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TESTING OF SPACECRAFT IN LONG-TERM STORAGE

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SUMMARY

This paper addresses the problem of developing a storage and test policy which may be applied to equipment placed in long-term storage prior to utilization. A closed-form analytic solution is developed to aid in evaluating the characteristics of a given policy in terms of test efficiency, on time delivery, and subsequent reliable operation of the equipment in its intended application. The analysis model is, to the authors knowledge, new and hence is described in detail; a computer program based on the model is outlined and a flow diagram of its logic included. Problems associated with estimating valid input data are treated. An example of the application of the analysis to spacecraft is presented to fully illustrate the approach. Finally, the paper closes with a discussion of some of the many situations in which such a tool could be employed in a variety of industrial, research, and sports contexts.

1. INTRODUCTION

The advent of replenishable multi-satellite systems in recent years (TIROS is a good example) has created a requirement for the long-term storage of spacecraft. Such a requirement led to the development of the analysis tool described in this paper. The problems will vary from case to case depending largely on two types of factors: (i) the engineering characteristics of the hardware involved (e.g., susceptibility to corrosion, sensitivity to a 1.0g field, potential temperature effects, etc.); and (ii) the characteristics of the mission which the hardware is called upon to perform (e.g., is the system repairable or not after it is placed in operation?, is the demand for the equipment random or based upon a predetermined schedule?, how soon after usage demand must the hardware be put into service?, etc.). This paper deals largely with the second class of decisions which must be approached in many cases on a statistical basis. The first class of problems is more deterministic in nature, and generally fairly well understood in the industry: storage in dry nitrogen with periodic rotation of 1.0g sensitive components are among widely followed policies.

While the illustrations included in the paper are written largely in the context of a stored spacecraft subject to an unscheduled launch call, the same problem occurs for other classes of equipment; notably weapon systems held in readiness for use only in the event of an emergency, electronic parts stored prior to assembly, TV sets stored in a warehouse or showroom, and used cars on the corner lot. The primary concern with stored equipment is that it works properly when it is called upon to be used. This motivation usually results in some testing being performed on the equipment after it is taken out of storage prior to its actual use. Problems uncovered during the post call-up tests are repaired prior to use to provide maximum confidence that a successful mission will result. Another factor important in many operational contexts is a requirement to respond very rapidly to the activation call-up; to compensate for reduced testing after call-up, periodic testing during the storage period is often considered. This paper describes a dynamic model of this situation which may be exercised to define a storage and test policy consistent with the dual objectives of (i) responding on time to the call-up, and (ii) having adequate assurance that the equipment is failure free at the time its utilization begins.

2. ANALYSIS MODEL

The Storage Sequence of Events

The general sequence of events occurring in a typical storage situation is illustrated in Figure 1. The equipment is placed into storage; at that time there may be undetected failures present. These failures could result from inadequate testing or the inability of the test equipment to detect the failure. Some storage time occurs and depending upon the individual storage policy being evaluated, testing may be done on a periodic basis. Failures may occur during storage, during test or may be induced by the testing itself. The test will detect some percentage (typically not all) of whatever defects are present (including previously undetected defects) before the equipment is returned to storage. Finally, the call to use the stored item occurs, a final test may or may not be done and the equipment is then applied to its end use, hopefully free of failures (no undetected failures).

The model described herein is a probabilistic analysis of the various events which take place in the storage sequence. It uses an analytic of closed-form approach as contrasted with a Monte Carlo simulation approach; consequently, the computer run time required to evaluate an individual case is very nominal. The direct thrust of the model output focuses on (i) the number of failures which may be detected after the call-up decision has been made and (ii) the consequent delay induced by these detected failures assuming that usage will not begin until all anomalies are repaired and retest completed. As was indicated in the summary, however, almost any type of information describing the effectiveness of a storage policy may be determined. Through a suitable structuring of multiple cases, one may estimate (i) the efficiency of a test (how many failures it detects versus how many it introduces); (ii) the number of defects present when storage begins; and (iii) the number of defects likely to remain when the equipment is put into service. These points are further illustrated in the examples discussed in Section 3 of this paper. The computer program which implements this analysis thus represents a tool which may be used in a variety of ways to evaluate many aspects of the storage problem. As with any tool, the way in which it will be applied depends upon the job to be done.

Computer Program Inputs and Outputs

The computer program requires inputs which describe the pertinent characteristics of the hardware and of the storage policy being contemplated for that hardware. In addition, certain input variables are defined solely in the interests of computer processing efficiency and output format standardization. The direct outputs of the program describe the number of failures detected after the use decision, and the days of delay induced by these failures before the equipment is available for actual service. As discussed

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earlier, many other conclusions may be drawn based upon the joint evaluation of several structured cases.

The basic inputs and outputs are listed in Table 1. The launch call time is treated as an input variable; by varying launch call time, a given test schedule can be evaluated against a range of contingencies. Many of the inputs are accumulated into a data file made up of data which remains largely invariant for a large number of cases. These include the characteristics of the hardware itself for each item: its likelihood of failure in various tests; its storage failure rate; the likelihood failures will be detected for each item in various tests; the probability each item will have undetected failures when entering storage; and the repair time in days should an item fail. Other inputs which vary from case to case are input directly for each case.

Table 1. Analysis Model Inputs and Outputs

INPUTS

- Call-up time and call-up test type.
- Number and types of tests scheduled prior to call-up.
- Interval between tests.
- Storage failure rates for each item (or subcategory of equipment).
- Probability of no defects present when put into storage for each item.
- Restoration times should failure occur during testing for each item.
- For each type of test:
  - Probability of no additional failures during test for each item,
  - Probability failure present before test will be detected during test for each item,
  - Probability new failure occurring during test will be detected during test for each item.
- Complexity factor (a measure of number of failures anticipated, used only to size matrices in computer program).
- Units factor (delay measured in days of some multiple thereof).
- Efficiency factor (measure of non-additivity of actual delays, amount of multiple repairs being simultaneously performed).

OUTPUTS

- Probability distribution of number of detected failures for each item during call-up test sequence.
- Probability distribution of days of delay due to failures detected during call-up test sequence.
- Average days of delay due to failures detected during launch call-up test sequence.

Steps in Analysis

The analysis of the storage process shown in Figure 1 is implemented through the steps described in Figure 2. These steps also correlate with sections of the computer program. The method of analysis operates upon probability distributions which govern the various events. Some overall assumptions about the form of these distributions built into the analysis include:

- Storage failure rates are constant with time; hence, the number of failures, F, occurring in storage follows a Poisson distribution,

$$P(F=x) = \frac{(\lambda t)^x e^{-\lambda t}}{x!}, \; x = 0, 1, 2, \ldots$$

where,

λ = in-storage failure rate
t = time in storage
F = number of failures

- Number of failures occurring during test also is treated with Poisson distribution; also number of defects present prior to storage.
- An item is spared or unspared; for items which are spared it is assumed that a spare is available in the event of test failure.

Figure 2 is a simplified flow diagram of these steps. A careful review of Table 2 and Figure 2 should result in the development of an adequate understanding of the analysis so that the reader could apply the methology with his own computer program. The method is further illustrated by the examples contained in Section 3. Another approach to modeling a similar situation using Markov chains may be found in Reference 1.

Table 2. Steps in Analysis and Computer Program

1. Input complexity factor, units factor, efficiency factor, E'.
2. Input time to call-up in days, type of call-up test.
3. Input number of scheduled tests prior to call-up.
4. Dimension matrices.
5. Input test type for each scheduled test.
6. Input storage time between each scheduled test.
7. Read data file.
8. N = Number of subsystems or items, N1 = Number of tests prior to use.
9. Start with first item.
10. W = Probability of at least one defect entering storage.
11. Determine distribution of number of defects present upon entering storage:

    $W(0) = 1 - W$

    Thus, letting $v = -\log(1-W)$, the Poisson parameter consistent with $W(0) = 1 - W$, one obtains

    $$W(y) = \frac{e^{-v} v^y}{y!}, \; y = 0, 1, 2, \ldots$$

12. Determine distribution of number of defects occurring in storage prior to first test.

    $$R(x) = \frac{e^{-\lambda t} (\lambda t)^x}{x!}, \; x = 0, 1, 2, \ldots$$

    where λ = in-storage failure rate
    t = time to start of first test

13. Convolute R and W to obtain distribution of total defects present upon entering first test.

    $$B(x) = \sum_{k=0}^{x} R(k)\, W(x-k), \; x = 0, 1, 2, \ldots$$

    B is the distribution of R+W.

14. D = Probability defect entering test will be detected.

15. Determine matrix D(M1, M2) the probability that M2 of M1 defects will be detected.

$$D(M1, M2) = \binom{M1}{M2} D^{M2}(1-D)^{M1-M2}, \; M1=0, 1, 2, \ldots, \; M2=0, 1, 2, \ldots, M1$$

using the standard binomial distribution for M2 successes out of M1 trials.

16. X = Probability of at least one defect occurring during test.

17. Determine distribution of number of defects occurring during test:

$X(0) = 1-X$

Letting $a = -\log(1-X)$, one obtains

$$X(x) = \frac{e^{-a} a^{x}}{x!}, \; x = 0, 1, 2, \ldots$$

18. E = Probability of detecting failure occurring during test.

19. Determine matrix E(M1, M2):

$$E(M1M2) = \binom{M1}{M2} E^{M2} (1-E)^{M1-M2}, \; M1=1,2,\ldots; \; M2=0,1,2,\ldots,M1$$ similar to D.

20. Determine distribution of number of failures present prior to test which go undetected:

$$N(x) = \sum_{k=x}^{\infty} B(k)\, D(k,k-x), \; x = 0, 1, 2, \ldots$$

21. Determine distribution of number of failures occurring during test which go undetected:

$$N\$(x) = \sum_{k=x}^{\infty} X(k)\, E(k,k-x), \; x = 0,1,2,\ldots$$

22. Convolute N and N$ to obtain distribution of total defects which are present but undetected at end of test:

$$W(x) = \sum_{k=0}^{x} N(k)\, N\$(x-k), \; x = 0, 1, 2, \ldots$$

23. Proceed to next test using W from 22 as the distribution of defects present prior to next test. Repeat steps 12 through 22 for next test.

24. Repeat 23 until last test prior to call-up is completed, test Number N1-1.

25. Repeat steps 12 through 19 for call-up test.

26. Determine distribution of number of failures present prior to call-up test which are detected:

$$N(x) = \sum_{k=x}^{\infty} B(k)\, D(k,x), \; x = 0, 1, 2, \ldots$$

27. Determine distribution of number of failures occurring during call-up test which are detected:

$$N\$(x) = \sum_{k=x}^{\infty} X(k)\, E(k,x), \; x = 0, 1, 2, \ldots$$

28. Convolute N and N$ to obtain distribution of total defects which are detected during call-up test:

$$W(x) = \sum_{k=0}^{w} N(k)\, N\$(x-k), \; x = 0, 1, 2, \ldots$$

29. Print out distribution of number of detected failures for item number one. Also determine and print out average number of detected failures.

30. Determine Z(y), the probability of y days delay due to i em number one:

$$Z(y) = \sum_{k\epsilon M} W(k), \; y = 0, 1, 2, \ldots \text{ in days}$$

where $M = (k: y < k \cdot T' \cdot E' \leq y+1)$
T' = repair time for item for one detected defect.

Probability associated with repair times greater than y days but less than y+1 days are grouped as the probability of a y day delay due to item number one.

31. Repeat steps 10 through 29 for item number two.

32. Determine Z$(y), the probability of y days delay due to item two:

$$Z\$(y) = \sum_{k\epsilon M} w(k), \; y = 0, 1, 2, \ldots \text{ in days}$$

where $M = (K: y < k \cdot T' \cdot E' \leq y+1)$

33. Convolute Z and Z$ to obtain distribution of the probability of y days delay due to items one and two:

$$Y(y) = \sum_{k=0}^{y} Z(k) \cdot Z\$(y-k), \; y = 0, 1, 2, \ldots$$

34. Let Z(y) = Y(y) for y = 0, 1, 2, . . .

35. Repeat steps 10 through 29 and steps 32 through 34 for items three, four, ..., N.

36. Print out average days delay for each item and percent of total each contributes.

37. Print out final Z(y), y = 0, 1, 2, ..., the distribution of days delay due to items one through N.

3. EXAMPLE OF SPACECRAFT APPLICATION

This section illustrates the application of the analysis to the storage of a spacecraft while awaiting an unscheduled launch call. The manner in which input data were estimated, the way cases were structured, and the types of conclusions which were drawn are all described.

Data Requirements

The inputs to the model can be determined from a variety of sources. If the equipment under consideration is mature (e.g., a TV set), then the probability of failure could be determined using the failure rate and the operating time of the test. Another method would be the failure history of the equipment during tests similar to those to be conducted during storage and reactivation. If the equipment is stored in the unpowered state, References 2, 3, and 4 provide data for determining the probability of failure during storage.

The probability of detecting falures (test efficiency) is a function of the parameters tested, the environment of the test (ambient, hot, cold) and the failure rates of the test equipment (probability of not detecting a failure when it occurs). A method of determining test eeficiency is to compare, for each test considered, those parameters tested versus those not tested. This results in a percentage of the total parameters tested and allows for a comparison of the efficiencies of the various tests; however, the environments and test equipment must still be accounted for. It is also possible to determine the test efficiency from the failure data.

For the example shown herein, it was decided to use the failure data collected during spacecraft testing. It was felt that this single data source accounted for all aspects of determining the probability of detecting failures. The two inputs that differed from this were the storage failure rate and the repair time. The storage failure rate used was taken to be 10% of the predicted operating failure rate. The repair time was estimated based on experience from troubleshooting, removing, replacing, and retest for the spacecraft under consideration.

Each failure report was reviewed and classified as to type of failure, type of test, subsystem and environment where the failure could be detected. The types of failures were as follows:

- Spacecraft Hardware Failure - This category was further subdivided to identify latent failures. These were workmanship failures attributed to manufacturing or a vendor that should (or could) have been detected during earlier testing.
- Test Failure - This category included all test equipment failures, procedure problems, operator error, etc.
- Non-Failure - These were usually minor out-of-tolerance conditions which did not result in replacement of hardware and were dispositioned "use-as-is." These were deleted from the sample since they did not require repair.

The types of testing were identified because the same types of testing as accomplished during integration and test were proposed for storage and reactivation. This allowed for the determination of failure probability and detection for the tests involved. Three general areas of testing were identified: subsystem integration, ambient test, and thermal vacuum. The ambient testing was further subdivided into integration system testing (IST), pre-thermal vacuum, and post-thermal vacuum.

The subsystems were those normally identified with a spacecraft; however, in some instances it was necessary to regroup some of the hardware into different categories because of differences in repair time since the program will only accept one repair time per subsystem. All the test failures were grouped into a subsystem identified as Test Equipment. This category also accounted for the possibility that test equipment could erroneously indicate the presence of a failure when none was present. The "subsystems" correspond to the "items" described earlier.

The identification of the various environments where the failure could be detected was necessary because some failures could only be detected at thermal vacuum conditions while others could only be detected at ambient conditions (visual inspection, etc.). For the most part, the failures could be detected at either environment.

Upon completion of the data review it was decided to eliminate those faillures occurring during subsystem integration since the objective was to determine the failures expected of a completely assembled spacecraft. This left a total of 12 ambient/thermal vacuum cycles upon which to base the probabilities required by the analysis model.

The task of determining failure probabilities from number of failures was accomplished by using the average number of failures detected and the Poisson distribution. The method is illustrated for a typical subsystem using the 12 ambient/thermal vacuum tests noted above.

a. Total number of failures detected - 28

b. Average failures per test $(\frac{28}{12})$ - 2.33

c. Probability of failure occurring:

$$P = 1-e^{-x} = 1-e^{-2.33} = 1-0.097$$

$$P = 0.903$$

Each subsystem was handled in the same manner. If no failure occurred in the subsystem, one failure was conservatively assumed. The probability of a defect existing when entering storage was determined in the same manner as above except the latent failures identified earlier were used.

The probability of detecting failures was determined from the latent failures and the environment where detected. As an example, one subsystem showed 10 latent failures which could be detected at either ambient or thermal vacuum. Of these, eight were detected at ambient and two at thermal vacuum; therefore, the probability of detecting latent failures at ambient was 80% and the probability for thermal vacuum was 20% better or 96%. The probability of detecting a failure occurring during test was assumed to be the same.

All subsystems did not display the above trend since latent failures were not prevalent and/or total failures were small and detected at both environments. It was assumed the detection capabilities would be the same regardless of the type of testing and would be at least as efficient as the most effective test (.96).

Results

A study was initiated with the purpose of evaluating an existing test plan for the long-term storage of a spacecraft which must be launched within 75 to 140 days after an unscheduled call-up. The difference in launch schedule resulted from the type of reactivation testing conducted prior to shipment (ambient versus ambient plus environmental testing). The original purpose of the study was to determine whether or not the recommended shipment dates could be met (30 days prior to launch). The analysis model developed for this study was directed at the number of days delay due to failures (and their repair times) in the system and had to be compared to the contingency allowed for these failures.

The test plan consisted of three different types of reactivation testing based on the time since the last thermal vacuum test (T/V). The least of the tests was an integrated system test (IST), the second was a very detailed ambient test and the final test was the ambient test plus a very difficult thermal vacuum (T/V) test. In addition the test plan called for the spacecraft to be stored without power applied, with the Propulsion Subsystem pressurized, a controlled humidity and a nitrogen environment.

In-storage testing was to consist of a quarterly electrical test which was basically an "aliveness test." Additionally a detailed ambient test, a T/V test and a post T/V ambient test were to be conducted at nine month intervals.

The analysis model was exercised for a variety of conditions to arrive at conclusions and recommendations for the test program under consideration. Table 3 is a sample of the cases conducted upon which the final conclusions and recommendations resulting from the study were based.

The first three cases were a variation in the launch call to exercise each of the three reactivation test schedules contained in the test plan. Case Number 1 shows the minimum reactivation testing; based on the failures and days delay it was considered to be a useless test and was eliminated from further consideration.

Knowing that the in-storage test was basically an "aliveness test," it was decided to study elimination of these tests to determine their effect on the overall program. Case 4 of Table 3 shows that they have no effect on either the days delay or the number of failures detected. As a result, these tests were also eliminated from further cosideration.

Table 3. Sample of Storage Study Considerations

Case Number	Launch Call (Mo.)	Tests During Storage (1)	Reactivation Testing	Average Failures Detected	Average Days Delay
1	12	1,1,2	IST	3.2	9.3
2	18	1,1,2, 1,1	T/V	13.1	28.8
3	24	1,1,2, 1,1,2	Ambient	7.7	18.7
4	24	2,2	Ambient	7.7	18.7
5	24	None	Ambient	9.9	22.8
6	24	None	T/V	14.1	30.7
7	24	None	T/V (2)	4.2	8.6
8	24	None	Ambient (3)	13.1	30.6
9	24	None	T/V (3)	15.9	38.4
1C	24	2	T/V	11.9	26.4
11	24	2,2	T/V	11.3	25.2
12	24	2,2,2	T/V	11.3	25.1
13	24	2	T/V (3)	13.4	29.9
14	24	2,2	T/V (3)	12.7	28.5
15	24	2,2,2	T/V (3)	12.7	28.5
16	24	None	T/V	14.1	80.3

(1) Test Number 1 is an in-storage electrical (aliveness) test. Test Number 2 is an ambient plus a T/V test.

(2) Indicates that no failures occur during reactivation testing.

(3) Indicates perfect detection during reactivation testing.

The next step was to evaluate the effect of no testing during storage. Cases 5 and 6 study these effects. Both the failures and the delay were increased over Cases 2 and 3; however, these increases were not considered significant. The test plan contained 17 days contingency for the ambient test and 22 days for the T/V test. Since the test plan was based on a 40-hour single shift work week, the delays estimated by the analysis model were not considered excessive.

At this point a question was raised concerning the source of the failures; e.g., how many were being introduced by the testing and how many were present at the beginning of the test. Additionally, concern was shown over the efficiency of the tests and how many failures would still be remaining in the system after the reactivation testing, i.e., at launch. Cases Number 7, 8 and 9 are examples of runs conducted to answer the above questions. By changing the working copy of the program at the terminal, Case Number 7 was accomplished allowing no failures to occur during reactivation testing; comparing Cases 6 and 7 indicates that at least 4.2 failures were present at the start of test and 9.9 were caused by the test (14.1-4.2=9.9). The failures introduced by the tests were further identified as test or spacecraft failures. Some spacecraft failure were also identified as incipient failures accelerated by the T/V tests. Cases Number 8 and 9 were created by changing the program to allow perfect detection during reactivation testing. Comparing them with Cases 5 and 6 shows that failures will be undetected and remain in the system at launch. Also by dividing the failures in Cases 5 and 6 by those in Cases 8 and 9 it is seen that the T/V test is the most efficient even though more failures are introduced. (ambient is 76% effective while T/V is 89% effective). As a result, only T/V testing was considered in the remainder of the cases.

Cases 10 through 12 of the table represent an attempt to determine whether or not more intensive testing during the storage period would eliminate the failures remaining in the spacecraft. These three cases when compared to Case 6, indicated that some of the failures could be eliminated by interim testing; however, Cases 13 through 15 indicate that some failures are left in the system and cannot be eliminated (e.g., Cases 12 and 15 - 12.7-11.3=1.4). Since this matched our launch experience, the study was terminated at this point. It should also be pointed out that the failures used in the study were reviewed to determine their effect on orbit. For the most part, these failures were considered minor; this also coincided with past experience.

Up to this point in time, the spares complement was considered unlimited; e.g., it was assumed that an on-going program was following or that several vehicles were in storage allowing for units to be removed from other spacecraft. During the study, units began failing which had not failed previously and for which no spares were available. This resulted in a reevaluation of the spares complement and their recycle time through manufacturing, test, and return to the spacecraft. Case Number 16 is a sample of the days delay associated with this type of situation and represents an unacceptable condition.

Based upon the study results represented by Table 3, the conclusion was to place the spacecraft in storage, conduct no tests until the launch call is received and then to conduct a T/V test. Additionally, it was recommended that a complete complement of spares be provided. Management took the above results and, considering cost, manpower requirements, etc., arrived at the conclusion that interim T/V tests should be conducted at one year intervals for crew training purposes. They also recommended that the spares complement be increased over the present level.

Our customer has not, to date, directed us to revise our test program per the recommendations. He has, however, issued a contract to complete our spares complement.

4. OTHER APPLICATIONS

Other potential applications of the analysis tool described in this paper have been alluded to, things such as stored weapon system held in readiness in case of an emergency; piece parts placed in electronic stores prior to assembly; electronic boxes stored prior to integration into a system; TV sets and hi-fi equipment stored in warehouses before shipment to showrooms; used cars sitting on a lot waiting for a new owner to arrive. The list of such applications is potentially a very long one. This section examines a few such situations in more detail, pointing out some of the important questions which could be studied by use of such analyses. Two less obvious examples relating to psychology and baseball are touched upon.

Missiles in Silos

The equipment constituting the U.S. retaliatory strike capability is a classic example of stored equipment subject to a random or non-predetermined call-up use. The problems of what storage conditions, what type of checkout procedures to apply and how often, have received extensive study over a long period of time. Analyses of the type discussed in the preceding sections should have played a key role in the reaching of decisions on these matters. Indeed, the need for nearly instantaneous response to the call-up has led to very frequent checkout routines; in many cases critical items are turned on continuously and monitored, an instance of infinitely frequent testing as a means of dealing with a near zero-time reaction goal.

Spare Electronic Boxes

In many cases electronic boxes are available for integration into a system long before the system build-up process is ready for them. The boxes are then stored until they are needed. In a normal assembly situation the questions of test frequency in storage are not acute since the time of use is hopefully known well in advance. The situation is more critical in the case of a spare box required only in the event of a failure of a primary unit already integrated into the system. Such a spare box is indeed subject to a random demand: its rapid availability to the system is more critical than normal since the spare is only required when some other anomaly has already occurred and schedules are very likely in jeopardy. Finding that the spare has also failed when it is taken from storage would certainly insure (i) significant delays; (ii) imposition of penalties for tardy delivery if such provision were in the contract; and (iii) a damage to the company reputation. Stored spares could be treated exactly as stored spacecraft were in the examples above.

Spare Tire in a Passenger Car

The previous example hits particularly close to home if you have ever had a flat tire only to find that your spare is also flat when it is pulled from its hiding place. How often do you check the air pressure in your spare?

Learning Theory in Psychology

Knowledge is stored in the brain and called upon in special situations. The longer it has been since some class of knowledge has been called upon, the less is ones assurance that it will be accessible when needed. Reviews of previously learned information correspond to the storage tests of our model; forgotten data corresponds to defects uncovered by storage tests; re-learning forgotten data is the repair action adopted to remedy the failure. An interesting learning theory study could be based upon this storage model, investigating the optimum review frequency and intensity for various types of information, so that an adequate recall would occur when the data were needed at some unexpected time.

Relief Pitcher in Baseball

The relief pitchers lolling in the bullpen are actually in storage awaiting an unscheduled demand for their services. The more days which go by without his pitching, the less becomes the manager's confidence that the pitcher will "have it" when called up with the bases loaded. The lower the manager's confidence, the less frequently does he call upon the pitcher. This cycle leads to the often observed dependence of a manager upon one or two relief pitchers whom he tests often enough to have confidence in. They each appear in roughly half of the games in a season and typically burn themselves out in two or three seasons. A manager wishing to profit from aerospace technology would evaluate existing data on times-between appearances and its correlation with performance for each of his relief pitchers.

An analysis using a framework similar to that found in the storage model would doubtless identify a maximum number of days off which each pitcher can typically tolerate. Periodic games pitched entirely by little used relief pitchers would be one way to keep his entire staff in shape to be called upon when needed. This approach is also analogous to peridic calibration of electronic test equipment. No pitcher should be allowed to exceed his recommended calibration periods.

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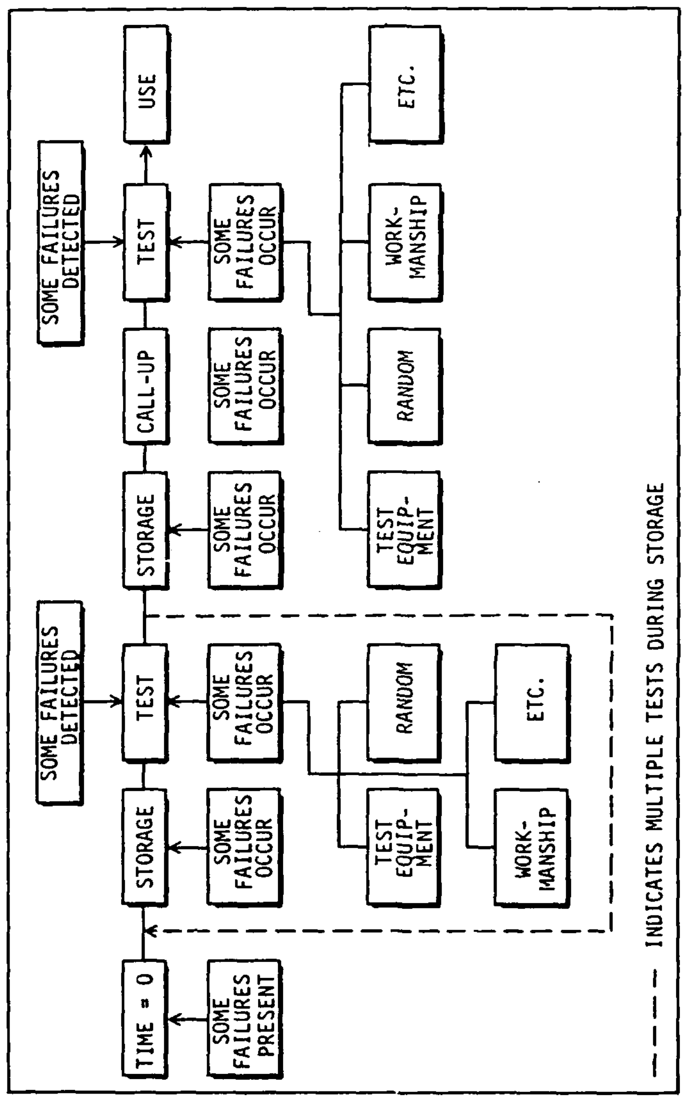

Figure 1. Flow of Storage Events

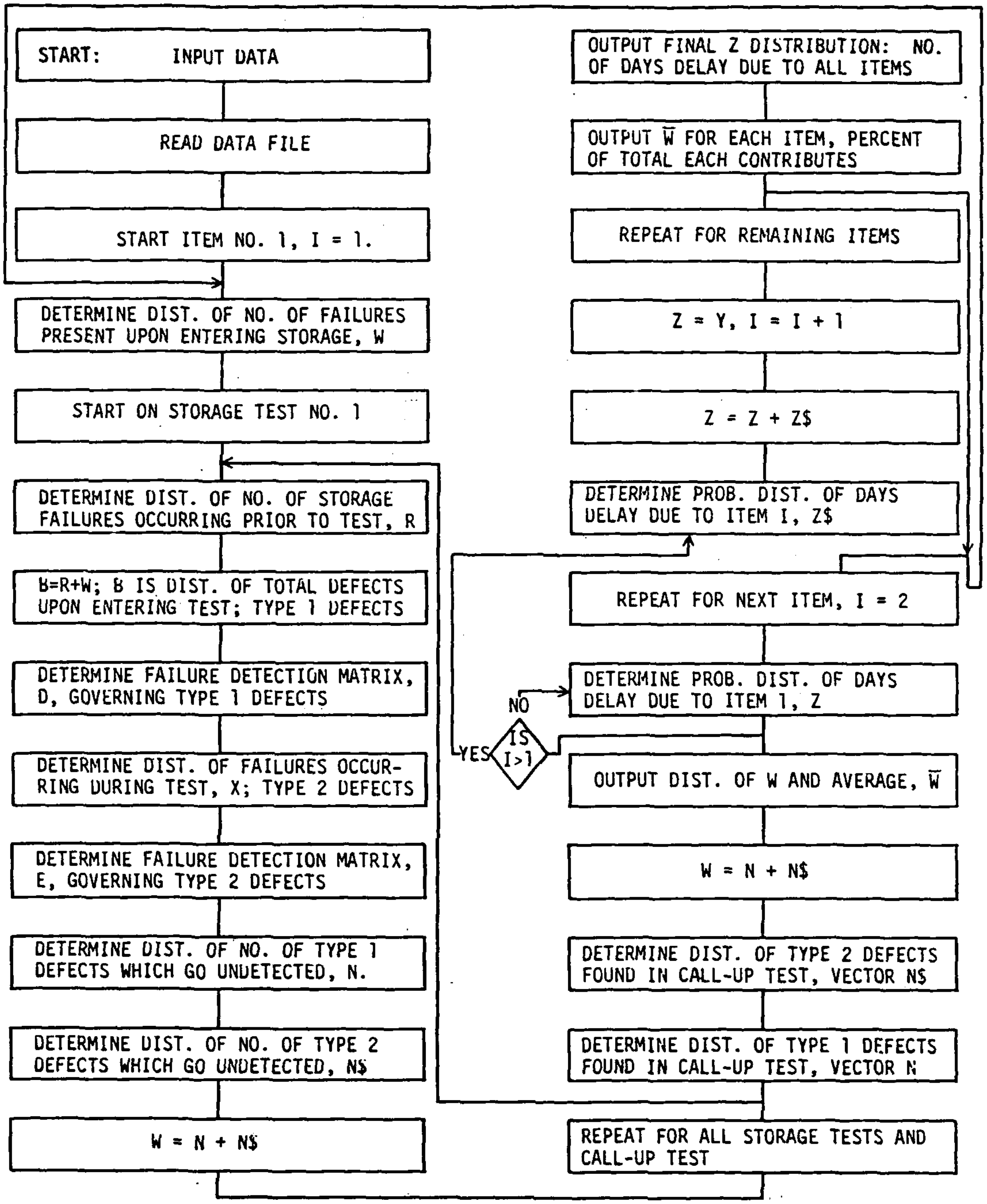

Figure 2. Computer Program Flow Diagram

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification
By Per Ltr.
Distribution/
Availability Codes
Avail and/or
Dist Special
A-1