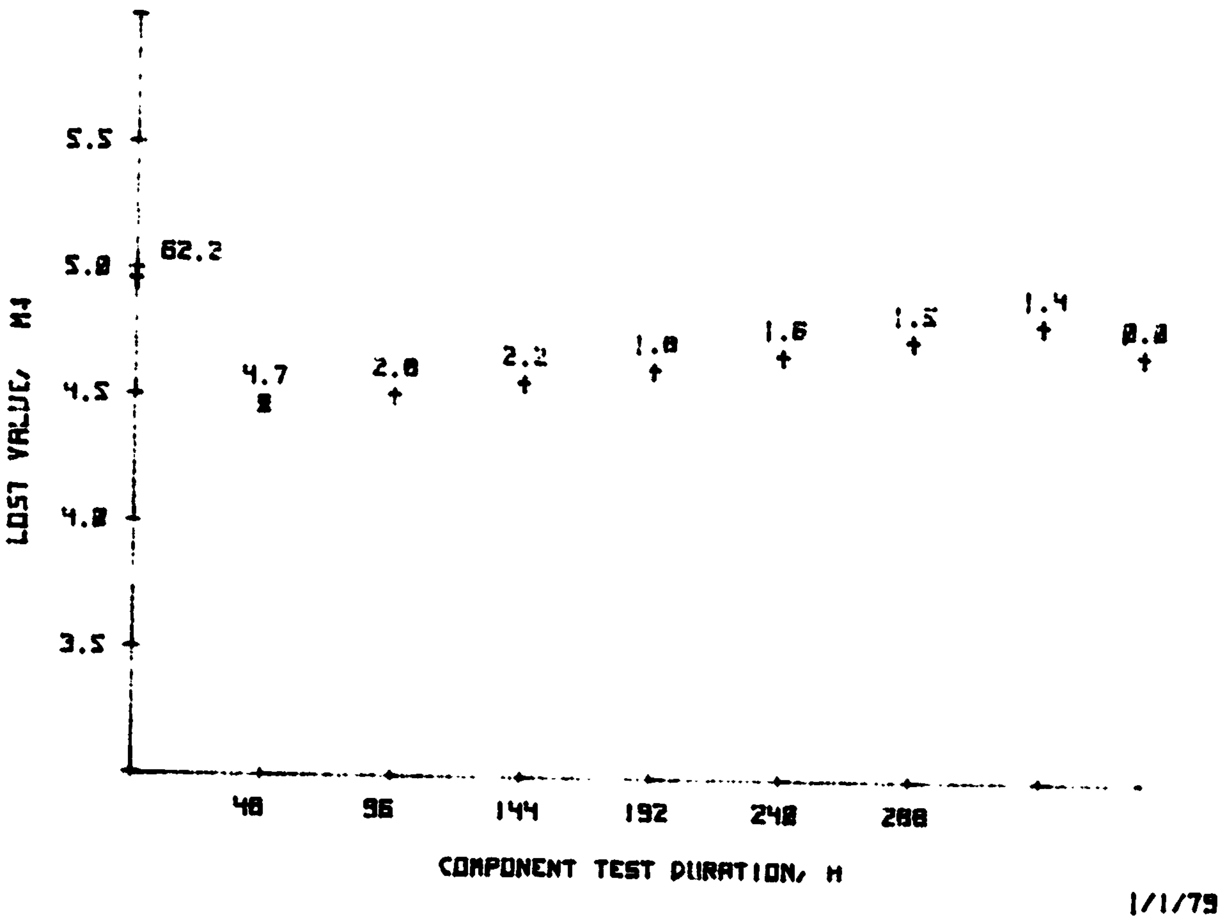


Figure J-F-3. Desired Average Availability Entered as 0.3

ADDENDUM J-G

EFFECT OF LAUNCH COST

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 450
Payload cost, M$: 4.060

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 1.21

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads! STS cost, M$: 5.468

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 48
Component test min, max temperatures, deg C: -5 , 45
System test min, max temperatures! deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 93.3

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 35
Component test length, hours: 336.0
Planned system test length, days: 79.3
Component test program cost, M$: 0.491
System test program cost, M$: 0.657
Marching army cost, M$: 0.176
Mission average availability: 0.811
Mission end instantaneous availability: 0.755
Minimum lost value, M$: 3.112

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PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 450
Payload cost, M$: 4.000

MISSION PARAMETERS:

Mission length, days: 365
Desired average availability: 0.30
Expected number of malfunctions over the mission duration: 7.24

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS cost, M$: 5.468

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 48
Component test min, max temperatures, deg C:-5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 69.6

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 1
Component test length, hours: 48.0
Planned system test length, days: 5.1
Component test program cost, M$: 0.091
System test program cost, M$: 0.207
Marching army cost, M$: 0.011
Mission average availability: 0.300
Mission end instantaneous availability: 0.186
Minimum lost value, M$: 6.935

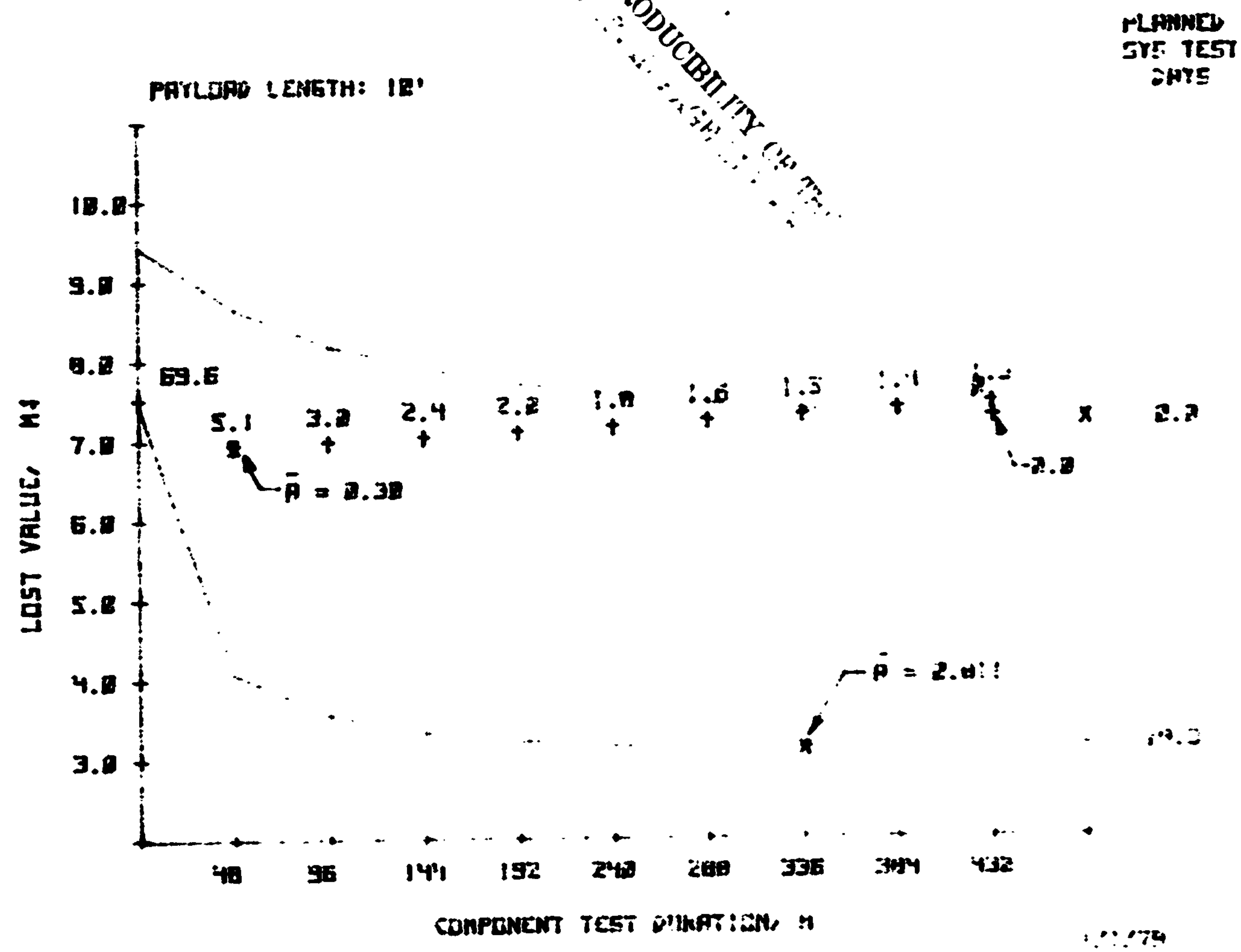

Figure J-G-1. Effect of Launch Cost; Payload Length 10'

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 450
Payload cost, M$: 4.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 1.39

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS cost, M$: 2.864

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 48
Component test min, max temperatures, deg C: -5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 93.3

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 28
Component test length, hours: 288.0
Planned system test length, days: 63.0
Component test program cost, M$: 0.418
System test program cost, M$: 0.559
Marching army cost, M$: 0.140
Mission average availability: 0.786
Mission end instantaneous availability: 0.724
Minimum lost value, M$: 2.586

RUN(S) COMPLETE.

LAST DATA ARRAY IS STORED ON TRACK#1,FILE # 1

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 450
Payload cost, M$: 4.000

MISSION PARAMETERS:

Mission length, days: 365
Desired average availability: 0.30
Expected number of malfunctions over the mission duration: 7.24

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS cost, M$: 2.864

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 48
Component test min, max temperatures, deg C:-5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 69.6

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 1
Component test length, hours: 48.0
Planned system test length, days: 5.1
Component test program cost, M$: 0.091
System test program cost, M$: 0.207
Marching army cost, M$: 0.011
Mission average availability: 0.300
Mission end instantaneous availability: 0.186
Minimum lost value, M$: 5.113

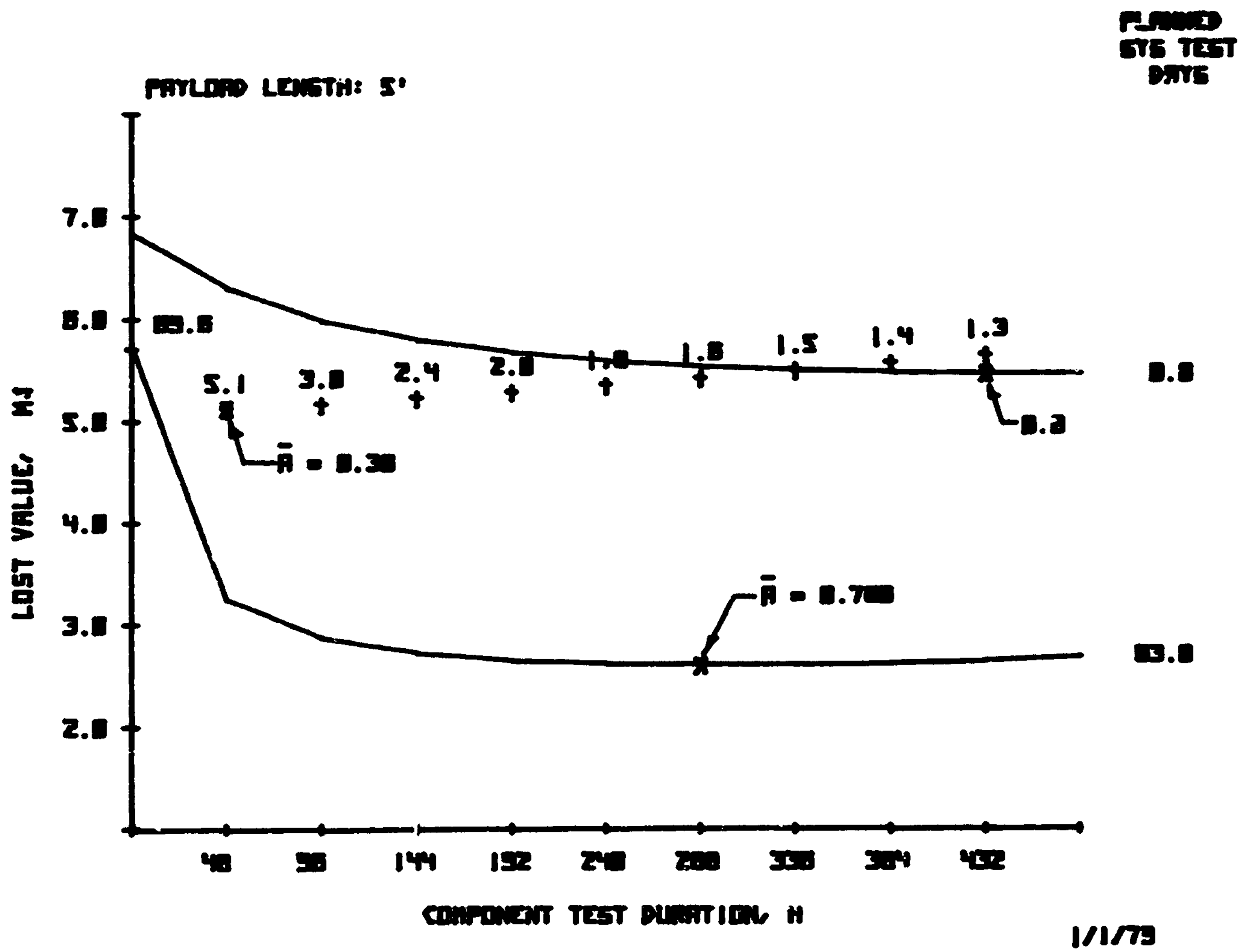

Figure J-G-2. Effect of Launch Cost, Payload Length 5'

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 450
Payload cost, M$: 4.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 1.55

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS cost, M$: 1.570

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 48
Component test min, max temperatures, deg C: -5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 93.3

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 25
Component test length, hours: 240.0
Planned system test length, days: 56.0
Component test program cost, M$: 0.348
System test program cost, M$: 0.518
Marching army cost, M$: 0.124
Mission average availability: 0.766
Mission end instantaneous availability: 0.698
Minimum lost value, M$: 2.296

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 450
Payload cost, M$: 4.000

MISSION PARAMETERS:

Mission length, days: 365
Desired average availability: 0.30
Expected number of malfunctions over the mission duration: 7.24

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS co[illegible] , M$: 1.570

TEST PARAMETERS:

Component test transition time , dwell time, hours: [illegible] , 6
System test transition , dwell time, hou[illegible] , 4[illegible]
Component test min, max temperatures [illegible] , 45
System test min, max temperatures; [illegible] C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 69.6

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 1
Component test length, hours: 48.0
Planned system test length, days: 5.1
Component test program cost, M$: 0.091
System test program cost, M$: 0.207
Marching army cost, M$: 0.011
Mission average availability: 0.300
Mission end instantaneous availability: 0.186
Minimum lost value, M$: 4.207

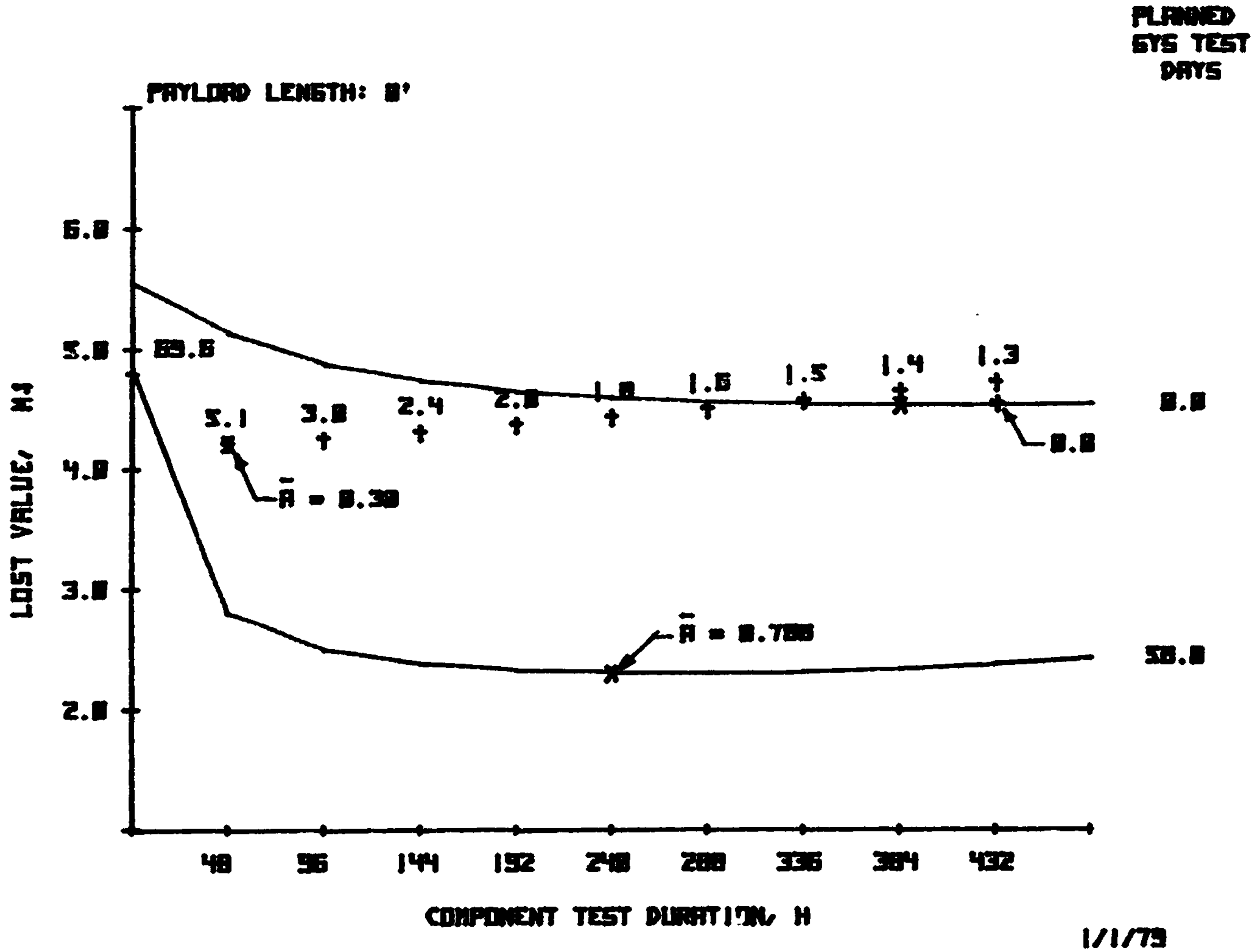

Figure J-G-3. Effect of Launch Cost, Payload Length 0′

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 450
Payload cost, M$: 4.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 1.77

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS cost, M$: 5.468

TEST PARAMETERS:

Component test transition time ; dwell time, hours: 3 ; 6
System test transition ; dwell time, hours: 8 ; 48
Component test min, max temperatures, deg C:-5 ; 45
System test min, max temperatures; deg C: 0 ; 40

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 93.3

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 12
Component test length, hours: 432.0
Planned system test length, days: 25.7
Component test program cost, M$: 0.642
System test program cost, M$: 1.057
Marching army cost, M$: 0.057
Mission average availability: 0.737
Mission end instantaneous availability: 0.663
Minimum lost value, M$: 4.246

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PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 450
Payload cost, M$: 4.000

MISSION PARAMETERS:

Mission length, days: 365
Desired average availability: 0.30
Expected number of malfunctions over the mission duration: 7.24

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS cost, M$: 5.468

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 48
Component test min, max temperatures, deg C:-5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 69.6

OPTIMIZED PARAMETERS:

Minimum-cost program,-other than zero test, on file 1
Component test length, hours: 96.0
Planned system test length, days: 3.0
Component test program cost, M$: 0.153
System test program cost, M$: 0.362
Marching army cost, M$: 0.007
Mission average availability: 0.300
Mission end instantaneous availability: 0.186
Minimum lost value, M$: 7.146

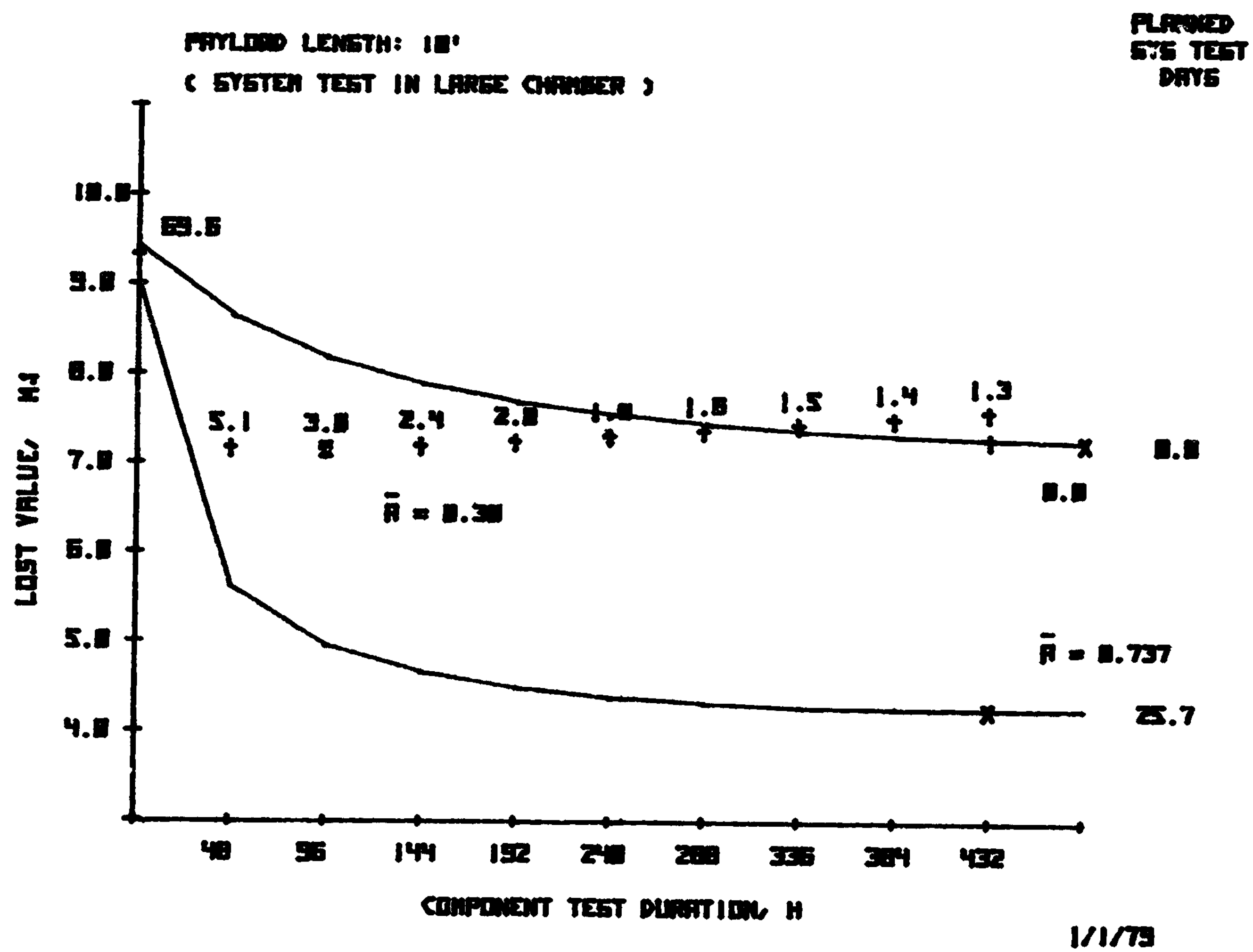

Figure J-G-4. Effect of Launch Cost (Large Chamber), Payload Length 10′

ADDENDUM J-H

EFFECT OF AVAILABILITY

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 15
Payload weight, lbs: 200
Payload cost, M$: 1.831
9 reflights are planned in addition to this flight.

MISSION PARAMETERS:

Mission length, days: 7
Average availability not specified.
Expected number of malfunctions over the mission duration: 0.52

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is an attached (non-Spacelab) payload.
This is a shared mission; cost, M$: 1.570

TEST PARAMETERS:.

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 12
Component test min, max temperatures, deg C:-5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 240
Maximum planned system test length investigated, days: 33.3

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 9
Component test length, hours: 96.0
Planned system test length, days: 13.3
Component test program cost, M$: 0.072
System test program cost, M$: 0.171
Marching army cost, M$: 0.014
Mission average availability: 0.899
Mission end instantaneous availability: 0.867
Minimum lost value, M$: 0.434

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 15
Payload weight, lbs: 200
Payload cost, M$: 1.831
9 reflights are planned in addition to this flight.

MISSION PARAMETERS:

Mission length, days: 7
Desired average availability: 0.75
Expected number of malfunctions over the mission duration: 1.41

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is an attached (non-Spacelab) payload.
This is a shared mission; cost, M$: 1.570

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 12
Component test min, max temperatures, deg C:-5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 240
Maximum planned system test length investigated, days: 30.3

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 1
Component test length, hours: 136.0
Planned system test length, days: 0.0
Component test program cost, M$: 0.096
System test program cost, M$: 0.000
Marching army cost, M$: 0.000
Mission average availability: 0.750
Mission end instantaneous availability: 0.679
Minimum lost value, M$: 0.535

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 15
Payload weight, lbs: 200
Payload cost, M$: 1.831
9   reflights are planned in addition to this flight.

MISSION PARAMETERS:

Mission length, days: 7
Desired average availability: 0.85
Expected number of malfunctions over the mission duration: 0.80

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is an attached (non-Spacelab) payload.
This is a shared mission; cost, M$: 1.570

TEST PARAMETERS:

Component test transition time , dwell time, hours: 3 , 6
System test transition , dwell time, hours: 8 , 12
Component test min, max temperatures, deg C:-5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a medium (e.g. 12ftx15ft) facility.
Maximum component test length investigated, hours: 240
Maximum planned system test length investigated, days: 125.0

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 2
Component test length, hours: 48.0
Planned system test length, days: 8.8
Component test program cost, M$: 0.043
System test program cost, M$: 0.154
Marching army cost, M$: 0.009
Mission average availability: 0.850
Mission end instantaneous availability: 0.804
Minimum lost value, M$: 0.470

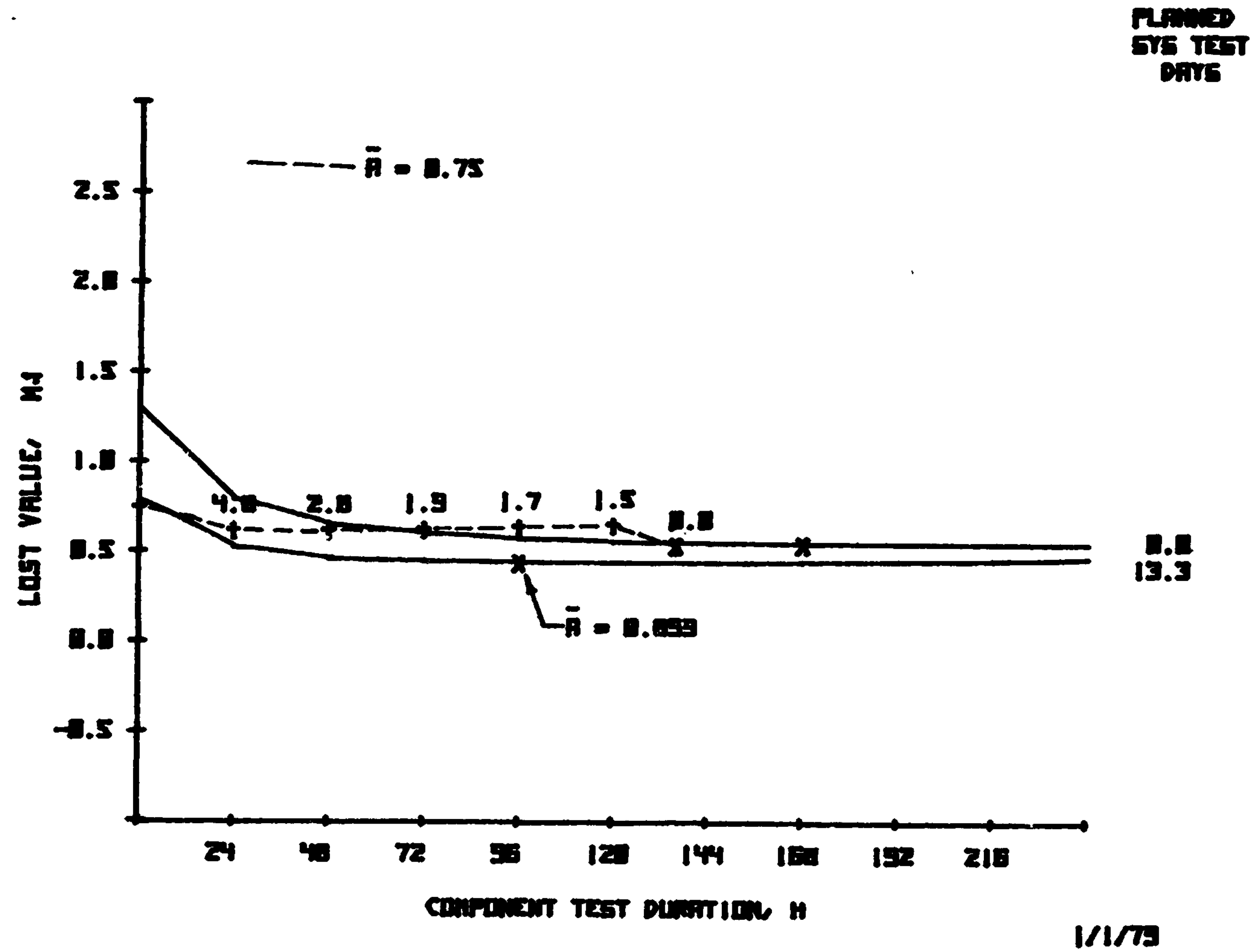

Figure J-H-1. Effect of Average Availability of 0.75 Compared to Entering 0.0

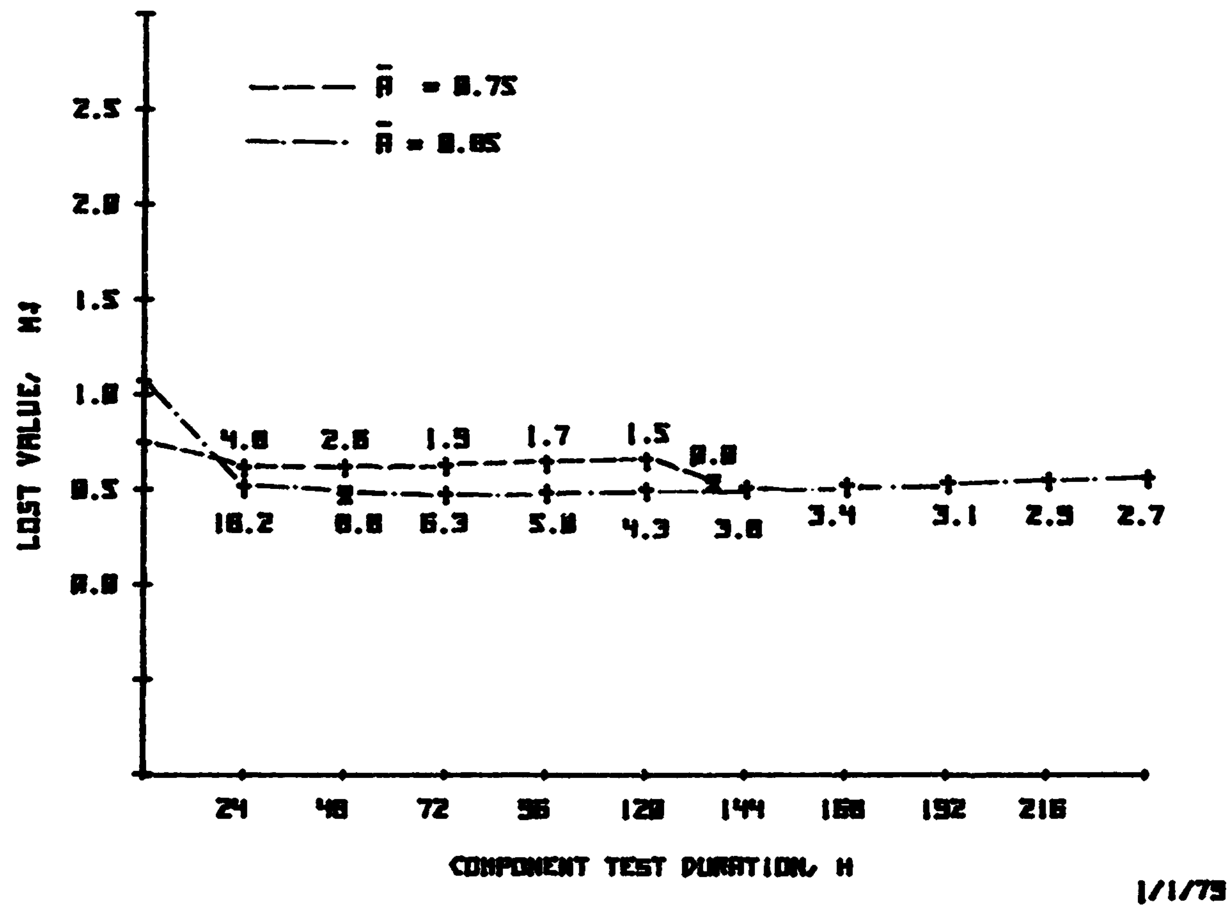

Figure J-H-2. Solutions for Average Availabilities of 0.75 and 0.85

ADDENDUM J-I

EFFECT OF TRANSITION/DWELL RATIO

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 750
Payload cost, M$: 5.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 2.20

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads: STS cost, M$: 1.570

TEST PARAMETERS:

Component test transition time , dwell time, hours: 8 , 16
System test transition , dwell time, hours: 8 , 16
Component test min, max temperatures, deg C: -5 , 45
System test min, max temperatures: deg C: 0 , 40

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 40.0

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 11
Component test length, hours: 384.0
Planned system test length, days: 20.0
Component test program cost, M$: 0.535
System test program cost, M$: 0.884
Marching army cost, M$: 0.044
Mission average availability: 0.685
Mission end instantaneous availability: 0.600
Minimum lost value, M$: 3.533

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PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 750
Payload cost, M$: 5.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 2.60

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS cost, M$: 1.570

TEST PARAMETERS:

Component test transition time , dwell time, hours: 22 , 2
System test transition , dwell time, hours: 8 , 16
Component test min, max temperatures, deg C: -5 , 45
System test min, max temperatures; deg C: 0 , 40

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 40.0

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 13
Component test length, hours: 480.0
Planned system test length, days: 24.0
Component test program cost, M$: 0.549
System test program cost, M$: 1.011
Marching army cost, M$: 0.053
Mission average availability: 0.640
Mission end instantaneous availability: 0.546
Minimum loss value, M$: 3.980

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 750
Payload cost, M$: 5.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 2.18

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads! STS cost, M$: 1.570

TEST PARAMETERS:

Component test transition time , dwell time, hours: 2 , 22
System test transition , dwell time, hours: 8 , 16
Component test min, max temperatures, deg C:-5 , 45
System test min, max temperatures! deg C: 0 , 40

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 430
Maximum planned system test length investigated, days: 40.0

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 11
Component test length, hours: 336.0
Planned system test length, days: 20.0
Component test program cost, M$: 0.485
System test program cost, M$: 0.884
Marching army cost, M$: 0.044
Mission average availability: 0.687
Mission end instantaneous availability: 0.603
Minimum lost value, M$: 3.467

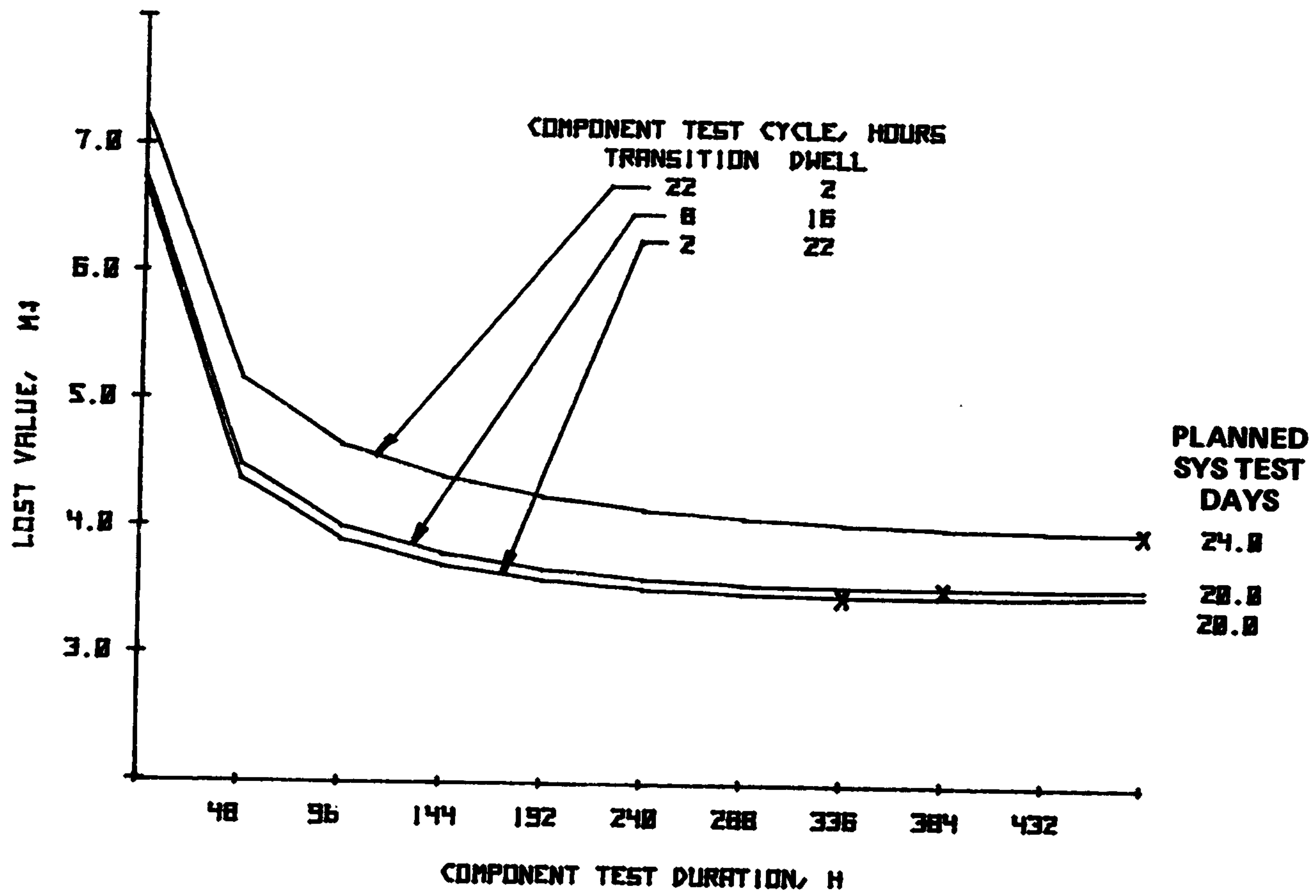

Figure J-I-1. Effect of Transition to Dwell Ratio

ADDENDUM J-J

EFFECT OF CYCLING

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 750
Payload cost, M$: 5.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 2.04

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads! STS cost, M$: 1.570

TEST PARAMETERS:

Component test transition time , dwell time, hours: 1 , 2
System test transition , dwell time, hours: 8 , 16
Component test min, max temperatures, deg C: -5 , 45
System test min, max temperatures! deg C: 0 , 40

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 40.0

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 32
Component test length, hours: 288.0
Planned system test length, days: 20.0
Component test program cost, M$: 0.457
System test program cost, M$: 0.883
Marching army cost, M$: 0.044
Mission average availability: 0.703
Mission end instantaneous availability: 0.622
Minimum lost value, M$: 3.334

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 750
Payload cost, M$: 5.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 2.20

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads; STS cost, M$: 1.570

TEST PARAMETERS:

Component test transition time ; dwell time, hours: 8 ; 16
System test transition ; dwell time, hours: 8 ; 16
Component test min, max temperatures, deg C: -5 ; 45
System test min, max temperatures; deg C: 0 ; 40

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 40.0

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 11
Component test length, hours: 384.0
Planned system test length, days: 20.0
Component test program cost, M$: 0.535
System test program cost, M$: 0.884
Marching army cost, M$: 0.044
Mission average availability: 0.685
Mission end instantaneous availability: 0.600
Minimum lost value, M$: 3.533

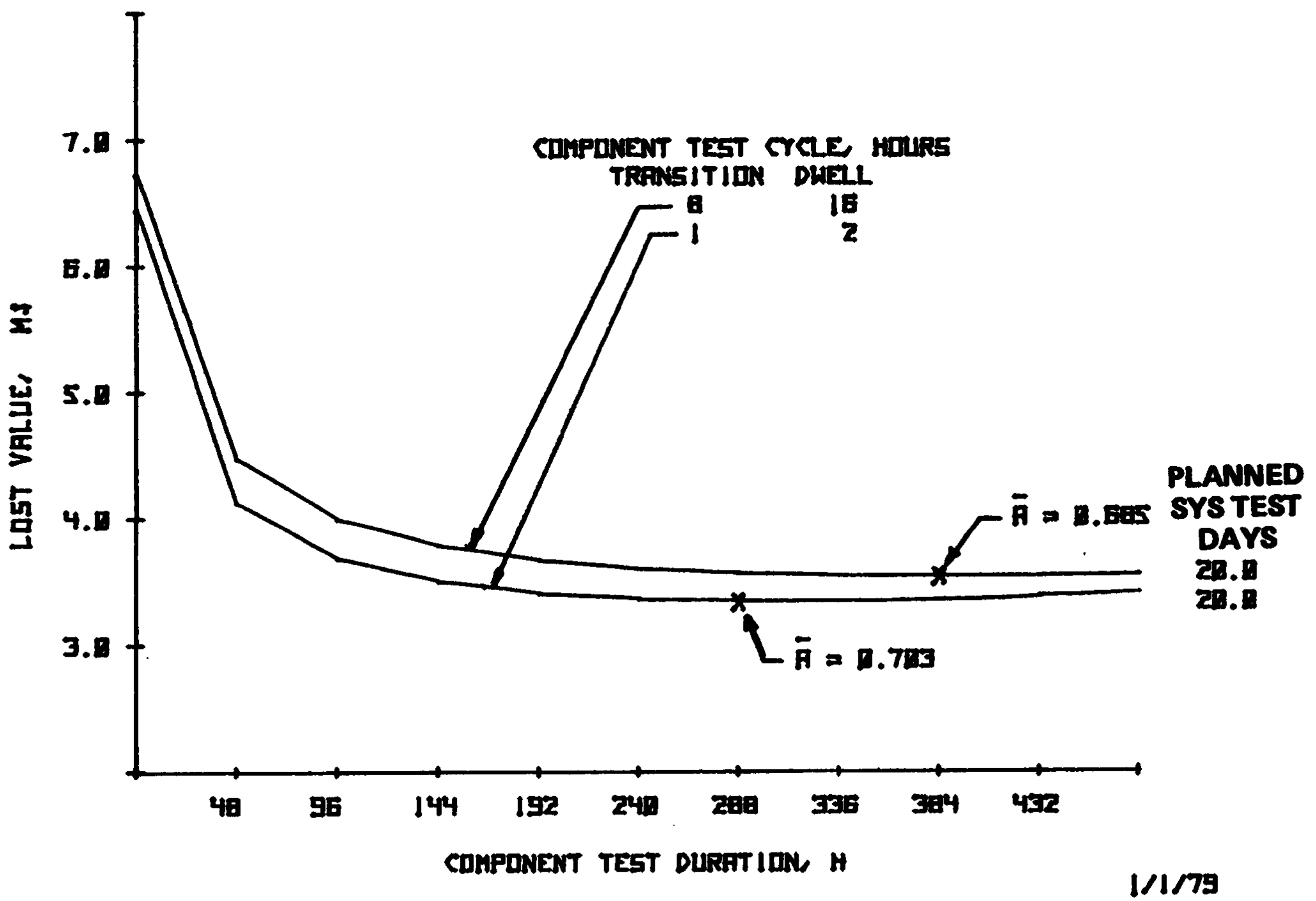

Figure J-J-1. Effect of Cycling

ADDENDUM J-K

EFFECT OF TEMPERATURE

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 750
Payload cost, M$: 5.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 2.28

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads! STS cost, M$: 1.570

TEST PARAMETERS:

Component test transition time ; dwell time, hours: 8 ; 16
System test transition ; dwell time, hours: 8 ; 16
Component test min, max temperatures, deg C: 5 , 45
System test min, max temperatures! deg C: 10 , 40

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 40.0

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 33
Component test length, hours: 384.0
Planned system test length, days: 22.0
Component test program cost, M$: 0.522
System test program cost, M$: 0.945
Marching army cost, M$: 0.049
Mission average availability: 0.676
Mission end instantaneous availability: 0.589
Minimum lost value, M$: 3.644

1/1/79

PROGRAM PARAMETERS:

PAYLOAD:

Protoflight Unit
Number of components: 32
Payload weight, lbs: 750
Payload cost, M$: 5.000

MISSION PARAMETERS:

Mission length, days: 365
Average availability not specified.
Expected number of malfunctions over the mission duration: 2.49

LAUNCH VEHICLE INFORMATION:

Shuttle launch
This is a Free-flier payload.
This mission is shared with other payloads! STS cost, M$: 1.570

TEST PARAMETERS:

Component test transition time ; dwell time, hours: 8 ; 16
System test transition ; dwell time, hours: 8 ; 16
Component test min, max temperatures, deg C: 5 ; 35
System test min, max temperatures! deg C: 10 ; 30

System test is conducted in a large (e.g. 30ftx60ft) facility.
Maximum component test length investigated, hours: 480
Maximum planned system test length investigated, days: 40.0

OPTIMIZED PARAMETERS:

Minimum cost program, other than zero test, on file 12
Component test length, hours: 432.0
Planned system test length, days: 22.0
Component test program cost, M$: 0.569
System test program cost, M$: 0.944
Marching army cost, M$: 0.049
Mission average availability: 0.652
Mission end instantaneous availability: 0.560
Minimum lost value, M$: 3.849

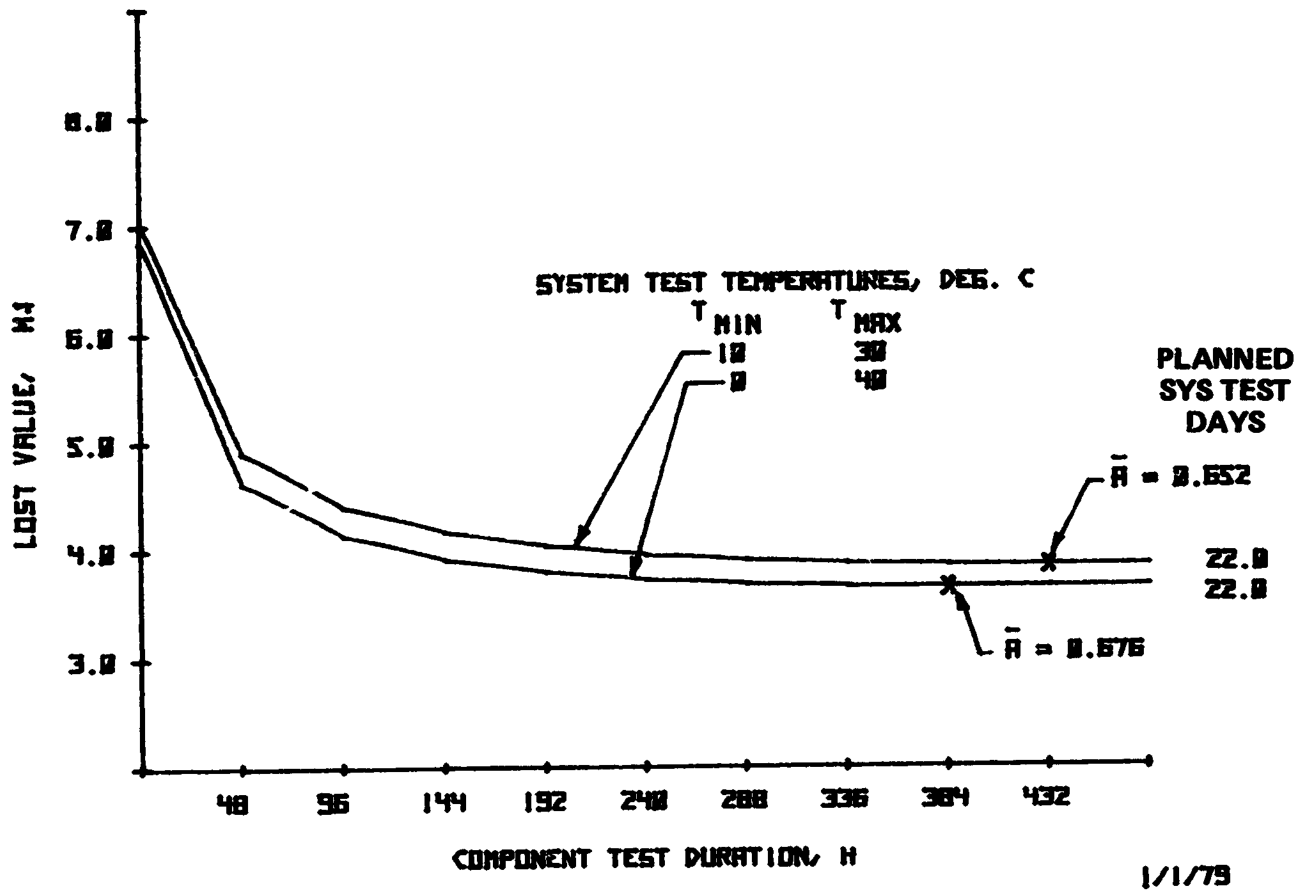

Figure J-K-1. Effect of Test Temperature