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# AN EXPERIMENT IN SOFTWARE RELIABILITY ADDITIONAL ANALYSES USING DATA FROM AUTOMATED REPLICATIONS

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# Chapter 1

# INTRODUCTION

## 1.1 BACKGROUND

### 1.1.1 Software Reliability Research Goals

The software reliability research sponsored by NASA–Langley Research Center (NASA–LaRC) focuses on the development of a credible method for predicting operational reliability — that is, predicting the improbability that the system will fail due to residual faults remaining in the software [1]. It is these residual faults, which surface infrequently, that cause the rare event or extremely improbable failures. As evidenced by the first well-publicized Space Shuttle software bug, the failure of the initialization logic in J. Garman's words resulted from a "very small, very improbable, very intricate, and a very old mistake" [2]. This bug typifies the rare and convoluted combination of events which causes carefully developed software to fail.

Although considering all faults is important in reliability prediction, the most probable faults are often eliminated using the software quality assurance methods such as those described in the new DoD standards STD-2167 for software development [3], STD-2168 for software quality evaluation [4], and in the certification guidelines described in [5] . In systems critical to the flight of civil aircraft, safety requirements impose demanding reliability requirements. Accordingly, the System Validation Methods Branch of NASA–LaRC has used a value of $10^{-9}$ as the maximum probability of system failure for a ten-hour flight as an informal standard in the search for a credible reliability prediction method for validating critical software [6]. To date no known software has been validated to that extent.

### 1.1.2 Software Error Experiments

As Phyllis Nagel wrote in the first report on the repetitive run experiments for gathering software error data, "Little software reliability growth modeling has been based on feedback gained from controlled experiments" [7, page 2]. The method of investigation, then, is to conduct a series of controlled experiments which provides this feedback. These experiments constitute one aspect of the NASA–LaRC software reliability program, viz, the collection and analysis of software failure data of laboratory controlled quality.

The Research Triangle Institute (RTI) has participated in this program by conducting software error experiments using the computing facilities of AIRLAB at NASA–LaRC. RTI has conducted two software error gathering studies. Both studies were conducted in a controlled environment to (i) emulate the production environment of a software engineer developing life-critical software and (ii) as much as possible, hold constant the usually varying exogenous factors in actual development environments [8,9]. This report describes the first of these studies; specifically, a three-version implementation of a radar tracking problem.

## 1.2 DEFINITION OF TERMS

The following lists defines the terms which are used throughout this report.

- APPLICATION TASK – A software module being tested for reliability, previously referred to as an $AT_i$, or Application Task i.
- DESIGN STAGE – One more than the number of *corrections* made sequentially to the code under test during a replicate. A *correction* is to be interpreted as "the set of all faults fixed at the same time."
- DESIGN STATE or VERSION – An instantiation of an implementation of the code under test. During the software fault diagnosis-correction process, the program fixes result in several design states or versions of the code.

- PROGRAM or IMPLEMENTATION – An independently coded version of the same functional specification (i.e., one of the application tasks).
- REPLICATE, REPLICATION, or REPETITIVE RUN – A set of test cases applied to the code under test. (See Section 2.4.1 for further explanation.)

The use of the terms failure, error, fix, and fault in this report are consistent with the definitions given below:

- FAILURE – A program failure occurs when one or more observed output value(s) disagree(s) with the correct output value(s).
- ERROR – The incorrect element(s) of the observed output value(s) at the time of failure.
- FIX – The minimum code change required to correct an error.
- FAULT – The conceptual flaw in the program which is corrected by a fix.

## 1.3 SUMMARY

The software error data compiled and analyzed as a part of the NASA-LaRC program of experimentation and documented in this report, were collected with the following specific goals in mind:

- determining if the error rates corresponding to the (sequentially generated) design stages of a program follow a log-linear pattern,
- testing the hypothesis of equal error rates associated with each known fault, and
- providing additional insight into how software fails.

With respect to the first goal, analysis of software error data yielded an independent confirmation of the results of Nagel, et al. [7] in that the error rates of design stages were observed to follow a log-linear pattern, as described in Section 3.1.

The testing of the hypothesis of equal error rates associated with each known fault also confirmed the findings of Nagel, et al [7] . This result renders suspect the assumption that the program's failure rate is a constant multiple of the number of residual bugs which underlies some of the current software reliability growth models [10].

In Section 3.4, the identification of interacting faults provides additional insight into the software failure process. The authors suspect that less reliance on black box modeling of software reliability growth may prove useful for improving the predictive validity of models of software reliability growth.

## 1.4 RELATED RESEARCH REPORTS

Additional information about the experiment can be found in NASA CR-172553 [11]. Additional information about the automated repetitive run modeling tool, AUTOSIM, developed for the purpose of this study, can be found in NASA-CR 177930 [12]. The related Boeing Computer Services' study is documented in NASA CR-165836 [13] and NASA CR-16481 [7]. N-version experimentation with the radar tracking problem can be found in [14] and [15,16] .

# Chapter 2

# EXPERIMENT OVERVIEW

## 2.1 THE CODE UNDER TEST

### 2.1.1 The Radar Tracking Problem

The modules from which error data were gathered were independently coded programs for a hypothetical radar tracking problem. Slightly differing specifications of the problem exist. The first use of the problem was in a 1973 TRW study which dealt with the quantitative measurement of software reliability and safety [17] . The problem (specification) was used in 1979 in the repetitive run modeling study by Nagel et al. [13] that is the forerunner of this study. The version of the specification from which the modules used in this study were coded is contained in the recent RTI contractor report [11] to NASA. A paraphrased version of the specification used in this study has since been used by Knight et al. [15,16] in a study of coincidental errors in dissimilar, functionally equivalent (i.e., N-Version) software.

## 2.2 SOFTWARE DEVELOPMENT

### 2.2.1 Task Staffing and Management

The functionally redundant software components developed as a part of this study were coded at RTI by programmers (with 2 to 8 years of programming experience) using a link to the computational facilities in the AIRLAB at NASA's Langley Research Center. Senior software engineers and software analysts implemented the error detection algorithms and constructed the test harness used. English language specifications were provided to the programmers to develop the system components. The specification provided was written by the senior systems analyst who also coded and extensively tested a comparison version to solve the radar tracking problem. The comparison version was coded prior to providing the specifications to the programmers and therefore served as a prototype used to debug the test harness. The programming activity was managed in a conventional fashion with the exception that the programmers were instructed not to discuss their code with anyone other than their manager or the senior systems analyst who was responsible for answering all specification questions. The programmers were instructed to optimize the reliability of their code.

### 2.2.2 Programmer Selection

The moderate to advanced skill level programmers were selected by considering the criteria reported by Moher and Schneider [18]. A form based on this criteria was used to screen applicants and those considered were exposed to a series of interviews by the project staff. A competitive salary was paid to attract qualified programmers.

### 2.2.3 Data Collection

#### 2.2.3.1 Secondary Data

Data were collected both manually and automatically during code development and repair. These data are primarily descriptive of the development process. Manual data collection was achieved through the use of project notebooks and special forms. An instrumented data collection environment [11] was used to automatically collect data on programmer activity.

When a program fails during testing, the programmer is notified by electronic mail that his or her program has failed. The mail message indicates if an abend occurred or which outputs are in error. If an abend occurred, the trace back message was provided. The input case which the program failed to execute successfully was also provided. Changes made by the programmer to the failed program were annotated in the code using a standard syntax. These changes were also reported on a program change report form.

#### 2.2.3.2 Faults/Fixes Data

This data compilation augments a previous manual data collection activity using the same radar tracking software implementations. The manual data collection activity identified 11 faults in one program, 1 fault in a second program, and 20 faults in a third program version. Table 2.1 describes the faults observed for each program. These faults are defined by the fixes required. Note that fixes 3 and 4 of the third program have been identified as invalid fixes. These fixes are fixes for perceived faults that did not exist, thus reducing the number of valid faults observed from 20 to 18. Fixes 3 and 4 have been kept in the table merely to keep the fix numbering consistent with the raw data files. A more complete documentation of this manual data collection activity and the corresponding analyses can be found in Dunham, et al. [11].

The execution of the 100 automated replications resulted in no observations of an error requiring application of fix 7 to one of the independently coded modules to correct the error. Since this fix was applied five times during 25 earlier replications (See [11, page 56] ), this lack of observation prompted the checking of its validity.

The logical condition bit CMM(7) is set to 1 if the following logical condition as stated in the specifications is satisfied:

*At least one of any $n$ consecutive data points lies a distance greater than $\epsilon_1$ from the line joining the first and last of these points.*

Fix 7 corresponds to handling of degenerate conditions, i.e. when $N > P$, where $P$ is the number of $(x, y)$ coordinates provided to the subroutine which tests the logical condition. Figure 2.1 depicts this subroutine, named COND7, with and without fix 7 installed. As shown in this figure, fix 7 changes code in the COND7 subroutine so that the subroutine exits with CMM(7)=0 prior to the execution of a DO LOOP if the upper bound on the DO LOOP is less than the lower bound. If the upper bound is less than the lower bound in FORTRAN77 and fix 7 is not installed, then the DO LOOP is not executed. The control flow bypasses the DO LOOP, executes

Table 2.1: Faults/Fix Descriptions

| PROGRAM | FIX NO. | DESCRIPTION |
|---|---|---|
| ONE | 1 | FUNCTION ANGLEA - overwrote data in common region by making assignments to input variables. |
| | 2 | CMM(5) - wrong data point was discarded due to erroneous index specification in a loop. |
| | 3 | CMM(7) - three erroneous index specifications. |
| | 4 | CMM(5) - did not specify logic that if M $\leq$ 1, CMM(5) cannot be met. |
| | 5 | FUNCTION RAD - program abended due to an out-of-bound argument when calling the FORTRAN library routine which computes the arccosine. |
| | 6 | CMM(8) - specified LT. on bound instead of LE. |
| | 7 | Function ANGLEA failed to complete FIX DO 1 by not changing all variable names. |
| | 8 | Function ANGLEA program abended due to an out-of-bound argument when calling the FORTRAN library routine which computes the arccosine. |
| | 9 | CMM(1) - used wrong formula to compute the difference between 2 points. |
| | 10 | CMM(3) - inconsistent definition of a null vector with other ATs. |
| | 11 | CMM(10) - inconsistent definition of a null vector with other ATs. |
| TWO | 1 | Used integer variable instead of boolean variable when setting the FC. |
| THREE | 1 | CMM(7) fix for misinterpretation of any |
| | 2 | CMM(13) fix for wrong variable N6 thru N1 |
| | 3 thru 6 | CMM(2) through CMM(5) inappropriate handling of computation when the No. of data points is small. |
| | 7 thru 15 | CMM(7) thru CMM(15) inappropriate handling of computation when the No. of data points is small. |
| | 16 | CMM(7) - the upper bound of a do loop was incorrectly set. |
| | 17 | Function AGLCOS program abended when trying to compute cosine. |
| | 18 | Program abended due to a division by zero in FUNCTION RADCIR. |
| | 19 | CMM(3) - Program returned wrong value from AGLCOS. This fix is related to fix 17. |
| | 20 | FUNCTION PERDIS - program abended when all 3 points were the same. |

the statement CMM(7)=0 and returns with CMM(7)=0. Thus, the result is the same with and without fix 7 installed.

Re-execution of the test cases for the manual replications during which fix 7 was observed indicated that fix 7 was applied in conjunction with fix 16 and should not have been applied at all. For these failed cases, fix 16 corrected the error when applied by itself. Fix 7 did not correct the error when applied by itself.

The above analyses resulted in the determination that fix 7 is an invalid fix and should never have been applied. It is similar to fixes 3 and 4 which were applied to handle the same degenerate condition which was observed in other subroutines as a result of errors in the CMM bits. It is a fix for a perceived fault that was not there. These invalid fixes were the results of a relaxed fault identification procedure used at the start of the experiment; a procedure which permitted the programmer to correct perceived but nonexistent faults. The procedure was later revised to reduce the probability of such erroneous fixes.

The automated testing did not result in the observation of any new faults, and in fact resulted in the consideration of fix 7 as an invalid fix, thus further reducing the number of valid faults to 17. Fix 7 has also been retained in the table to keep the fix numbering consistent with the raw data files.

## 2.3 ERROR DETECTION METHOD

The independently coded modules were run for over 13 million input cases in the test harness which relied on the technique of N-Version Programming to detect program errors. Approximately 1 million of the cases generated the error data that appear in the appendix to this report; the other 12 million cases were special, extra cases run to investigate the fault interaction phenomenon described in Section 3.4 . The test harness is described in an earlier contractor report for this study [11] which also contains an appendix with error data generated from an earlier set of 2 million input cases.

N-Version programming involves a voting procedure on the outputs of N software modules independent coded to a common specification and operating upon the same input values [19] Intermediate and final program outputs were compared, rather than voted, in this study. Whenever an

## Figure 2.1: Subroutine COND7

(WITHOUT FIX 7 INSTALLED)

```
C AT LEAST ONE OF ANY N CONSECUTIVE
C DATA POINTS LIES A DISTANCE THAN
C EPS1 FROM THE LINE JOINING
C THE FIRST AND LAST OF THESE POINTS
  IMPLICIT NONE
  INTEGER*4 NLIM,J,K,LOLIM,I
  REAL*4 PERDIS,DIST
  INCLUDE 'LICCOM.FOR'
C NOW INITIALIZE FOR A LOOP
  NLIM=NBIG
  CMM(7)=1
  LOLIM=P-NLIM+1
  DO I=1,LOLIM
    J=I+NBIG-1
    K=I
    IF(DIST(I,J).GT.0.0)THEN
      DO WHILE(K.LT.J)
        K=K+1
        IF(PERDIS(I,J,K).GT.EPS1)RETURN
      END DO
C
C WHEN THE FIRST AND LAST OF
C N CONSECUTIVE DATA POINTS
C ARE IDENTICAL THE CALCULATED
C DISTANCE TO COMPARE WILL BE
C THE DISTANCE FROM THE COINCIDENT
C POINT TO ALL OTHERS OF
C THE N CONSECUTIVE POINTS
    ELSE
    DO WHILE(K.LT.J)
      K=K+1
      IF(DIST(I,K).GT.EPS1)RETURN
      END DO
    END IF
  END DO
  CMM(7)=0
  RETURN
  END
```

(WITH FIX 7 INSTALLED)

```
C AT LEAST ONE OF ANY N CONSECUTIVE
C DATA POINTS LIES A DISTANCE THAN
C EPS1 FROM THE LINE JOINING
C THE FIRST AND LAST OF THESE POINTS
  IMPLICIT NONE
  INTEGER*4 NLIM,J,K,LOLIM,I
  REAL*4 PERDIS,DIST
  INCLUDE 'LICCOM.FOR'
C NOW INITIALIZE FOR A LOOP
  NLIM=NBIG
C** FIX 7 changes next line from CMM(7)=1
  CMM(7)=0
  LOLIM=P-NLIM+1
C** FIX 7 adds the next two lines
  IF (LOLIM.LT.1)RETURN
  CMM(7)=1
  DO I=1,LOLIM
    J=I+NBIG-1
    K=I
    IF(DIST(I,J).GT.0.0)THEN
      DO WHILE(K.LT.J)
        K=K+1
        IF(PERDIS(I,J,K).GT.EPS1)RETURN
      END DO
C
C WHEN THE FIRST AND LAST OF
C N CONSECUTIVE DATA POINTS
C ARE IDENTICAL THE CALCULATED
C DISTANCE TO COMPARE WILL BE
C THE DISTANCE FROM THE COINCIDENT
C POINT TO ALL OTHERS OF
C THE N CONSECUTIVE POINTS
    ELSE
    DO WHILE(K.LT.J)
      K=K+1
      IF(DIST(I,K).GT.EPS1)RETURN
      END DO
    END IF
  END DO
  CMM(7)=0
  RETURN
  END
```

output inequality occurred, the testing was halted and the faulty module(s) identified, analyzed, and corrected. This test method detected errors except when all three modules and the extensively tested version failed identically in the same output bit(s).

In addition to providing software error data for computing component version reliability, the N-version test harness provided data on the effectiveness of different strategies for selecting an answer from occasionally differing outputs. Analysis of this data is reported elsewhere [14].

## 2.4 THE REPETITIVE RUN TECHNIQUE

### 2.4.1 Replicates

A repetitive run technique [13] is used for error rate estimation. This approach provides better estimates of the program error rates as well as estimates of the error rates associated with the individual faults. It involves repetitively testing a software module from its pre-release version through the detection and correction of $m$ faults. The testing uses inputs generated at random according to a pre-specified program usage distribution. During the testing called the first replicate, the faults are identified and removed, and the fixes corresponding to each fault are saved. Next, the software is returned to its initial state and executed with a different set of randomly generated inputs. As the errors due to a specific fault are again detected, the corresponding fix is applied and the number of input cases to observation of each output error is again recorded. This process is called the second replication. By generating additional replicates (i.e. the repetitive run technique) an estimate of the error rate can be determined by the program design stage, by the specific fault, or by the program design state or version.

### 2.4.2 Number and Length

To determine the number of automated replications to be conducted, the number of failures required to accurately estimate $p$, the probability that the program will fail due to a specific fault on a given execution is determined using the same argument given in [11]. This determination is based on controlling the relative error, $r$, in the estimated failure probability, $\hat{p}$ for

Table 2.2: Upper Limits for Replication Sample Sizes

| | r | | | |
|---|---|---|---|---|
| $1-\alpha$ | .5 | .25 | .1 | .01 |
| .901057 | 11 | 44 | 272 | 27,200 |
| .950004 | 16 | 62 | 384 | 38,400 |
| .980194 | 22 | 87 | 543 | 54,300 |
| .998626 | 41 | 164 | 1,024 | 102,400 |
| .999855 | 58 | 232 | 1,444 | 144,400 |
| .999993 | 81 | 324 | 2,025 | 202,500 |
| .999999 | 100 | 400 | 2,500 | 250,000 |

the allowable risk $(1-\alpha)$ close to 1. That is we wish to determine $k$, the number of replicated observations required such that $Pr(|\hat{p}-p| \geq rp) \leq (1-\alpha)$. Table 2.2 shows the upper limits for the number of replicated observations required for different values of $(1-\alpha)$ and $r$ assuming $p$ is sufficiently close to 0. Based on this table, we chose 100 replications for estimating $p$.

The length of a replication was set to 10,000 test cases which is the same stopping rule selected for the manual data collection activity.

The error data collected are in Tables 2 through 32 in the Appendix.

## 2.5 THE AUTOSIM TOOL

Figure 2.2 portrays AUTOSIM [12], the automated error diagnosis and correction tool developed to expedite the software error data collection process under the repetitive run technique. This tool replaced a programmer with one year of experience who was performing the time consuming and error prone repetitive run testing task. The figure shows the quasi-static data structures which remain relatively constant during testing and the dynamic data structures which are updated by either the AUTOSIM software or the N-VERSION CONTROLLER software.

The contents of the quasi-static data structures depend on the code under test and are updated only when a new fault is identified. The overwrite, abend, and output error maps contain information on which code fixes are associated with different types of faults. The code library contains the version of the code after acceptance testing and the code fixes.

The dynamic structures include a trace describing which faults have been diagnosed and corrected during each replication. The system state includes the corrected versions of the code, the current replication number, the test case number, the input and output for the current test case, and synchronization information.

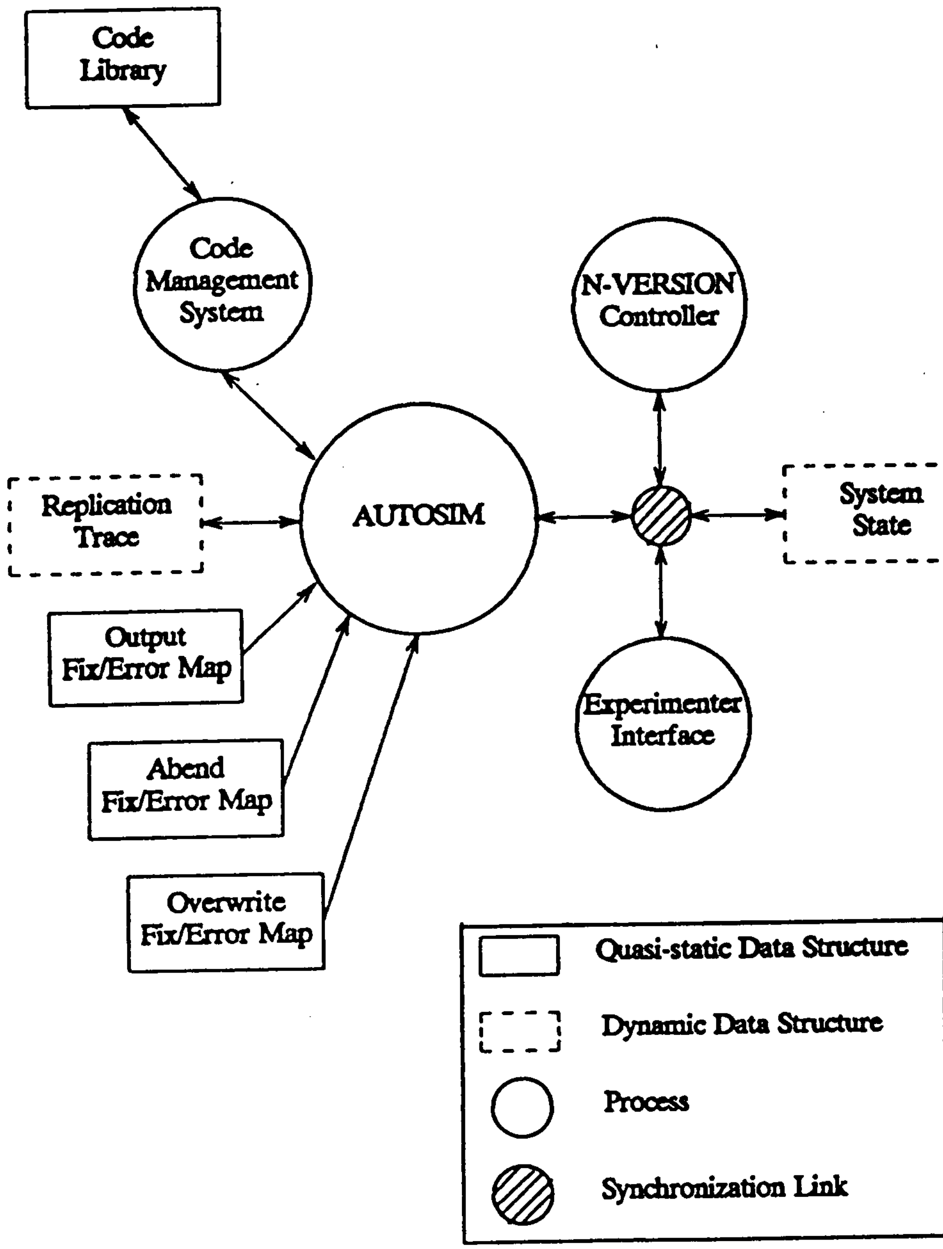



Figure 2.2: The AUTOSIM Tool

# Chapter 3

# ERROR ANALYSIS

## 3.1 ERROR RATES OF DESIGN STAGES

The (absolute value of the natural logarithm of the) maximum likelihood estimate of a design stage's error rate is tabulated in Table 3.1 . The estimate includes the effect of censored samples and is, of course, based on the assumption that a design stage of a software module has a constant probability of error per input case. The statistic, for programs 1 and 3, is plotted in Figures 3.1 and 3.2 . Also plotted are the natural logarithms of the corresponding minimum and maximum times to error of the design stages. The plots corroborate the observations of log linear trends that were made in the Boeing study [7,13] . The raw error data are in Tables 2 through 8 in the Appendix.

Table 3.1: Error Rates by Design Stage

| PROGRAM | DESIGN STAGE $j$ | $k_j$ | $\sum_{i=1}^{100} \tau_{ij}$ | $\lvert ln_e mle\ \lambda_j \rvert$ | $ln_e(MIN(\tau_{ij}))$ | $ln_e(MAX(\tau_{ij}))$ |
|---|---|---|---|---|---|---|
| ONE | 1 | 100 | 103 | 0.03 | 0.00 | 0.69 |
| | 2 | 100 | 915 | 2.21 | 0.00 | 4.13 |
| | 3 | 100 | 2,171 | 3.08 | 0.00 | 4.80 |
| | 4 | 100 | 4,200 | 3.74 | 0.00 | 5.38 |
| | 5 | 100 | 9,274 | 4.53 | 0.00 | 6.98 |
| | 6 | 99 | 42,458 | 6.06 | 2.30 | 9.07 |
| | 7 | 91 | 185,929 | 7.62 | 1.39 | 9.18 |
| | 8 | 45 | 439,878 | 9.17 | 4.45 | 9.20 |
| | 9 | 3 | 288,225 | 11.47 | 7.29 | 9.18 |
| TWO | 1 | 100 | 139 | 0.33 | 0.00 | 1.39 |
| THREE | 1 | 100 | 123 | 0.21 | 0.00 | 1.39 |
| | 2 | 100 | 1,418 | 2.65 | 0.00 | 4.25 |
| | 3 | 100 | 2,590 | 3.25 | 0.00 | 5.06 |
| | 4 | 100 | 25,073 | 5.52 | 0.00 | 8.06 |
| | 5 | 100 | 76,918 | 6.65 | 0.69 | 8.85 |
| | 6 | 72 | 288,440 | 8.30 | 2.40 | 9.20 |
| | 7 | 27 | 386,439 | 9.57 | 4.62 | 9.20 |
| | 8 | 5 | 182,417 | 10.50 | 7.13 | 9.13 |

where:

$i$ is the index of replications

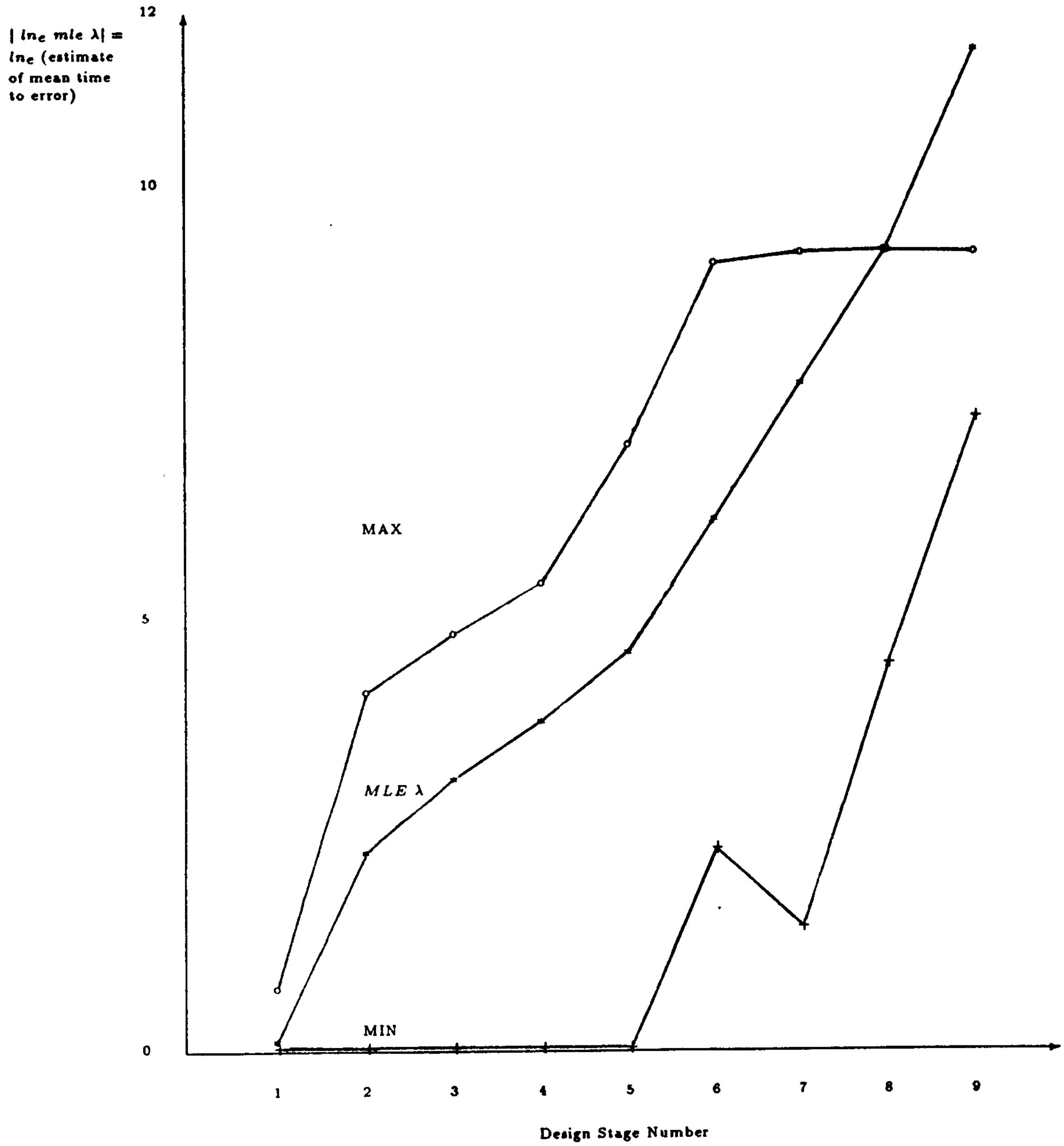
$j$ is the index of design stages

$k_j$ is the number of replicates containing a $j^{th}$ design stage in which an error was observed by the time of the stopping case of the replicate

$\tau_{ij}$ is the time (i.e., number of cases) to observation of an error of the $j^{th}$ design stage during the $i^{th}$ replicate <u>or</u> the time for the $j^{th}$ design stage to reach the stopping case of the $i^{th}$ replicate – whichever occurred first. (Note that $\tau_{ij}$ is measured from the start of the $j^{th}$ design stage during the $i^{th}$ replicate, not from the start of the $i^{th}$ replicate; thus, $\tau_{ij} \equiv 0$ for replicates that end before a $j^{th}$ design stage is created.)

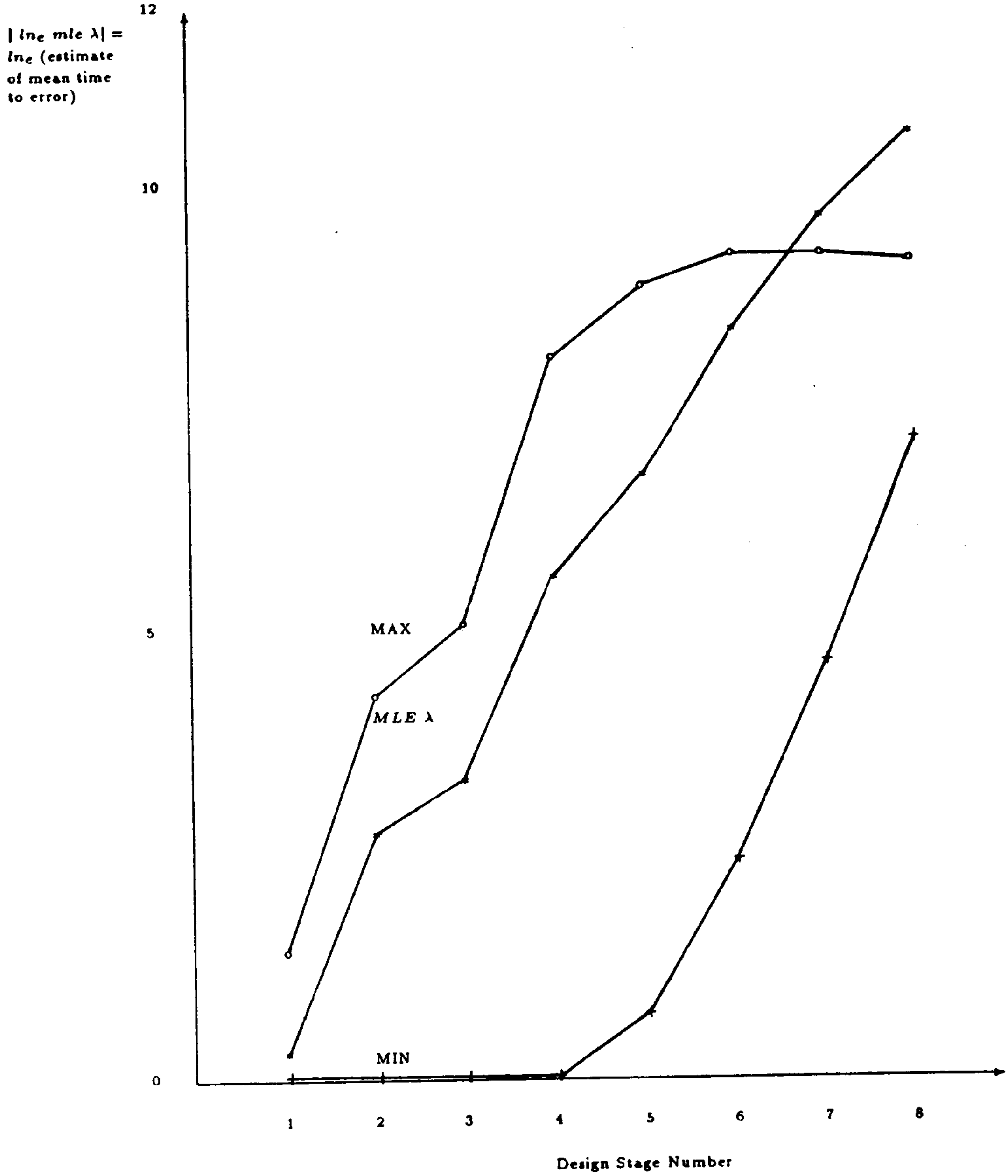
$mle\ \lambda_j$ is the maximum likelihood estimate of the error rate associated with the $j^{th}$ design stage and is given by $mle\ \lambda_j = |ln_e(l - k_j / \sum_{i=1}^{100} \tau_{ij})|$.

Figure 3.1: Logarithms of the Estimated Error Rates of the Design Stages for Program One




Curves Labelled " MLE λ " depict $|ln_e \lambda_j|$

Figure 3.2: Logarithms of the Estimated Error Rates of the Design Stages for Program Three




Curves labelled " $MLE$ $\lambda$ " depict $|ln_e \lambda_j|$

## 3.2 ERROR RATES OF INDIVIDUAL FAULTS

On the assumption that individual faults give rise to independent error processes, the hypothesis of equal error rates for the individual faults was tested by use of the maximum likelihood ratio test described on pages 236-239 in Cox and Lewis [20] . However, the expression for the test statistic has been modified since the form derived in Cox and Lewis does not account for censored data (and granulated time).

The modified test statistic is

$$\begin{aligned} H &= 2\sum_{j=1}^{J}[k_j ln_e(k_j/K) - s_j ln_e(s_j/S) \\ &+ (s_j - k_j) ln_e((s_j - k_j)/(S-K))] \end{aligned}$$

for

$$\begin{aligned} s_j &= \sum_{i=1}^{R} t_{ij}, \\ K &= \sum_{j=1}^{J} k_j, \end{aligned}$$

and

$$S = \sum_{j-1}^{J} s_j.$$

where:

$i$ is the index of replications,

$R$ is the total number of replications,

$j$ is the index of perceived faults (or, more precisely, fixes),

$J$ is the total number of uniquely identified fixes,

$t_{ij}$ is the time (counted from the start of replication $i$) of the first error ascribed to perceived fault $j$ (or uniquely identified fix $j$) during the $i^{th}$ replication <u>or</u> the ending time of the replication if no error was ascribed to perceived fault $j$ during the $i^{th}$ replication,

$k_j$ is the number of replications that contained an error ascribed to perceived fault $j$

The test statistic has, asymptotically, a Chi-squared distribution with the degrees-of-freedom parameter equal to one less than the number of uniquely identified faults (or more correctly, fixes) considered; for the full error data summarized in Table 3.2 , the degrees-of-freedom parameter is equal to J-1. For the data in Table 3.2 , using the full data the test statistic equals approximately 6975 and 7782 for programs 1 and 3, respectively; for the partial data (that exclude from consideration faults for which fewer than ten errors were observed) it equals approximately 3630 and 5220.

Clearly, the null hypothesis (of equal error rates for the individual faults) is rejected for both programs at an extremely high level of significance. If only the uncensored data are used, the null hypothesis is still rejected at an extremely high level of significance for both programs. (Program 2 was not considered, since only one fault was ever discovered in the program.)

Table 3.2: Summarized Error Data for MLE Ratio Test

| PROGRAM | Fix Number (j) | $k_j$ | $\sum_{i=1}^{100} t_{ij}$ |
|---|---|---|---|
| ONE | 1 | 100 | 109 |
| | 2 | 100 | 184 |
| | 3 | 100 | 3,310 |
| | 4 | 100 | 38,585 |
| | 5 | 100 | 6,463 |
| | 6 | 100 | 10,842 |
| | 7 | 100 | 20,555 |
| | 8 | 95 | 302,918 |
| | 9 | 9 | 957,237 |
| | 10 | 1 | 994,072 |
| | 11 | 2 | 990,641 |
| PARTIAL | — | 795 | 382,966 |
| FULL | — | 807 | 3,324,920 |
| THREE | 1 | 100 | 126 |
| | 2 | 78 | 221,559 |
| | 5 | 100 | 7,964 |
| | 6 | 100 | 4,698 |
| | 8 | 100 | 7,964 |
| | 9 | 100 | 4,698 |
| | 10 | 100 | 4,698 |
| | 11 | 100 | 4,698 |
| | 12 | 100 | 1,988 |
| | 13 | 100 | 7,964 |
| | 14 | 100 | 4,698 |
| | 15 | 100 | 4,698 |
| | 16 | 100 | 5,053 |
| | 17 | 96 | 250,239 |
| | 18 | 100 | 106,885 |
| | 19 | 5 | 978,071 |
| PARTIAL | — | 1,474 | 637,930 |
| FULL | — | 1,479 | 1,553,000 |

where:

$i$ is the index of replications,

$j$ is the index of perceived faults (or, more precisely, fixes),

$t_{ij}$ is the time (counted from the start of replication $i$) of the first error ascribed to perceived fault $j$ (or uniquely identified fix $j$) during the $i^{th}$ replication <u>or</u> the ending time of the replication if no error was ascribed to perceived fault $j$ during the $i^{th}$ replication,

$k_j$ is the number of replications that contained an error ascribed to perceived fault $j$.

## 3.3 DESIGN STATES

The 100 automated replications of testing resulted in the observation of 45 versions out of a possible 4,095 versions for the first program, and 36 versions out of a possible 131,071 versions for the third program as shown in Table 3.3. Each of these unique versions constitutes a design state. These small numbers of observed versions suggest that a (statistical) order of precedence of fault detection and removal exists among all faults.

Table 3.3 also gives the number of patterns of errors observed and the 16-bit output vector. These data indicate that (i) a version of the program can produce several error patterns (e.g., in the extreme case for the third program, one version produced 14 error patterns) and (ii) one error pattern can be produced by several distinct versions (e.g., in the extreme case for the first program, 20 versions produced the same pattern of errors). The latter indicates the unsurprising result that different faults can provoke the same error manifestation.

Tables 9 through 32 in the appendix contain the times to failure of each version or design state for the first and third programs respectively. These data are summarized in Tables 3.4 and 3.5 which show the combinations of faults present and the average life length of each of these design states.

Table 3.3: Version Statistics

| PROGRAM | NUMBER OF FAILED VERSIONS | NUMBER OF SUCCESSFUL VERSIONS | NUMBER OF ERROR PATTERNS | MAX. NUMBER OF ERROR PATTERNS OBSERVED FOR A SINGLE VERSION | MAX. NUMBER OF VERSIONS FAILING WITH THE SAME ERROR PATTERN |
|---|---|---|---|---|---|
| One | 43 | 2 | 33 | 13 | 20 |
| Three | 34 | 2 | 38 | 14 | 14 |

Table 3.4: Program One Design State Failure Times

| DESIGN STATE | FAULTS PRESENT | LIFE LENGTH | NO. OF OBSERVATIONS | AVERAGE LIFE LENGTH |
|---|---|---|---|---|
| 1 | 1-12 | 103 | 100 | 1.03 |
| 2 | 2-12 | 113 | 39 | 2.90 |
| 3 | 3-12 | 1,501 | 90 | 16.68 |
| 4 | 3-6, 8-12 | 225 | 8 | 28.12 |
| 5 | 4-6, 8-12 | 279 | 9 | 31.00 |
| 6 | 4, 5, 8-12 | 751 | 12 | 62.58 |
| 7 | 5, 8-12 | 139 | 2 | 69.50 |
| 8 | 8-12 | 246,420 | 89 | 2768.76 |
| 9 | 4-12 | 1,492 | 43 | 34.70 |
| 10 | 4, 5, 7-12 | 1,124 | 25 | 44.96 |
| 11 | 5, 7-12 | 308 | 3 | 102.67 |
| 12 | 4, 6-12 | 2,489 | 40 | 62.22 |
| 13 | 6-12 | 1,283 | 11 | 116.64 |
| 14 | 6, 8-12 | 611 | 6 | 101.83 |
| 15 | 4, 6, 8-12 | 2,061 | 21 | 98.14 |
| 16 | 4, 8-12 | 16,569 | 54 | 306.83 |
| 17 | 9-12 | 650,067 | 9 | 72,229.70 |
| 18 | 4, 7-12 | 6,214 | 47 | 132.21 |
| 19 | 7-12 | 4,859 | 30 | 161.97 |
| 20 | 1, 3-12 | 12 | 6 | 2.00 |
| 21 | 3-5, 7-12 | 373 | 17 | 21.94 |
| 22 | 4, 9-12 | 4,345 | 7 | 620.71 |
| 23 | 3, 4, 6-12 | 520 | 30 | 17.33 |
| 24 | 3, 4, 7-12 | 352 | 14 | 25.14 |
| 25 | 3, 4, 6, 8-12 | 55 | 4 | 13.75 |
| 26 | 3, 4, 8-12 | 58 | 3 | 19.3 |
| 27 | 3, 7-12 | 69 | 1 | 69.00 |
| 28 | 8-10, 12 | 6,320 | 1 | 6,320.00 |
| 29 | 4, 6, 9-12 | 248 | 2 | 124.00 |
| 30 | 4, 5, 9-12 | 166 | 1 | 166.00 |
| 31 | 5, 9-12 | 38 | 1 | 38.00 |
| 32 | 5-12 | 65 | 3 | 21.67 |
| 33 | 8, 10-12 | 8,712 | 2 | 4,356.00 |
| 34 | 5, 6, 8-12 | 9 | 1 | 9.00 |
| 35 | 3, 6, 8-12 | 13 | 1 | 13.00 |
| 36 | 3, 8-12 | 57 | 1 | 57.00 |
| 37 | 3, 5-12 | 20 | 2 | 10.00 |
| 38 | 2, 4-12 | 7 | 2 | 3.50 |
| 39 | 3, 6-12 | 49 | 1 | 49.00 |
| 40 | 2-6, 8-12 | 2 | 1 | 2.00 |
| 41 | 2-5, 7-12 | 2 | 1 | 2.00 |
| 42 | 10-12 | 33,764 | 1 | 33,764.00 |
| 43 | 9, 11, 12 | 5,930 | 1 | 5,930.00 |
| 44 | 9, 10, 12 | 2,738 | 1 | 2,738.00 |
| 45 | 8, 10, 12 | 306 | 1 | 306.00 |

Table 3.5: Program Three Design State Failure Times

| DESIGN STATE | FAULTS PRESENT | LIFE LENGTH | NO. OF OBSERVATIONS | AVERAGE LIFE LENGTH |
|---|---|---|---|---|
| 1 | 1-20 | 100 | 123 | 1.23 |
| 2 | 2, 5, 6, 8-20 | 89 | 1,359 | 15.27 |
| 3 | 5, 6, 8-20 | 8 | 58 | 7.25 |
| 4 | 5, 6, 8-11, 13-20 | 37 | 929 | 25.10 |
| 5 | 16-20 | 23 | 784 | 34.09 |
| 6 | 17-20 | 69 | 47,830 | 693.19 |
| 7 | 17, 19-20 | 47 | 133,183 | 2,833.68 |
| 8 | 5, 8, 13, 16-20 | 20 | 484 | 24.20 |
| 9 | 5, 8, 13, 17-20 | 33 | 2210 | 66.97 |
| 10 | 2, 16-20 | 18 | 1,167 | 64.83 |
| 11 | 2, 17-20 | 21 | 17,185 | 818.33 |
| 12 | 2, 18-20 | 5 | 4,081 | 816.20 |
| 13 | 2, 5, 6, 8-17, 19, 20 | 1 | 6 | 6.00 |
| 14 | 5, 8, 13, 16, 17, 19, 20 | 1 | 70 | 70.00 |
| 15 | 5, 8, 13, 17, 19, 20 | 4 | 458 | 114.50 |
| 16 | 18-20 | 22 | 28,502 | 1,295.55 |
| 17 | 5, 6, 8-11, 13-15, 17-20 | 31 | 1,506 | 48.58 |
| 18 | 1, 2, 5, 6, 8-11, 13-20 | 2 | 4 | 2.00 |
| 19 | 2, 5, 6, 8-11, 13-20 | 8 | 97 | 12.12 |
| 20 | 2, 17, 19, 20 | 17 | 42,467 | 2,498.06 |
| 21 | 2, 5, 6, 8-15, 17-20 | 19 | 353 | 18.58 |
| 22 | 2, 5, 6, 8-11, 13-15, 17-20 | 6 | 135 | 22.50 |
| 23 | 5, 6, 8-15, 17-20 | 7 | 208 | 29.71 |
| 24 | 2, 5, 6, 8-16, 18-20 | 1 | 6 | 6.00 |
| 25 | 5, 6, 8-11, 13-16, 18-20 | 2 | 18 | 9.00 |
| 26 | 5, 6, 8-11, 13-15, 18-20 | 1 | 11 | 11.00 |
| 27 | 19, 20 | 5 | 546,351 | 109,270.00 |
| 28 | 2, 19, 20 | 2 | 148,825 | 74,412.50 |
| 29 | 2, 16, 18-20 | 1 | 54 | 54.00 |
| 30 | 5, 8, 13, 18-20 | 1 | 100 | 100.00 |
| 31 | 5, 8, 13, 16, 18-20 | 1 | 4 | 4.00 |
| 32 | 16, 18-20 | 2 | 103 | 51.50 |
| 33 | 1, 5, 6, 8-11, 13-20 | 1 | 2 | 2.00 |
| 34 | 5, 6, 8-11, 13-15, 17, 19-20 | 1 | 97 | 97.00 |
| 35 | 2, 20 | 1 | 5,930 | 5,930.00 |
| 36 | 20 | 1 | 16,009 | 16,009.00 |

## 3.4 INTERACTING FAULTS

The data in Table 3.6 were generated by special versions of one of the tested programs (specifically, faults 7 and 8 in program 1) operating upon identical input to the versions. The first column of the table can be considered to contain data from program 1 with only fault 7 present; the second column, program 1 with only fault 8 present; the third column, program 1 with both 7 and 8 but no others present. "S"s indicate successful operation; "F"s indicate failure. Thus, the first row of the table indicates that for 1,714,177 randomly chosen cases, the three version agreed on the correct output (the inputs to the three versions being the same in a case).

The phenomenon represented by these data has been called "fault interaction": to wit, two (or more) faults are said to be interacting faults when the error set (the set of points, from the input space of the module that translates into erroneous outputs) that exists when the faults are jointly present in the code differs from the set that is the union (in the mathematical sense) of the error sets of the faults separately (or in other combinations) present in the software.

Interacting faults were discovered serendipitously during this experiment because of a sometimes symptom of interacting faults. The symptom is the occurrence of an erroneous output that can be corrected by the repair of either of several seemingly unrelated faults - seemingly unrelated in the sense that they are logically unrelated from the perspective of their origins or causes; obviously they have some relationship in their synergistic effect on the computation. In Table 3.6 this corresponds to the S/S/F event that occurred 4990 times. A conventional debugging process is likely to miss this symptom because, upon detecting an error in the module containing both faults, a programmer will most likely correct just one fault (which ever one he discovers first) and never know that he had a choice. But the repetitive run technique is well suited for observing the option. And because of this "either-or" symptom during the generation of the error data that is collected in the appendix, several such interacting fault pairs were serendipitously discovered - faults 7 and 8 of program 1, faults 2 and 13 of program 3, and the triplet of faults 7 (later determined to not be a real fault), 16, and 20 of program 3. (Fault 20 is not listed in Table 3.2 or in the appendix because it did not cause an error and was not detected until well after the generation of the data in the appendix was completed and 12 million special cases were being run to seek and to examine the interaction phenomenon among fault pairs.)

Table 3.6: Counts for Interacting Faults

| Fault 7 present | Fault 8 present | Faults 7 & 8 present | Number of Cases |
|---|---|---|---|
| S | S | S | 1,714,177 |
| S | S | F | 4,990 |
| S | F | S | 349 |
| S | F | F | 19 |
| F | S | S | 473 |
| F | S | F | 0 |
| F | F | S | 1,122 |
| F | F | F | 12 |

Consider the following examples. It could happen that the error sets for faults jointly present or separately present could be approximately the same "size" but consist of different points (clearly the case for the value 4990 as opposed to the values 349, 473, and 1122 in Table 3.6 ) – so that after the detection of an error and proper correction of one of the faults, inputs that had previously tested out as not generating errors could be in the resulting error set.

Or it could happen that the error set when two faults are jointly present in code is much smaller than the error set of either fault taken separately (e.g., if the 4990 had been 10 in Table 3.6 ); in such a case, the faults could be considered to be almost compensating or mutually masking – so that upon the eventual detection of an error, if only one of the faults were corrected (and properly corrected), the error rate of the code would increase.

Although there are insufficient data to support statements about the significance of the phenomenon in reliability modeling, it is clear that the phenomenon is a mechanism that can give rise to insidious effects that plague software testing theory by causing any modification of software to leave all previous testing suspect.

# Chapter 4

# CONCLUDING REMARKS

The report presents the results of an experiment in software reliability based on program samples of a radar tracking problem, N-version programming as an error detection mechanism, and automated fault identification and correction.

Testing the software modules with over three million input cases (of which two million are reported in the earlier report to this study [11] ) corroborated the findings of a previous study [7,13]: the log-linear pattern of error rates of design stages and rejection of the hypothesis that all faults in a program have the same error rate.

Additional testing (approximately twelve million input cases) and analysis of the resulting error data indicated that there is a fault interaction phenomenon that complicates the estimation of the error rates to be associated with some faults. The frequency of interacting faults in software and, therefore, the importance of accounting for this complicating phenomenon in the modeling of software reliability is not yet known.

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# APPENDIX. ERROR DATA

# 1: Seeds

TABLE 1. Seeds Used with the Pseudo-Random Number Generator

| REPLICATION | SEED |
|---|---|
| 1 | 1050554872 |
| 26 | 1765936978 |
| 51 | 2008687904 |
| 71 | 1348542162 |
| 89 | 207784072 |

# 2: Input Cases to Failure

# TABLE 2. PROGRAM:ONE, FAULTS:1-12, REPLICATIONS:1-40

| REP | FIX NUMBER | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 2 | 3 | 23 | 107 | 205 | 31 | 17 | 504 | — | — | — | — |
| 2 | 1 | 5 | 22 | 98 | 316 | 84 | 277 | — | — | — | — | — |
| 3 | 1 | 1 | 3 | 17 | 7 | 476 | 240 | 4471 | — | — | — | — |
| 4 | 1 | 1 | 16 | 104 | 48 | 91 | 6 | 3159 | 4357 | — | — | — |
| 5 | 1 | 1 | 9 | 694 | 189 | 39 | 759 | 5090 | — | — | — | — |
| 6 | 1 | 1 | 19 | 171 | 78 | 66 | 103 | 2557 | — | — | — | — |
| 7 | 2 | 1 | 26 | 224 | 122 | 9 | 54 | 138 | 4483 | — | — | — |
| 8 | 1 | 1 | 10 | 1020 | 119 | 9 | 40 | 6260 | — | — | — | — |
| 9 | 2 | 4 | 60 | 138 | 28 | 55 | 123 | 4455 | — | — | — | — |
| 10 | 1 | 1 | 43 | 72 | 16 | 114 | 151 | 9811 | — | — | — | — |
| 11 | 1 | 2 | 36 | .500 | 131 | 22 | 113 | 3281 | — | — | — | — |
| 12 | 1 | 1 | 27 | 84 | 17 | 17 | 10 | 7539 | — | — | — | — |
| 13 | 1 | 1 | 48 | 353 | 34 | 32 | 171 | 668 | — | — | — | — |
| 14 | 1 | 2 | 27 | 319 | 6 | 148 | 70 | 4813 | 6271 | — | — | — |
| 15 | 1 | 1 | 84 | 264 | 17 | 53 | 62 | 990 | — | — | — | — |
| 16 | 1 | 2 | 37 | 254 | 27 | 87 | 124 | 1020 | — | — | — | — |
| 17 | 1 | 1 | 6 | 430 | 20 | 305 | 50 | 1728 | — | — | — | — |
| 18 | 1 | 2 | 152 | 84 | 46 | 15 | 227 | 2046 | — | — | — | — |
| 19 | 1 | 2 | 40 | 807 | 60 | 3 | 209 | 4088 | — | — | — | — |
| 20 | 1 | 1. | 53 | 152 | 108 | 149 | 463 | — | 9696 | — | 3377 | — |
| 21 | 1 | 1 | 57 | 558 | 1 | 15 | 119 | 2524 | — | — | — | — |
| 22 | 1 | 1 | 38 | 253 | 62 | 39 | 338 | 1874 | — | — | — | — |
| 23 | 2 | 1 | 10 | 403 | 17 | 34 | 228 | 2870 | — | — | — | — |
| 24 | 1 | 1 | 12 | 805 | 139 | 24 | 23 | — | — | — | — | — |
| 25 | 1 | 4 | 49 | 364 | 57 | 10 | 319 | 1811 | — | 4072 | — | — |
| 26 | 1 | 1 | 93 | 1757 | 63 | 71 | 140 | 1201 | — | — | — | — |
| 27 | 1 | 3 | 93 | 323 | 25 | 17 | 237 | 712 | — | — | — | — |
| 28 | 1 | 4 | 76 | 151 | 75 | 22 | 168 | 3274 | — | — | — | — |
| 29 | 2 | 1 | 28 | 355 | 25 | 26 | 476 | 4092 | — | — | — | — |
| 30 | 1 | 4 | 39 | 509 | 83 | 204 | 321 | 2492 | — | — | — | — |
| 31 | 1 | 2 | 117 | 880 | 3 | 36 | 216 | 299 | — | — | — | — |
| 32 | 1 | 1 | 48 | 219 | 10 | 174 | 16 | 3045 | — | — | — | — |
| 33 | 1 | 1 | 37 | 452 | 49 | 69 | 154 | 229 | — | — | 7264 | — |
| 34 | 1 | 2 | 61 | 701 | 103 | 24 | 130 | 1891 | — | — | — | — |
| 35 | 1 | 1 | 22 | 232 | 100 | 13 | 78 | 2506 | — | — | — | — |
| 36 | 1 | 2 | 47 | 865 | 151 | 18 | 169 | 4042 | — | — | — | — |
| 37 | 1 | 1 | 25 | 132 | 24 | 108 | 424 | 789 | — | — | — | — |
| 38 | 1 | 1 | 35 | 56 | 16 | 117 | 19 | 2273 | — | — | — | — |
| 39 | 1 | 2 | 50 | 92 | 16 | 150 | 207 | 3235 | — | — | — | — |
| 40 | 1 | 1 | 10 | 2072 | 76 | 407 | 228 | 293 | — | — | — | — |

TABLE 3. PROGRAM:ONE, FAULTS:1-12, REPLICATIONS:41-80

| REP | FIX NUMBER | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 41 | 1 | 2 | 19 | 187 | 113 | 76 | 95 | 701 | — | — | — | — |
| 42 | 1 | 2 | 36 | 148 | 87 | 323 | 58 | 1947 | — | — | — | — |
| 43 | 1 | 1 | 9 | 610 | 270 | 8 | 92 | 4137 | — | — | — | — |
| 44 | 1 | 2 | 2 | 221 | 21 | 108 | 100 | 789 | — | — | — | — |
| 45 | 1 | 1 | 20 | 594 | 24 | 199 | 39 | 3995 | — | — | — | — |
| 46 | 1 | 5 | 17 | 178 | 16 | 27 | 10 | 4480 | — | — | — | — |
| 47 | 1 | 1 | 10 | 261 | 298 | 34 | 86 | 96 | — | — | — | — |
| 48 | 1 | 1 | 33 | 504 | 156 | 154 | 227 | 2200 | — | — | — | — |
| 49 | 1 | 7 | 38 | 553 | 143 | 156 | 41 | 4500 | — | — | — | — |
| 50 | 1 | 1 | 33 | 104 | 20 | 68 | 386 | 839 | — | — | — | — |
| 51 | 1 | 1 | 27 | 54 | 131 | 67 | 176 | 2547 | — | — | — | — |
| 52 | 1 | 1 | 15 | 49 | 2 | 123 | 238 | 1396 | 4616 | — | — | — |
| 53 | 1 | 1 | 51 | 661 | 82 | 7 | 951 | 2756 | 1491 | — | — | — |
| 54 | 1 | 1 | 16 | 50 | 58 | 149 | 14 | 311 | 7925 | — | — | — |
| 55 | 2 | 1 | 19 | 112 | 37 | 116 | 56 | 323 | — | — | — | — |
| 56 | 1 | 1 | 31 | 234 | 1 | 123 | 259 | 2496 | — | — | — | — |
| 57 | 1 | 2 | 39 | 481 | 41 | 385 | 106 | 253 | — | — | — | — |
| 58 | 1 | 3 | 24 | 273 | 46 | 273 | 124 | 3443 | — | — | — | — |
| 59 | 1 | 4 | 43 | 153 | 12 | 17 | 177 | 4147 | — | — | — | — |
| 60 | 1 | 1 | 134 | 66 | 64 | 78 | 10 | 1281 | — | — | — | — |
| 61 | 1 | 1 | 10 | 677 | 36 | 83 | 119 | 1805 | — | — | — | — |
| 62 | 1 | 1 | 50 | 69 | 27 | 42 | 322 | 628 | — | — | — | — |
| 63 | 1 | 1 | 43 | 280 | 141 | 62 | 3 | 471 | — | — | — | — |
| 64 | 1 | 2 | 19 | 2 | 87 | 25 | 354 | 9327 | — | — | — | — |
| 65 | 1 | 1 | 2 | 932 | 58 | 32 | 423 | 4371 | — | — | — | — |
| 66 | 1 | 3 | 15 | 717 | 132 | 98 | 154 | 2186 | — | — | — | — |
| 67 | 1 | 1 | 8 | 422 | 17 | 233 | 1116 | 4838 | — | — | — | — |
| 68 | 1 | 5 | 1 | 271 | 116 | 258 | 395 | 4774 | — | — | — | — |
| 69 | 1 | 1 | 68 | 19 | 20 | 209 | 171 | 1806 | — | — | — | — |
| 70 | 1 | 1 | 68 | 272 | 54 | 196 | 553 | 1187 | — | — | — | — |
| 71 | 1 | 2 | 47 | 130 | 14 | 24 | 24 | 478 | — | — | — | — |
| 72 | 1 | 1 | 25 | 86 | 9 | 44 | 108 | 112 | — | — | — | — |
| 73 | 1 | 2 | 44 | 415 | 56 | 195 | 72 | 3193 | — | — | — | — |
| 74 | 1 | 1 | 3 | 236 | 67 | 366 | 429 | 4410 | — | — | — | — |
| 75 | 1 | 2 | 12 | 260 | 3 | 43 | 79 | 7964 | — | — | — | — |
| 76 | 1 | 5 | 49 | 248 | 12 | 129 | 414 | 3531 | — | — | — | — |
| 77 | 1 | 1 | 27 | 446 | 41 | 19 | 168 | — | 2556 | — | — | — |
| 78 | 1 | 3 | 34 | 375 | 33 | 114 | 52 | 1979 | — | — | — | — |
| 79 | 1 | 1 | 3 | 210 | 50 | 50 | 210 | 1281 | — | — | — | — |
| 80 | 2 | 2 | 8 | 490 | 27 | 267 | 222 | 2835 | — | — | — | — |

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TABLE 4. PROGRAM:ONE, FAULTS:1-12, REPLICATIONS:81-100

| REP | FIX NUMBER | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 81 | 1 | 2 | 62 | 1108 | 15 | 47 | 451 | 1870 | — | — | — | — |
| 82 | 1 | 2 | 94 | 385 | 119 | 155 | 1 | 6589 | — | — | — | — |
| 83 | 1 | 3 | 8 | 1543 | 51 | 27 | 40 | 417 | — | — | — | — |
| 84 | 1 | 3 | 29 | 335 | 65 | 133 | 839 | 6416 | — | — | — | — |
| 85 | 1 | 5 | 15 | 404 | 22 | 13 | 189 | 4365 | — | — | — | — |
| 86 | 1 | 2 | 26 | 95 | 66 | 1 | 95 | 4045 | — | — | — | — |
| 87 | 1 | 1 | 55 | 96 | 31 | 107 | 146 | 1351 | — | — | — | — |
| 88 | 1 | 1 | 34 | 317 | 213 | 37 | 290 | 4682 | — | — | — | — |
| 89 | 1 | 1 | 7 | 29 | 2 | 244 | 532 | 1082 | 5842 | — | — | — |
| 90 | 1 | 1 | 33 | 109 | 1 | 26 | 179 | 1291 | — | — | — | — |
| 91 | 1 | 1 | 3 | 221 | 22 | 221 | 86 | 580 | — | — | — | — |
| 92 | 1 | 2 | 1 | 75 | 118 | 332 | 454 | 3821 | — | — | — | — |
| 93 | 1 | 1 | 11 | 667 | 36 | 459 | 16 | 1770 | — | — | — | — |
| 94 | 1 | 4 | 18 | 1171 | 116 | 161 | 137 | 1334 | — | — | — | — |
| 95 | 2 | 1 | 15 | 67 | 37 | 108 | 131 | 3489 | — | — | — | — |
| 96 | 1 | 1 | 8 | 439 | 46 | 28 | 174 | 2888 | — | — | — | — |
| 97 | 1 | 3 | 9 | 1551 | 66 | 75 | 247 | 2766 | — | — | — | — |
| 98 | 2 | 1 | 2 | 362 | 91 | 26 | 26 | 1104 | — | — | — | — |
| 99 | 1 | 2 | 31 | 408 | 10 | 36 | 295 | — | — | — | — | — |
| 100 | 1 | 2 | 9 | 82 | 5 | 243 | 315 | 1175 | — | — | — | — |

TABLE 5. PROGRAM:TWO, FAULTS:1, REPLICATIONS:1-100

| REP | FIX NO. 1 | REP | FIX NO. 1 |
|---|---|---|---|
| 1 | 1 | 51 | 1 |
| 2 | 1 | 52 | 3 |
| 3 | 1 | 53 | 1 |
| 4 | 1 | 54 | 1 |
| 5 | 1 | 55 | 1 |
| 6 | 1 | 56 | 1 |
| 7 | 1 | 57 | 2 |
| 8 | 1 | 58 | 1 |
| 9 | 4 | 59 | 1 |
| 10 | 1 | 60 | 1 |
| 11 | 2 | 61 | 1 |
| 12 | 1 | 62 | 1 |
| 13 | 1 | 63 | 1 |
| 14 | 1 | 64 | 1 |
| 15 | 1 | 65 | 1 |
| 16 | 2 | 66 | 1 |
| 17 | 3 | 67 | 1 |
| 18 | 1 | 68 | 2 |
| 19 | 1 | 69 | 2 |
| 20 | 1 | 70 | 1 |
| 21 | 2 | 71 | 1 |
| 22 | 1 | 72 | 1 |
| 23 | 1 | 73 | 2 |
| 24 | 1 | 74 | 4 |
| 25 | 1 | 75 | 2 |
| 26 | 1 | 76 | 3 |
| 27 | 2 | 77 | 1 |
| 28 | 2 | 78 | 3 |
| 29 | 1 | 79 | 2 |
| 30 | 1 | 80 | 2 |
| 31 | 1 | 81 | 1 |
| 32 | 1 | 82 | 2 |
| 33 | 1 | 83 | 2 |
| 34 | 2 | 84 | 3 |
| 35 | 2 | 85 | 1 |
| 36 | 1 | 86 | 2 |
| 37 | 1 | 87 | 1 |
| 38 | 1 | 88 | 1 |
| 39 | 2 | 89 | 1 |
| 40 | 1 | 90 | 1 |
| 41 | 1 | 91 | 1 |
| 42 | 1 | 92 | 1 |
| 43 | 1 | 93 | 3 |
| 44 | 1 | 94 | 1 |
| 45 | 1 | 95 | 2 |
| 46 | 1 | 96 | 1 |
| 47 | 1 | 97 | 1 |
| 48 | 2 | 98 | 1 |
| 49 | 1 | 99 | 2 |
| 50 | 1 | 100 | 1 |

ORIGINAL PAGE IS
OF POOR QUALITY

# TABLE 6. PROGRAM:THREE, FAULTS:1-20, REPLICATIONS:1-40

| REP | FIX NUMBER | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 6 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 1 | 1 | 15 | 30 | 30 | 30 | 30 | 30 | 30 | 17 | 30 | 30 | 30 | 52 | 3234 | 1506 | — | — |
| 2 | 1 | 20 | 98 | 20 | 98 | 20 | 20 | 20 | 20 | 98 | 20 | 20 | 22 | 3681 | 235 | — | — |
| 3 | 1 | — | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 68 | 1091 | 1777 | — | — |
| 4 | 1 | 6 | 26 | 15 | 26 | 15 | 15 | 15 | 6 | 26 | 15 | 15 | 89 | 2282 | 457 | — | — |
| 5 | 1 | 2 | 8 | 8 | 8 | 8 | 8 | 8 | 2 | 8 | 8 | 8 | 89 | — | 789 | — | — |
| 6 | 1 | 4 | 123 | 4 | 123 | 4 | 4 | 4 | 4 | 123 | 4 | 4 | 96 | 4822 | 636 | — | — |
| 7 | 1 | 54 | 224 | 54 | 224 | 54 | 54 | 54 | 54 | 224 | 54 | 54 | 123 | 2072 | 49 | — | — |
| 8 | 1 | 9 | 19 | 9 | 19 | 9 | 9 | 9 | 9 | 19 | 9 | 9 | 40 | 965 | 4521 | — | — |
| 9 | 1 | 1 | 32 | 1 | 32 | 1 | 1 | 1 | 1 | 32 | 1 | 1 | 37 | 2277 | 2957 | — | — |
| 10 | 1 | 17 | 63 | 63 | 63 | 63 | 63 | 63 | 17 | 63 | 63 | 63 | 21 | 1789 | 776 | — | — |
| 11 | 2 | 5 | 63 | 51 | 63 | 51 | 51 | 51 | 1 | 63 | 51 | 51 | 32 | 5816 | 2705 | — | — |
| 12 | 1 | — | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 9 | 2195 | 1245 | — | — |
| 13 | 1 | — | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 17 | 3207 | 126 | — | — |
| 14 | 1 | 70 | 75 | 75 | 75 | 75 | 75 | 75 | 27 | 75 | 75 | 75 | 28 | 1342 | 163 | — | — |
| 15 | 1 | — | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 52 | 4770 | 303 | — | — |
| 16 | 2 | 15 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 18 | 4081 | 412 | — | — |
| 17 | 3 | 13 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 41 | 1950 | 1950 | — | — |
| 18 | 1 | 84 | 89 | 84 | 89 | 84 | 84 | 84 | 84 | 89 | 84 | 84 | 71 | 1027 | 633 | — | — |
| 19 | 1 | 36 | 587 | 209 | 587 | 209 | 209 | 209 | 42 | 587 | 209 | 209 | 8 | 1840 | 349 | — | — |
| 20 | 1 | 6 | 19 | 19 | 19 | 19 | 19 | 19 | 8 | 19 | 19 | 19 | 9 | 3 | 1199 | 3377 | — |
| 21 | 2 | 6 | 79 | 45 | 79 | 45 | 45 | 45 | 6 | 79 | 45 | 45 | 23 | 2887 | 2746 | — | — |
| 22 | 1 | — | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 116 | 628 | 285 | — | — |
| 23 | 1 | — | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 40 | 1598 | 630 | — | — |
| 24 | 1 | 15 | 223 | 23 | 223 | 23 | 23 | 23 | 23 | 223 | 23 | 23 | 12 | — | 483 | — | — |
| 25 | 1 | — | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 69 | 2973 | 1131 | 4072 | — |
| 26 | 1 | — | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 94 | 8158 | 1156 | — | — |
| 27 | 2 | 34 | 89 | 89 | 89 | 89 | 89 | 89 | 34 | 89 | 89 | 89 | 50 | 1062 | 124 | — | — |
| 28 | 1 | 1 | 73 | 31 | 73 | 31 | 31 | 31 | 1 | 73 | 31 | 31 | 25 | 1226 | 891 | — | — |
| 29 | 1 | 38 | 66 | 38 | 66 | 38 | 38 | 38 | 26 | 66 | 38 | 38 | 42 | 402 | 764 | — | — |
| 30 | 1 | 17 | 251 | 186 | 251 | 186 | 186 | 186 | 17 | 251 | 186 | 186 | 19 | 2759 | 421 | — | — |
| 31 | 1 | — | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 7 | 299 | 855 | — | — |
| 32 | 1 | 19 | 142 | 142 | 142 | 142 | 142 | 142 | 19 | 142 | 142 | 142 | 116 | 2649 | 284 | — | — |
| 33 | 1 | 24 | 63 | 24 | 63 | 24 | 24 | 24 | 24 | 63 | 24 | 24 | 33 | 3099 | 92 | 7264 | — |
| 34 | 2 | 24 | 146 | 24 | 146 | 24 | 24 | 24 | 24 | 146 | 24 | 24 | 8 | 558 | 84 | — | — |
| 35 | 1 | — | 17 | 17 | 17 | 17 | 17 | 17 | 11 | 17 | 17 | 17 | 210 | 157 | 435 | — | — |
| 36 | 1 | — | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 16 | 90 | 92 | — | — |
| 37 | 1 | 22 | 132 | 132 | 132 | 132 | 132 | 132 | 22 | 132 | 132 | 132 | 57 | 210 | 199 | — | — |
| 38 | 1 | 19 | 159 | 19 | 159 | 19 | 19 | 19 | 19 | 159 | 19 | 19 | 45 | 60 | 3834 | — | — |
| 39 | 1 | 15 | 92 | 92 | 92 | 92 | 92 | 92 | 1 | 92 | 92 | 92 | 185 | 1206 | 2174 | — | — |
| 40 | 1 | 84 | 295 | 84 | 295 | 84 | 84 | 84 | 21 | 295 | 84 | 84 | 10 | 939 | 3099 | — | — |

TABLE 7. PROGRAM:THREE, FAULTS:1-20, REPLICATIONS:41-80

| REP | FIX NUMBER | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 6 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 41 | 1 | 47 | 83 | 83 | 83 | 83 | 83 | 83 | 47 | 83 | 83 | 83 | 96 | 980 | 223 | — | — |
| 42 | 1 | 17 | 99 | 17 | 99 | 17 | 17 | 17 | 17 | 99 | 17 | 17 | 52 | 1443 | 384 | — | — |
| 43 | 1 | 7 | 10 | 10 | 10 | 10 | 10 | 10 | 7 | 10 | 10 | 10 | 29 | 1473 | 999 | — | — |
| 44 | 1 | — | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 169 | 2418 | 411 | — | — |
| 45 | 1 | 9 | 42 | 39 | 42 | 39 | 39 | 39 | 9 | 42 | 39 | 39 | 64 | 24 | 4297 | — | — |
| 46 | 1 | 2 | 68 | 10 | 68 | 10 | 10 | 10 | 2 | 68 | 10 | 10 | 34 | 1157 | 1157 | — | — |
| 47 | 1 | 6 | 57 | 57 | 57 | 57 | 57 | 57 | 6 | 57 | 57 | 57 | 103 | 2578 | 191 | — | — |
| 48 | 1 | 41 | 74 | 74 | 74 | 74 | 74 | 74 | 41 | 74 | 74 | 74 | 77 | 2245 | 426 | — | — |
| 49 | 1 | 13 | 15 | 13 | 15 | 13 | 13 | 13 | 13 | 15 | 13 | 13 | 9 | 4137 | 620 | — | — |
| 50 | 1 | 31 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 33 | 839 | 453 | — | — |
| 51 | 1 | 9 | 102 | 54 | 102 | 54 | 54 | 54 | 27 | 102 | 54 | 54 | 16 | 4739 | 204 | — | — |
| 52 | 3 | 17 | 49 | 20 | 49 | 20 | 20 | 20 | 20 | 49 | 20 | 20 | 80 | 3166 | 422 | — | — |
| 53 | 1 | 17 | 120 | 120 | 120 | 120 | 120 | 120 | 7 | 120 | 120 | 120 | 6 | 137 | 137 | — | — |
| 54 | 1 | — | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 161 | 1592 | 1027 | — | — |
| 55 | 1 | — | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 115 | 909 | 3516 | — | — |
| 56 | 1 | 3 | 20 | 3 | 20 | 3 | 3 | 3 | 3 | 20 | 3 | 3 | 61 | — | 463 | — | — |
| 57 | 2 | 1 | 163 | 106 | 163 | 106 | 106 | 106 | 1 | 163 | 106 | 106 | 9 | 2139 | 1012 | — | — |
| 58 | 1 | 15 | 62 | 62 | 62 | 62 | 62 | 62 | 15 | 62 | 62 | 62 | 120 | 557 | 975 | — | — |
| 59 | 1 | 16 | 153 | 153 | 153 | 153 | 153 | 153 | 16 | 153 | 153 | 153 | 35 | 346 | 418 | — | — |
| 60 | 1 | — | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 59 | 6396 | 465 | — | — |
| 61 | 1 | 29 | 139 | 29 | 139 | 29 | 29 | 29 | 29 | 139 | 29 | 29 | 33 | 2542 | 326 | — | — |
| 62 | 1 | — | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 50 | 1070 | 386 | — | — |
| 63 | 1 | 3 | 119 | 25 | 119 | 25 | 25 | 25 | 3 | 119 | 25 | 25 | 15 | 778 | 1753 | — | — |
| 64 | 1 | 16 | 43 | 16 | 43 | 16 | 16 | 16 | 16 | 43 | 16 | 16 | 114 | 353 | 932 | — | — |
| 65 | 1 | 2 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 76 | 1159 | 950 | — | — |
| 66 | 1 | 23 | 45 | 45 | 45 | 45 | 45 | 45 | 15 | 45 | 45 | 45 | 30 | 837 | 1469 | — | — |
| 67 | 1 | — | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 90 | 4914 | 3266 | — | — |
| 68 | 2 | 12 | 14 | 14 | 14 | 14 | 14 | 14 | 12 | 14 | 14 | 14 | 99 | 20 | 186 | — | — |
| 69 | 2 | — | 19 | 19 | 19 | 19 | 19 | 19 | 18 | 19 | 19 | 19 | 18 | 4953 | 2856 | — | — |
| 70 | 1 | — | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 29 | 4800 | 781 | — | — |
| 71 | 1 | 13 | 21 | 18 | 21 | 18 | 18 | 18 | 13 | 21 | 18 | 18 | 47 | 2728 | 341 | 6331 | — |
| 72 | 1 | 11 | 24 | 11 | 24 | 11 | 11 | 11 | 11 | 24 | 11 | 11 | 6 | 471 | 792 | — | — |
| 73 | 2 | 29 | 101 | 60 | 101 | 60 | 60 | 60 | 29 | 101 | 60 | 60 | 110 | 931 | 2691 | — | — |
| 74 | 4 | 42 | 173 | 173 | 173 | 173 | 173 | 173 | 42 | 173 | 173 | 173 | 123 | 9060 | 286 | — | — |
| 75 | 1 | 11 | 101 | 45 | 101 | 45 | 45 | 45 | 11 | 101 | 45 | 45 | 1 | — | 1266 | — | — |
| 76 | 2 | 86 | 146 | 86 | 146 | 86 | 86 | 86 | 86 | 146 | 86 | 86 | 22 | 3352 | 3352 | — | — |
| 77 | 1 | — | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 69 | 22 | 973 | 678 | — | — |
| 78 | 1 | 1 | 42 | 42 | 42 | 42 | 42 | 42 | 1 | 42 | 42 | 42 | 53 | 1864 | 1520 | — | — |
| 79 | 2 | 12 | 149 | 16 | 149 | 16 | 16 | 16 | 3 | 149 | 16 | 16 | 3 | 781 | 781 | — | — |
| 80 | 1 | 1 | 106 | 106 | 106 | 106 | 106 | 106 | 1 | 106 | 106 | 106 | 10 | 1186 | 3300 | — | — |

ORIGINAL PAGE IS
OF POOR QUALITY

# TABLE 8. PROGRAM:THREE, FAULTS:1-20, REPLICATIONS:81-100

| REP | FIX NUMBER | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 6 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 81 | 1 | 8 | 56 | 56 | 56 | 56 | 56 | 56 | 8 | 56 | 56 | 56 | 53 | 6015 | 373 | — | — |
| 82 | 1 | 1 | 312 | 43 | 312 | 43 | 43 | 43 | 1 | 312 | 43 | 43 | 7 | 1076 | 464 | — | — |
| 83 | 2 | 35 | 71 | 35 | 71 | 35 | 35 | 35 | 35 | 71 | 35 | 35 | 29 | 3932 | 1808 | — | — |
| 84 | 3 | 20 | 50 | 33 | 50 | 33 | 33 | 33 | 20 | 50 | 33 | 33 | 21 | 2596 | 199 | 7027 | — |
| 85 | 1 | 8 | 49 | 49 | 49 | 49 | 49 | 49 | 8 | 49 | 49 | 49 | 12 | 428 | 189 | — | — |
| 86 | 2 | 26 | 173 | 95 | 173 | 95 | 95 | 95 | 95 | 173 | 95 | 95 | 6 | 592 | 1399 | — | — |
| 87 | 1 | 34 | 96 | 96 | 96 | 96 | 96 | 96 | 34 | 96 | 96 | 96 | 37 | 1351 | 3823 | — | — |
| 88 | 1 | 9 | 76 | 9 | 76 | 9 | 9 | 9 | 9 | 76 | 9 | 9 | 8 | 290 | 23 | — | — |
| 89 | 1 | 5 | 21 | 8 | 21 | 8 | 8 | 8 | 5 | 21 | 8 | 8 | 46 | 2541 | 301 | — | — |
| 90 | 1 | 30 | 109 | 109 | 109 | 109 | 109 | 109 | 26 | 109 | 109 | 109 | 4 | 4966 | 176 | — | — |
| 91 | 1 | — | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 59 | 1420 | 1287 | — | — |
| 92 | 2 | 23 | 75 | 57 | 75 | 57 | 57 | 57 | 1 | 75 | 57 | 57 | 23 | 1590 | 2459 | — | — |
| 93 | 3 | 8 | 23 | 8 | 23 | 8 | 8 | 8 | 8 | 23 | 8 | 8 | 61 | 2120 | 2315 | — | — |
| 94 | 1 | — | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 17 | 6550 | 132 | — | — |
| 95 | 2 | 18 | 22 | 18 | 22 | 18 | 18 | 18 | 18 | 22 | 18 | 18 | 27 | 1011 | 1376 | — | — |
| 96 | 1 | 8 | 115 | 115 | 115 | 115 | 115 | 115 | 13 | 115 | 115 | 115 | 13 | 463 | 19 | — | — |
| 97 | 1 | 62 | 198 | 198 | 198 | 198 | 198 | 198 | 38 | 198 | 198 | 198 | 149 | 5242 | 581 | — | — |
| 98 | 1 | 10 | 51 | 26 | 51 | 26 | 26 | 26 | 10 | 51 | 26 | 26 | 2 | 1767 | 355 | — | — |
| 99 | 1 | 11 | 48 | 48 | 48 | 48 | 48 | 48 | 26 | 48 | 48 | 48 | 1 | 1455 | 606 | — | — |
| 100 | 1 | 24 | 229 | 33 | 229 | 33 | 33 | 33 | 24 | 229 | 33 | 33 | 100 | 5383 | 721 | — | — |

# 3: Design State Failure Times

ORIGINAL PAGE IS
OF POOR QUALITY

# TABLE 9. PROGRAM:ONE, VERSIONS:1-13, REPLICATIONS:1-25

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1 | 2 | 2 | 15 | 7 | 9 | 77 | 99 | 300 | — | — | — | — | — |
| 2 | 1 | 5 | 18 | — | — | — | 40 | 9686 | 63 | 15 | 180 | — | — |
| 3 | 1 | — | 3 | — | — | — | — | 3996 | 5 | — | — | 11 | 224 |
| 4 | 1 | — | 6 | 11 | 33 | — | — | 3056 | — | — | — | — | — |
| 5 | 1 | — | 9 | — | — | — | — | 4332 | 31 | 151 | — | — | — |
| 6 | 1 | — | 19 | — | — | — | — | 2387 | 48 | 13 | — | — | — |
| 7 | 1 | — | 8 | — | — | 69 | — | — | — | 29 | — | — | — |
| 8 | 1 | — | 9 | — | — | 80 | — | 5241 | — | 31 | — | — | — |
| 9 | 2 | 3 | 25 | — | — | — | — | 4318 | — | — | — | — | — |
| 10 | 1 | — | 16 | — | — | — | — | 9661 | — | — | — | 30 | 43 |
| 11 | 1 | 2 | 21 | — | — | 19 | — | 2782 | — | 78 | — | — | — |
| 12 | 1 | — | 10 | 8 | — | — | — | 7456 | — | — | — | — | — |
| 13 | 1 | — | 32 | — | — | — | — | 316 | — | — | — | — | — |
| 14 | 1 | 2 | 5 | — | — | — | — | 4495 | — | — | — | 44 | — |
| 15 | 1 | — | 17 | — | — | — | — | 727 | — | — | — | — | — |
| 16 | 1 | 2 | 26 | — | — | — | — | 767 | — | — | — | 51 | — |
| 17 | 1 | — | 6 | — | — | — | — | 1299 | 15 | — | — | 31 | — |
| 18 | 1 | 2 | 14 | — | — | — | — | 1820 | — | — | — | — | — |
| 19 | 1 | 2 | 2 | — | — | — | — | 3282 | — | 41 | — | — | — |
| 20 | 1 | — | 53 | — | — | — | — | 2915 | 56 | — | — | 42 | — |
| 21 | 1 | — | — | — | — | — | — | 1967 | — | — | — | — | — |
| 22 | 1 | — | 38 | — | — | — | — | 1537 | 2 | 24 | — | — | — |
| 23 | 1 | — | 9 | — | — | — | — | 2468 | 8 | — | — | 18 | — |
| 24 | 1 | — | 12 | — | 2 | 116 | — | 9197 | 12 | — | — | — | — |
| 25 | 1 | 4 | 7 | — | — | — | — | 1448 | — | 9 | — | — | — |

TABLE 10. PROGRAM:ONE, VERSIONS:1-13, REPLICATIONS:26-50
(Version 8 did not fail on replications 2, 24, and 99.)

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 26 | 1 | — | 63 | — | — | — | — | — | — | — | — | — | — |
| 27 | 1 | 3 | 15 | — | — | — | — | 390 | — | — | — | — | — |
| 28 | 1 | 4 | 19 | — | — | — | — | 3107 | — | — | — | — | — |
| 29 | 1 | — | 24 | — | — | — | — | 3617 | — | — | — | — | — |
| 30 | 1 | 4 | 36 | — | — | — | — | 1984 | 45 | — | — | 122 | — |
| 31 | 1 | 2 | 2 | — | — | — | — | — | — | — | — | — | — |
| 32 | 1 | — | 10 | — | — | — | — | 2827 | — | — | — | — | — |
| 33 | 1 | — | 37 | — | — | — | — | — | 13 | — | — | 21 | — |
| 34 | 1 | 2 | 23 | — | — | — | — | 1191 | — | 43 | — | — | — |
| 35 | 1 | — | 13 | — | — | 23 | — | 2275 | — | 57 | — | — | — |
| 36 | 1 | 2 | 17 | — | — | — | — | 3178 | — | 105 | — | — | — |
| 37 | 1 | — | 24 | — | — | — | — | 366 | — | — | — | 84 | — |
| 38 | 1 | — | 16 | — | — | — | — | 2157 | — | — | — | — | — |
| 39 | 1 | 2 | 15 | — | — | — | — | 3029 | — | — | — | 43 | 59 |
| 40 | 1 | — | 10 | — | — | — | — | — | 67 | — | — | 153 | — |
| 41 | 1 | 2 | 18 | — | — | 19 | — | 515 | 58 | 20 | — | — | — |
| 42 | 1 | 2 | 35 | — | 30 | — | — | 1625 | 23 | — | — | — | — |
| 43 | 1 | — | 8 | — | — | 179 | — | 3528 | — | 84 | — | — | — |
| 44 | 1 | 2 | — | — | — | — | — | 569 | 20 | — | — | 80 | — |
| 45 | 1 | — | 20 | — | — | — | — | 3402 | 5 | — | — | 16 | — |
| 46 | 1 | 5 | 6 | 7 | — | — | — | 4303 | — | — | — | — | — |
| 47 | 1 | — | 10 | — | — | 11 | — | — | 25 | 53 | — | — | — |
| 48 | 1 | — | 33 | — | — | — | — | 1697 | 122 | 3 | — | — | — |
| 49 | 1 | 7 | 32 | — | 103 | — | — | 3948 | 4 | — | — | — | — |
| 50 | 1 | — | 20 | — | — | — | — | 454 | — | — | — | 36 | — |

ORIGINAL PAGE IS
OF POOR QUALITY

# TABLE 11. PROGRAM:ONE, VERSIONS:1-13, REPLICATIONS:51:75

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 51 | 1 | — | 27 | — | — | — | — | 2372 | 28 | — | 65 | — | — |
| 52 | 1 | — | 2 | — | — | — | — | 1159 | — | — | — | 35 | 75 |
| 53 | 1 | — | 7 | — | — | — | — | 541 | — | 32 | — | — | — |
| 54 | 1 | — | 14 | 3 | 35 | — | — | 163 | — | — | — | — | — |
| 55 | 1 | — | 18 | — | — | — | — | 208 | 19 | — | — | 20 | — |
| 56 | 1 | — | — | — | — | — | — | 2238 | — | — | — | 93 | — |
| 57 | 1 | 2 | 38 | — | — | — | — | — | 3 | — | — | 66 | — |
| 58 | 1 | 3 | 22 | — | — | — | — | 3171 | 23 | — | — | 79 | — |
| 59 | 1 | 4 | 9 | — | — | — | — | 3971 | — | — | — | — | — |
| 60 | 1 | — | 10 | 55 | — | — | — | 1148 | — | — | — | — | — |
| 61 | 1 | — | 10 | — | — | — | — | 1129 | 27 | — | — | 48 | — |
| 62 | 1 | — | 27 | — | — | — | — | 307 | — | — | — | — | — |
| 63 | 1 | — | 3 | 41 | 20 | 80 | — | 192 | — | — | — | — | — |
| 64 | 1 | 2 | — | — | — | — | — | 8974 | — | — | 63 | — | — |
| 65 | 1 | — | 2 | — | — | — | — | 3440 | 31 | 27 | — | — | — |
| 66 | 1 | 3 | 13 | — | — | — | — | 1470 | 84 | 35 | — | — | — |
| 67 | 1 | — | 8 | — | — | — | — | 3723 | 10 | — | — | 217 | — |
| 68 | 1 | — | — | — | — | — | — | 4380 | 112 | — | — | 143 | — |
| 69 | 1 | — | 19 | — | — | — | — | 1598 | — | — | — | — | 104 |
| 70 | 1 | — | 54 | — | — | — | — | 635 | — | — | — | 129 | — |
| 71 | 1 | 2 | 13 | — | — | — | — | 349 | — | — | — | — | — |
| 72 | 1 | — | 9 | — | — | — | — | 5 | — | — | — | 20 | — |
| 73 | 1 | 2 | 43 | — | — | — | — | 2779 | 13 | — | — | 17 | — |
| 74 | 1 | — | 3 | — | — | — | — | 3982 | 65 | — | — | 170 | 131 |
| 75 | 1 | 2 | 2 | — | — | — | — | 7705 | — | — | — | 32 | — |

# TABLE 12. PROGRAM:ONE, VERSIONS:1-13, REPLICATIONS:76:100

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 76 | 1 | 5 | 8 | — | — | — | — | 3118 | — | — | — | 81 | — |
| 77 | 1 | — | 19 | — | — | — | — | 2111 | — | 15 | — | — | — |
| 78 | 1 | 3 | 31 | — | — | — | — | 1605 | — | — | — | 19 | — |
| 79 | 1 | — | 3 | — | — | — | — | 1072 | 48 | — | — | — | — |
| 80 | 2 | — | 7 | — | — | — | — | 2346 | 20 | — | — | 196 | — |
| 81 | 1 | 2 | 14 | — | — | — | — | 763 | — | — | — | — | — |
| 82 | 1 | — | — | 93 | 26 | — | — | 6205 | — | — | — | — | — |
| 83 | 1 | 3 | 6 | — | — | 12 | — | — | 20 | 14 | — | — | — |
| 84 | 1 | 3 | 27 | — | — | — | — | 5578 | 37 | — | — | 69 | — |
| 85 | 1 | 5 | 9 | — | — | — | — | 3962 | — | 8 | — | — | — |
| 86 | 1 | — | — | — | — | — | — | 3951 | — | 41 | — | — | — |
| 87 | 1 | — | 31 | — | — | — | — | 1206 | — | — | — | 42 | 12 |
| 88 | 1 | — | 34 | — | — | — | — | 4366 | 4 | 177 | — | — | — |
| 89 | 1 | — | 2 | — | — | — | — | 551 | — | — | — | 23 | 216 |
| 90 | 1 | — | — | — | — | — | — | 1113 | — | — | — | — | — |
| 91 | 1 | — | 3 | — | — | — | — | 360 | 20 | — | — | 65 | — |
| 92 | 1 | — | — | — | — | — | — | 3368 | 74 | — | — | — | 215 |
| 93 | 1 | — | 11 | — | 21 | — | — | 1104 | 6 | — | — | — | — |
| 94 | 1 | 4 | 15 | — | — | — | — | 164 | 99 | — | — | 22 | — |
| 95 | 1 | — | 14 | — | — | — | — | 3359 | 23 | — | — | 31 | 42 |
| 96 | 1 | — | 8 | — | — | — | — | 2450 | 21 | 19 | — | — | — |
| 97 | 1 | 3 | 7 | — | — | — | — | 1216 | 58 | — | — | 10 | — |
| 98 | 1 | — | — | — | — | 66 | — | 743 | 25 | — | — | — | — |
| 99 | 1 | 2 | 9 | — | — | — | — | 9594 | — | — | — | 6 | — |
| 100 | 1 | 2 | 4 | — | — | — | — | 861 | — | — | — | 74 | 162 |
| SUM | 103 | 113 | 1501 | 225 | 279 | 751 | 139 | 246420 | 1492 | 1124 | 308 | 2489 | 1283 |

ORIGINAL PAGE IS
OF POOR QUALITY

## TABLE 13. PROGRAM:ONE, VERSIONS:14-26, REPLICATIONS:1-25

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 1 | — | — | — | 9498 | — | — | — | — | — | — | — | — | — |
| 2 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 3 | 237 | — | — | 5531 | — | — | — | — | — | — | — | — | — |
| 4 | — | 44 | 14 | 1199 | — | — | — | — | — | — | — | — | — |
| 5 | — | — | — | 4912 | 506 | 66 | — | — | — | — | — | — | — |
| 6 | — | — | 69 | 7445 | 26 | — | — | — | — | — | — | — | — |
| 7 | — | — | 17 | 4260 | — | — | 2 | 18 | 87 | — | — | — | — |
| 8 | — | — | 902 | 3742 | — | — | — | 2 | — | — | — | — | — |
| 9 | — | — | 16 | 5547 | 64 | — | — | — | — | 28 | 6 | — | — |
| 10 | — | — | — | 191 | — | 38 | — | — | — | 28 | — | — | — |
| 11 | — | — | 370 | 6721 | — | — | — | 15 | — | — | — | — | — |
| 12 | — | — | 58 | 2463 | — | — | — | — | — | — | — | — | 11 |
| 13 | — | — | 183 | 9334 | 124 | — | — | 3 | — | — | 15 | — | — |
| 14 | — | 79 | 172 | 1459 | — | — | — | — | — | 22 | — | — | — |
| 15 | — | — | 181 | 9012 | — | — | — | — | — | 37 | 10 | — | 23 |
| 16 | — | — | 131 | 8982 | 38 | — | — | — | — | 11 | — | — | — |
| 17 | — | 256 | 126 | 8274 | — | — | — | — | — | — | — | — | — |
| 18 | — | — | — | 7956 | — | 76 | — | 32 | — | — | 39 | — | — |
| 19 | — | — | 599 | 5914 | 130 | — | — | 38 | — | — | — | — | — |
| 20 | — | — | — | — | 4 | 312 | — | — | — | — | — | — | — |
| 21 | — | — | 440 | 7478 | 63 | — | — | — | — | 15 | 43 | — | — |
| 22 | — | — | — | 8128 | 192 | 86 | — | — | — | — | — | — | — |
| 23 | — | — | 176 | 7132 | 195 | — | 2 | — | — | — | — | — | — |
| 24 | — | — | 667 | — | — | — | — | — | — | — | — | — | — |
| 25 | — | — | 46 | 2262 | 263 | — | — | 40 | — | — | — | — | — |

TABLE 14. PROGRAM:ONE, VERSIONS:14-26, REPLICATIONS:26-50
(Version 17 only failed on replications 4, 7, 14, 25, 33, 52, 53, and 89.)

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 26 | — | — | 1062 | 8245 | 48 | — | — | — | 557 | 9 | 23 | — | — |
| 27 | — | — | 87 | 9290 | 145 | — | — | 9 | — | — | 69 | — | — |
| 28 | — | — | — | 6728 | 76 | 18 | — | 54 | — | — | 2 | — | — |
| 29 | — | — | — | 5910 | 328 | 122 | 2 | — | — | 2 | 3 | — | — |
| 30 | — | — | 189 | 7510 | 118 | — | — | — | — | — | — | — | — |
| 31 | — | — | 84 | 9122 | 100 | — | — | — | 582 | 34 | 82 | — | — |
| 32 | — | 127 | 46 | 6957 | — | — | — | — | — | 7 | — | 33 | — |
| 33 | — | — | 76 | 6813 | 86 | — | — | — | 224 | — | — | — | — |
| 34 | — | — | 572 | 8111 | 28 | — | — | 38 | — | — | — | — | — |
| 35 | — | — | 133 | 7496 | — | — | — | 10 | — | — | — | — | — |
| 36 | — | — | 697 | 5960 | 19 | — | — | 30 | — | — | — | — | — |
| 37 | — | — | — | 9213 | 25 | 293 | — | — | — | 2 | — | — | — |
| 38 | 62 | 22 | — | 7729 | — | — | — | — | — | 4 | — | 17 | — |
| 39 | — | — | — | 6767 | — | 58 | — | — | — | 35 | — | — | — |
| 40 | — | 66 | — | 7930 | — | — | — | — | 1666 | — | — | — | — |
| 41 | — | — | 75 | 9301 | — | — | — | — | — | — | — | — | — |
| 42 | 176 | 62 | — | 8055 | — | — | — | — | — | — | — | — | — |
| 43 | — | — | 341 | 5865 | — | — | — | 2 | — | — | — | — | — |
| 44 | — | 9 | 114 | 9213 | — | — | — | — | — | — | — | — | — |
| 45 | — | 161 | 396 | 6007 | — | — | — | — | — | — | — | — | — |
| 46 | — | 11 | 152 | 5522 | — | — | — | — | — | — | — | 2 | — |
| 47 | — | — | — | 9704 | — | — | — | — | — | — | — | — | — |
| 48 | — | — | 278 | 7802 | 72 | — | — | — | — | — | — | — | — |
| 49 | — | 14 | 398 | 5502 | — | — | — | — | — | — | — | — | — |
| 50 | — | — | — | 9163 | 37 | 263 | — | — | — | 14 | — | — | — |

# TABLE 15. PROGRAM:ONE, VERSIONS:14-26, REPLICATIONS:51-75

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 51 | — | — | — | 7455 | — | 46 | — | — | — | — | — | — | — |
| 52 | — | — | — | 3221 | — | 116 | — | — | — | 14 | — | — | — |
| 53 | — | — | — | — | 580 | 291 | — | 45 | — | — | — | — | — |
| 54 | 92 | — | — | 7615 | — | — | — | — | — | — | — | — | — |
| 55 | 5 | 57 | — | 9679 | — | — | 2 | — | — | — | — | — | — |
| 56 | — | — | — | 7506 | 112 | 26 | — | — | — | 31 | — | — | — |
| 57 | — | 148 | — | 9521 | — | — | — | — | 97 | — | — | — | — |
| 58 | — | 150 | — | 6559 | — | — | — | — | — | — | — | — | — |
| 59 | — | — | — | 5855 | 111 | 25 | — | — | — | 6 | 27 | — | — |
| 60 | — | — | — | 8721 | — | — | — | — | — | — | — | 3 | — |
| 61 | — | — | 559 | 8197 | 37 | — | — | — | — | — | — | — | — |
| 62 | — | — | — | 9374 | 20 | 254 | — | — | — | 16 | 9 | — | — |
| 63 | — | — | 140 | 9531 | — | — | — | — | — | — | — | — | — |
| 64 | — | — | — | 675 | — | 268 | — | — | — | — | — | — | — |
| 65 | — | — | 510 | 5631 | 366 | — | — | — | — | — | — | — | — |
| 66 | — | — | 564 | 7816 | 23 | — | — | — | — | — | — | — | — |
| 67 | — | — | — | 5164 | 190 | 695 | — | — | — | — | — | — | — |
| 68 | — | — | — | 5228 | 14 | 125 | — | — | — | — | — | — | — |
| 69 | 39 | — | — | 8196 | — | — | — | — | — | — | — | — | — |
| 70 | — | — | — | 8815 | 77 | 282 | — | — | — | 15 | — | — | — |
| 71 | — | — | 84 | 9524 | — | — | — | — | — | 11 | — | — | 24 |
| 72 | — | — | — | 9890 | 43 | 23 | — | — | — | 17 | — | — | — |
| 73 | — | 124 | 221 | 6809 | — | — | — | — | — | — | — | — | — |
| 74 | — | — | — | 5592 | — | 64 | — | — | — | — | — | — | — |
| 75 | — | — | 182 | 2038 | 37 | — | — | — | — | 10 | — | — | — |

## TABLE 16. PROGRAM:ONE, VERSIONS:14-26, REPLICATIONS:76-100

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 76 | — | — | — | 6471 | 120 | 167 | — | — | — | 38 | — | — | — |
| 77 | — | — | 279 | — | 128 | — | — | 9 | — | — | — | — | — |
| 78 | — | 63 | 262 | 8023 | — | — | — | — | — | 2 | — | — | — |
| 79 | — | — | — | 8721 | ·161 | — | — | — | — | — | — | — | — |
| 80 | — | 46 | 224 | 7167 | — | — | — | — | — | — | — | — | — |
| 81 | — | — | 658 | 8132 | 390 | — | — | — | — | 33 | 16 | — | — |
| 82 | — | 37 | 231 | 3413 | — | — | — | — | — | — | — | — | — |
| 83 | — | — | 367 | 8459 | — | — | — | — | 1127 | — | — | — | — |
| 84 | — | — | — | 3586 | 203 | 505 | — | — | — | — | — | — | — |
| 85 | — | — | 216 | 5637 | 168 | — | — | 3 | — | — | — | — | — |
| 86 | — | — | — | 5957 | 30 | — | — | 25 | — | — | — | — | — |
| 87 | — | — | — | 8651 | — | 40 | — | — | — | 25 | — | — | — |
| 88 | — | — | 28 | 5320 | 78 | — | — | — | — | — | — | — | — |
| 89 | — | — | — | 4761 | — | 289 | — | — | — | 6 | — | — | — |
| 90 | — | — | — | 8711 | 77 | 71 | — | — | — | 26 | 8 | — | — |
| 91 | — | 136 | — | 9422 | — | — | — | — | — | — | — | — | — |
| 92 | — | — | — | 6181 | — | 123 | — | — | — | — | — | — | — |
| 93 | — | 424 | 209 | 8232 | — | — | — | — | — | — | — | — | — |
| 94 | — | 25 | 1011 | 8668 | — | — | — | — | — | — | — | — | — |
| 95 | — | — | — | 6513 | — | 24 | 2 | — | — | — | — | — | — |
| 96 | — | — | 266 | 7114 | 129 | — | — | — | — | — | — | — | — |
| 97 | — | — | 1305 | 7236 | 173 | — | — | — | — | — | — | — | — |
| 98 | — | — | 272 | 8898 | — | — | 2 | — | — | — | — | — | — |
| 99 | — | — | 114 | — | 260 | — | — | — | — | 22 | — | — | — |
| 100 | — | — | — | 8827 | — | 73 | — | — | — | 5 | — | — | — |
| SUM | 611 | 2061 | 16569 | 650067 | 6214 | 4859 | 12 | 373 | 4345 | 520 | 352 | 55 | 58 |

# TABLE 17. PROGRAM:ONE, VERSIONS:27-39, REPLICATIONS:1-25

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| 1 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 2 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 3 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 4 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 5 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 6 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 7 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 8 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 9 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 10 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 11 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 12 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 13 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 14 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 15 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 16 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 17 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 18 | 69 | — | — | — | — | — | — | — | — | — | — | — | — |
| 19 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 20 | — | 6320 | — | — | — | — | — | — | — | — | — | — | — |
| 21 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 22 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 23 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 24 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 25 | — | — | — | — | — | — | — | — | — | — | — | — | — |

TABLE 18. PROGRAM:ONE, VERSIONS:27-39, REPLICATIONS:25-50
(Version 33 failed on Replication 53 only.)

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| 26 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 27 | — | — | — | — | — | — | — | — | — | — | — | — | — |
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| 29 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 30 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 31 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 32 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 33 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 34 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 35 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 36 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 37 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 38 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 39 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 40 | — | — | 115 | — | — | — | — | — | — | — | — | — | — |
| 41 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 42 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 43 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 44 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 45 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 46 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 47 | — | — | — | 166 | 38 | — | — | — | — | — | — | — | — |
| 48 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 49 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 50 | — | — | — | — | — | — | — | — | — | — | — | — | — |

# TABLE 19. PROGRAM:ONE, VERSIONS:27-39, REPLICATIONS:51-75

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| 51 | — | — | — | — | — | 14 | — | — | — | — | — | — | — |
| 52 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 53 | — | — | — | — | — | — | 1266 | — | — | — | — | — | — |
| 54 | — | — | — | — | — | — | — | 9 | — | — | — | — | — |
| 55 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 56 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 57 | — | — | 133 | — | — | — | — | — | — | — | — | — | — |
| 58 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 59 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 60 | — | — | — | — | — | — | — | — | 13 | 57 | — | — | — |
| 61 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 62 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 63 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 64 | — | — | — | — | — | 7 | — | — | — | — | 18 | — | — |
| 65 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 66 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 67 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 68 | — | — | — | — | — | — | — | — | — | — | — | 5 | — |
| 69 | — | — | — | — | — | — | — | — | — | — | 2 | — | 49 |
| 70 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 71 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 72 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 73 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 74 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 75 | — | — | — | — | — | — | — | — | — | — | — | — | — |

## TABLE 20. PROGRAM:ONE, VERSIONS:27-39, REPLICATIONS:76-100

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| 76 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 77 | — | — | — | — | — | — | 7446 | — | — | — | — | — | — |
| 78 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 79 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 80 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 81 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 82 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 83 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 84 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 85 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 86 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 87 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 88 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 89 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 90 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 91 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 92 | — | — | — | — | — | 44 | — | — | — | — | — | 2 | — |
| 93 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 94 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 95 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 96 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 97 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 98 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 99 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 100 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| SUM | 69 | 6320 | 248 | 166 | 38 | 65 | 8712 | 9 | 13 | 57 | 20 | 7 | 49 |

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 21. PROGRAM:ONE, VERSIONS:40-45, REPLICATIONS:1-50
(Versions 42, 43, 44, and 45 never failed.)

| REP | VERSION OR DESIGN STATE NUMBER | | | | | |
|---|---|---|---|---|---|---|
| | 40 | 41 | 42 | 43 | 44 | 45 |
| 1 | — | — | — | — | — | — |
| 2 | — | — | — | — | — | — |
| 3 | — | — | — | — | — | — |
| 4 | — | — | 5645 | — | — | — |
| 5 | — | — | — | — | — | — |
| 6 | — | — | — | — | — | — |
| 7 | — | — | 5519 | — | — | — |
| 8 | — | — | — | — | — | — |
| 9 | — | — | — | — | — | — |
| 10 | — | — | — | — | — | — |
| 11 | — | — | — | — | — | — |
| 12 | — | — | — | — | — | — |
| 13 | — | — | — | — | — | — |
| 14 | — | — | 3731 | — | — | — |
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| 16 | — | — | — | — | — | — |
| 17 | — | — | — | — | — | — |
| 18 | — | — | — | — | — | — |
| 19 | — | — | — | — | — | — |
| 20 | — | — | — | — | — | 306 |
| 21 | — | — | — | — | — | — |
| 22 | — | — | — | — | — | — |
| 23 | — | — | — | — | — | — |
| 24 | — | — | — | — | — | — |
| 25 | — | — | — | 5930 | — | — |
| 26 | — | — | — | — | — | — |
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| 28 | — | — | — | — | — | — |
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| 50 | — | — | — | — | — | — |

TABLE 22. PROGRAM:ONE, VERSIONS:40-45, REPLICATIONS:51,100

| REP | VERSION OR DESIGN STATE NUMBER | | | | | |
|---|---|---|---|---|---|---|
| | 40 | 41 | 42 | 43 | 44 | 45 |
| 51 | — | — | — | — | — | — |
| 52 | — | — | 5386 | — | — | — |
| 53 | — | — | 7246 | — | — | — |
| 54 | — | — | 2077 | — | — | — |
| 55 | — | — | — | — | — | — |
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| 79 | — | — | — | — | — | — |
| 80 | — | — | — | — | — | — |
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| 82 | 2 | — | — | — | — | — |
| 83 | — | — | — | — | — | — |
| 84 | — | — | — | — | — | — |
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| 86 | — | 2 | — | — | — | — |
| 87 | — | — | — | — | — | — |
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| 89 | — | — | 4160 | — | — | — |
| 90 | — | — | — | — | — | — |
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| 92 | — | — | — | — | — | — |
| 93 | — | — | — | — | — | — |
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| 97 | — | — | — | — | — | — |
| 98 | — | — | — | — | — | — |
| 99 | — | — | — | — | — | — |
| 100 | — | — | — | — | — | — |
| SUM | 2 | 2 | 33764 | 5930 | 2738 | 306 |

ORIGINAL PAGE IS
OF POOR QUALITY

# TABLE 23. PROGRAM:THREE, VERSIONS:1-13, REPLICATIONS:1-25

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1 | 1 | 15 | 3 | 14 | 23 | 1455 | 1729 | — | — | — | — | — | — |
| 2 | 1 | 20 | — | — | — | 138 | 3447 | 3 | 77 | — | — | — | — |
| 3 | 1 | 8 | — | — | — | — | — | — | — | 61 | 1024 | 687 | — |
| 4 | 1 | 6 | — | 10 | 64 | 369 | 1826 | 12 | — | — | — | — | — |
| 5 | 1 | 2 | — | 7 | 82 | 701 | 9213 | — | — | — | — | — | — |
| 6 | 1 | 4 | — | — | — | 514 | 4187 | 93 | 28 | — | — | — | — |
| 7 | 1 | 49 | — | — | — | — | 1849 | — | — | — | — | — | 6 |
| 8 | 1 | 9 | — | — | 22 | 926 | — | 11 | — | — | — | — | — |
| 9 | 1 | — | — | — | 6 | 2241 | — | 32 | — | — | — | — | — |
| 10 | 1 | 17 | — | 5 | — | 714 | 1014 | — | — | — | — | — | — |
| 11 | 1 | — | — | 28 | — | 2643 | 3112 | — | 13 | — | — | — | — |
| 12 | 1 | 5 | — | — | — | — | — | — | — | 5 | 1237 | — | — |
| 13 | 1 | 17 | — | — | — | — | — | — | — | — | 82 | — | — |
| 14 | 1 | 27 | — | — | — | 89 | 1180 | — | — | — | — | — | — |
| 15 | 1 | 5 | — | — | — | — | — | — | — | 48 | 252 | — | — |
| 16 | 2 | 14 | 4 | — | — | 368 | 3670 | — | — | — | — | — | — |
| 17 | 3 | 11 | 12 | — | 18 | 1910 | — | — | — | — | — | — | — |
| 18 | 1 | 71 | — | — | — | 545 | 395 | — | 6 | — | — | — | — |
| 19 | 1 | 8 | — | — | — | — | 1254 | — | 141 | — | — | — | — |
| 20 | 1 | 3 | — | — | — | — | — | — | — | — | — | — | — |
| 21 | 2 | 5 | — | 18 | — | 2668 | 142 | — | 35 | — | — | — | — |
| 22 | 1 | 7 | — | — | — | — | — | — | — | 110 | 170 | — | — |
| 23 | 1 | 4 | — | — | — | — | — | — | — | 37 | 591 | — | — |
| 24 | 1 | 12 | — | — | — | 261 | 9519 | — | 201 | — | — | — | — |
| 25 | 1 | 16 | — | — | — | — | — | — | — | 54 | 1063 | — | — |

## TABLE 24. PROGRAM:THREE, VERSIONS:1-13, REPLICATIONS:26-50

(Version 7 did not fail on Replications 5, 24, 56, and 75.)

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 26 | 1 | 23 | — | — | — | — | — | — | — | 72 | 1063 | — | — |
| 27 | 2 | 33 | — | 17 | — | 36 | 939 | — | — | — | — | — | — |
| 28 | 1 | — | — | 25 | — | 819 | 336 | — | 43 | — | — | — | — |
| 29 | 1 | 26 | — | — | — | 337 | — | 5 | 25 | — | — | — | — |
| 30 | 1 | 17 | — | 3 | — | 171 | 2339 | — | 66 | — | — | — | — |
| 31 | 1 | 5 | — | — | — | — | — | — | — | 3 | 293 | 557 | — |
| 32 | 1 | 19 | — | 98 | — | 143 | 2366 | — | — | — | — | — | — |
| 33 | 1 | 24 | — | — | — | 30 | 3008 | 10 | 31 | — | — | — | — |
| 34 | 2 | 7 | — | — | — | — | 413 | — | 61 | — | — | — | — |
| 35 | 1 | 11 | — | — | — | — | — | — | — | 141 | — | 226 | — |
| 36 | 1 | 5 | — | — | — | — | — | — | — | 12 | 75 | 3 | — |
| 37 | 1 | 22 | — | 36 | — | 68 | 12 | — | — | — | — | — | — |
| 38 | 1 | 19 | — | — | — | — | — | 27 | 16 | — | — | — | — |
| 39 | 1 | — | — | 78 | 94 | 1022 | — | — | — | — | — | — | — |
| 40 | 1 | 10 | — | — | — | 645 | — | — | 212 | — | — | — | — |
| 41 | 1 | 47 | — | 37 | 14 | 128 | 758 | — | — | — | — | — | — |
| 42 | 1 | 17 | — | — | — | 286 | 1060 | 36 | 48 | — | — | — | — |
| 43 | 1 | 7 | — | 4 | 20 | 971 | 475 | — | — | — | — | — | — |
| 44 | 1 | 19 | — | — | — | — | — | — | — | 151 | 243 | — | — |
| 45 | 1 | 9 | — | 16 | — | — | — | — | — | — | — | — | — |
| 46 | 1 | 2 | — | 9 | — | 1090 | — | 25 | 35 | — | — | — | — |
| 47 | 1 | 6 | — | 52 | 47 | 89 | 2388 | — | — | — | — | — | — |
| 48 | 1 | 41 | — | 34 | 4 | 350 | 1820 | — | — | — | — | — | — |
| 49 | 1 | 9 | — | — | — | 606 | 3518 | — | 3 | — | — | — | — |
| 50 | 1 | 31 | 3 | — | — | 356 | 387 | — | — | — | — | — | — |

ORIGINAL PAGE IS
OF POOR QUALITY

# TABLE 25. PROGRAM:THREE, VERSIONS:1-13, REPLICATIONS:51-75

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 51 | 1 | 9 | 8 | — | — | 103 | 4536 | — | 49 | — | — | — | — |
| 52 | 3 | 15 | 4 | — | 32 | 343 | 2745 | 30 | — | — | — | — | — |
| 53 | 1 | 6 | — | — | — | 18 | — | — | — | — | — | — | — |
| 54 | 1 | 3 | — | — | — | — | — | — | — | 159 | 867 | — | — |
| 55 | 1 | 40 | — | — | — | — | — | — | — | 76 | 795 | 2608 | — |
| 56 | 1 | 3 | — | — | 42 | 403 | 9539 | 18 | — | — | — | — | — |
| 57 | 1 | — | — | 8 | — | 850 | 1128 | — | 58 | — | — | — | — |
| 58 | 1 | 15 | — | 48 | 59 | 438 | — | — | — | — | — | — | — |
| 59 | 1 | 16 | — | 20 | — | 194 | — | — | — | — | — | — | — |
| 60 | 1 | 4 | — | — | — | — | — | — | — | 56 | 407 | — | — |
| 61 | 1 | 29 | — | — | — | 188 | 2217 | 5 | 107 | — | — | — | — |
| 62 | 1 | 2 | — | — | — | — | — | — | — | 49 | 337 | — | — |
| 63 | 1 | 3 | — | 13 | — | 660 | — | — | 95 | — | — | — | — |
| 64 | 1 | 16 | — | — | 72 | 240 | — | 28 | — | — | — | — | — |
| 65 | 1 | 2 | 18 | — | 58 | 875 | 210 | — | — | — | — | — | — |
| 66 | 1 | 15 | — | 8 | — | 793 | — | — | — | — | — | — | — |
| 67 | 1 | 29 | — | — | — | — | — | — | — | 62 | 3177 | — | — |
| 68 | 2 | 11 | — | 3 | 7 | — | — | — | — | — | — | — | — |
| 69 | 2 | 17 | — | — | — | — | — | — | — | — | 2838 | — | — |
| 70 | 1 | 13 | — | — | — | — | — | — | — | 17 | 753 | — | — |
| 71 | 1 | 13 | — | 6 | 27 | 295 | 2388 | 4 | — | — | — | — | — |
| 72 | 1 | 6 | — | — | — | 448 | — | — | 14 | — | — | — | — |
| 73 | 2 | 28 | — | 32 | 10 | 822 | — | 42 | — | — | — | — | — |
| 74 | 4 | 39 | — | 82 | — | 114 | 8775 | — | — | — | — | — | — |
| 75 | 1 | — | — | — | — | 1166 | 8736 | — | 57 | — | — | — | — |

# TABLE 26. PROGRAM:THREE, VERSIONS:1-13, REPLICATIONS:76-100

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 76 | 2 | 21 | — | — | — | 3207 | — | — | 61 | — | — | — | — |
| 77 | 1 | 22 | — | — | — | — | — | — | — | — | 610 | — | — |
| 78 | 1 | — | — | 42 | 12 | 1468 | 345 | — | — | — | — | — | — |
| 79 | 2 | 2 | — | — | — | 633 | — | — | 134 | — | — | — | — |
| 80 | 1 | — | — | 10 | — | 1081 | — | — | — | — | — | — | — |
| 81 | 1 | 8 | — | 46 | — | 318 | 5643 | — | — | — | — | — | — |
| 82 | 1 | — | — | 7 | — | 153 | 613 | — | 270 | — | — | — | — |
| 83 | 2 | 28 | — | — | — | 1738 | 2125 | — | 37 | — | — | — | — |
| 84 | 3 | 18 | — | 2 | — | 150 | 2398 | — | 18 | — | — | — | — |
| 85 | 1 | 8 | — | 5 | — | 141 | 240 | — | — | — | — | — | — |
| 86 | 2 | 5 | — | — | — | 420 | — | — | 79 | — | — | — | — |
| 87 | 1 | 34 | — | 4 | — | 1256 | — | — | — | — | — | — | — |
| 88 | 1 | 8 | — | — | — | — | 215 | — | 15 | — | — | — | — |
| 89 | 1 | 5 | — | 4 | 26 | 256 | 2241 | 14 | — | — | — | — | — |
| 90 | 1 | 4 | — | — | — | 68 | 4791 | — | — | — | — | — | — |
| 91 | 1 | 6 | — | — | — | — | — | — | — | 54 | 1229 | — | — |
| 92 | 1 | — | — | — | — | 1516 | — | — | 19 | — | — | — | — |
| 93 | 3 | 6 | — | — | 39 | 2060 | — | 16 | — | — | — | — | — |
| 94 | 1 | 17 | — | — | — | — | — | — | — | — | 79 | — | — |
| 95 | 2 | 17 | — | — | 6 | 985 | — | 5 | — | — | — | — | — |
| 96 | 1 | 8 | 6 | — | — | — | 349 | — | — | — | — | — | — |
| 97 | 1 | 38 | — | 88 | — | 384 | 4662 | — | — | — | — | — | — |
| 98 | 1 | 2 | — | — | — | 305 | 1413 | — | 26 | — | — | — | — |
| 99 | 1 | — | — | — | — | 559 | 850 | — | — | — | — | — | — |
| 100 | 1 | 24 | — | 10 | — | 493 | 4663 | 68 | 130 | — | — | — | — |
| SUM | 123 | 1359 | 58 | 929 | 784 | 47830 | 133176 | 484 | 2210 | 1167 | 17185 | 4081 | 6 |

ORIGINAL PAGE IS
OF POOR QUALITY

## TABLE 27. PROGRAM:THREE, VERSIONS:14-26, REPLICATIONS:1-25

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
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| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 1 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 2 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 3 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 4 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 5 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 6 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 7 | 70 | 102 | — | — | — | — | — | — | — | — | — | — | — |
| 8 | — | — | 3557 | — | — | — | — | — | — | — | — | — | — |
| 9 | — | — | 681 | — | — | — | — | — | — | — | — | — | — |
| 10 | — | — | — | 43 | — | — | — | — | — | — | — | — | — |
| 11 | — | — | — | 20 | 2 | 4 | — | — | — | — | — | — | — |
| 12 | — | — | — | — | — | — | 951 | — | — | — | — | — | — |
| 13 | — | — | — | — | — | — | 3082 | 29 | — | — | — | — | — |
| 14 | — | — | — | 6 | — | 2 | — | — | 43 | — | — | — | — |
| 15 | — | — | — | — | — | — | 4468 | — | — | — | — | — | — |
| 16 | — | — | — | — | — | — | — | — | — | 28 | — | — | — |
| 17 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 18 | — | — | — | — | — | — | — | 14 | — | — | — | — | — |
| 19 | — | 239 | — | 168 | — | — | — | 29 | — | 7 | — | — | — |
| 20 | — | — | 1181 | — | — | — | — | — | — | — | 6 | 2 | 11 |
| 21 | — | — | — | 23 | — | — | — | — | — | — | — | — | — |
| 22 | — | — | — | — | — | — | 344 | — | — | — | — | — | — |
| 23 | — | — | — | — | — | — | 969 | — | — | — | — | — | — |
| 24 | — | — | — | — | — | — | — | 4 | — | 9 | — | — | — |
| 25 | — | — | — | — | — | — | 1843 | — | — | — | — | — | — |

## TABLE 28. PROGRAM:THREE, VERSIONS:14-26, REPLICATIONS:26-50

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
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| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 26 | — | — | — | — | — | — | 7003 | — | — | — | — | — | — |
| 27 | — | — | — | 40 | — | — | — | — | — | — | — | — | — |
| 28 | — | — | — | 7 | — | — | — | — | — | — | — | — | — |
| 29 | — | — | 363 | — | — | 13 | — | — | — | — | — | — | — |
| 30 | — | — | — | 168 | — | — | — | — | — | — | — | — | — |
| 31 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 32 | — | — | — | 27 | — | — | — | — | — | — | — | — | — |
| 33 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 34 | — | 63 | — | — | — | — | — | 17 | — | — | — | — | — |
| 35 | — | — | — | — | — | 7 | — | — | — | — | — | — | — |
| 36 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 37 | — | — | — | 76 | — | — | — | — | — | — | — | — | — |
| 38 | — | — | 3676 | — | — | — | — | — | — | — | — | — | — |
| 39 | — | — | 969 | — | — | 15 | — | — | — | — | — | — | — |
| 40 | — | — | 2161 | — | — | — | — | 12 | 64 | — | — | — | — |
| 41 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 42 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 43 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 44 | — | — | — | — | — | — | 2008 | — | — | — | — | — | — |
| 45 | — | — | 4234 | — | — | — | — | — | — | — | — | 16 | — |
| 46 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 47 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 48 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 49 | — | — | — | — | — | — | — | 5 | — | — | — | — | — |
| 50 | — | — | — | — | — | — | — | — | — | 66 | — | — | — |

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 29. PROGRAM:THREE, VERSIONS:14-26,
REPLICATIONS:51-75

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 51 | — | — | — | 28 | — | — | — | — | — | 12 | — | — | — |
| 52 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 53 | — | — | — | 104 | — | — | — | 2 | 11 | — | — | — | — |
| 54 | — | — | — | — | — | — | 566 | — | — | — | — | — | — |
| 55 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 56 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 57 | — | — | — | 98 | — | — | — | — | — | — | — | — | — |
| 58 | — | — | 419 | — | — | — | — | — | — | — | — | — | — |
| 59 | — | — | 73 | 119 | — | — | — | — | — | — | — | — | — |
| 60 | — | — | — | — | — | — | 5932 | — | — | — | — | — | — |
| 61 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 62 | — | — | — | — | — | — | 685 | — | — | — | — | — | — |
| 63 | — | — | 976 | 11 | — | — | — | — | — | — | — | — | — |
| 64 | — | — | 580 | — | — | — | — | — | — | — | — | — | — |
| 65 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 66 | — | — | 633 | 16 | — | 9 | — | — | — | — | — | — | — |
| 67 | — | — | — | — | — | — | 1649 | — | — | — | — | — | — |
| 68 | — | — | 88 | — | — | — | — | — | — | — | — | — | — |
| 69 | — | — | — | — | — | — | 2098 | — | 2 | — | — | — | — |
| 70 | — | — | — | — | — | — | 4020 | — | — | — | — | — | — |
| 71 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 72 | — | — | 322 | — | — | — | — | 6 | — | — | — | — | — |
| 73 | — | — | 1761 | — | — | — | — | — | — | — | — | — | — |
| 74 | — | — | — | 51 | — | — | — | — | — | — | — | — | — |
| 75 | — | — | — | 35 | — | — | — | 11 | — | — | — | — | — |

# TABLE 30. PROGRAM:THREE, VERSIONS:14-26, REPLICATIONS:76-100

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 76 | — | — | — | — | — | — | — | 65 | — | — | — | — | — |
| 77 | — | — | — | — | — | — | 296 | 48 | — | — | — | — | — |
| 78 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 79 | — | — | — | 5 | — | — | — | — | 10 | — | — | — | — |
| 80 | — | — | 2115 | 97 | — | — | — | — | — | — | — | — | — |
| 81 | — | — | — | 4 | — | — | — | — | — | — | — | — | — |
| 82 | — | — | — | 37 | — | — | — | — | — | — | — | — | — |
| 83 | — | — | — | — | — | — | — | 7 | — | — | — | — | — |
| 84 | — | — | — | 13 | — | — | — | — | — | — | — | — | — |
| 85 | — | — | — | 38 | — | — | — | — | — | — | — | — | — |
| 86 | — | — | 808 | — | — | — | — | 21 | — | 70 | — | — | — |
| 87 | — | — | 2473 | 60 | — | — | — | — | — | — | — | — | — |
| 88 | — | 54 | — | — | — | — | — | 2 | — | — | — | — | — |
| 89 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 90 | — | — | — | 80 | — | — | — | 23 | 5 | — | — | — | — |
| 91 | — | — | — | — | — | — | 134 | — | — | — | — | — | — |
| 92 | — | — | 870 | 35 | 2 | 22 | — | — | — | — | — | — | — |
| 93 | — | — | 196 | — | — | — | — | — | — | — | — | — | — |
| 94 | — | — | — | — | — | — | 6419 | 38 | — | — | — | — | — |
| 95 | — | — | 366 | — | — | — | — | — | — | — | — | — | — |
| 96 | — | — | — | 7 | — | — | — | — | — | — | — | — | — |
| 97 | — | — | — | 50 | — | 25 | — | — | — | — | — | — | — |
| 98 | — | — | — | 17 | — | — | — | 9 | — | — | — | — | — |
| 99 | — | — | — | 23 | — | — | — | 11 | — | 16 | — | — | — |
| 100 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| SUM | 70 | 458 | 28502 | 1506 | 4 | 97 | 42467 | 353 | 135 | 208 | 6 | 18 | 11 |

TABLE 31. PROGRAM:THREE, VERSIONS:27-36,
REPLICATIONS:1-50
(Version 27 failed on Replications 20, 33, 71, and 84 only,
Version 28 failed on Replication 25 only, and
Versions 35 and 36 did not fail.)

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| 1 | 6768 | — | — | — | — | — | — | — | — | — |
| 2 | 6321 | — | — | — | — | — | — | — | — | — |
| 3 | — | 8225 | — | — | — | — | — | — | — | — |
| 4 | 7720 | — | — | — | — | — | — | — | — | — |
| 5 | — | — | — | — | — | — | — | — | — | — |
| 6 | 5180 | — | — | — | — | — | — | — | — | — |
| 7 | 7930 | — | — | — | — | — | — | — | — | — |
| 8 | 5481 | — | — | — | — | — | — | — | — | — |
| 9 | 7045 | — | — | — | — | — | — | — | — | — |
| 10 | 8213 | — | — | — | — | — | — | — | — | — |
| 11 | 4186 | — | — | — | — | — | — | — | — | — |
| 12 | — | 7807 | — | — | — | — | — | — | — | — |
| 13 | — | 6795 | — | — | — | — | — | — | — | — |
| 14 | 8660 | — | — | — | — | — | — | — | — | — |
| 15 | — | 5232 | — | — | — | — | — | — | — | — |
| 16 | 5921 | — | — | — | — | — | — | — | — | — |
| 17 | 8052 | — | — | — | — | — | — | — | — | — |
| 18 | 8975 | — | — | — | — | — | — | — | — | — |
| 19 | 8162 | — | — | — | — | — | — | — | — | — |
| 20 | 2179 | — | — | — | — | — | — | — | — | 6625 |
| 21 | 7115 | — | — | — | — | — | — | — | — | — |
| 22 | — | 9374 | — | — | — | — | — | — | — | — |
| 23 | — | 8404 | — | — | — | — | — | — | — | — |
| 24 | — | — | — | — | — | — | — | — | — | — |
| 25 | — | 1100 | — | — | — | — | — | — | 5930 | — |
| 26 | — | 1844 | — | — | — | — | — | — | — | — |
| 27 | 8940 | — | — | — | — | — | — | — | — | — |
| 28 | 8776 | — | — | — | — | — | — | — | — | — |
| 29 | 9238 | — | — | — | — | — | — | — | — | — |
| 30 | 7243 | — | — | — | — | — | — | — | — | — |
| 31 | — | 9147 | — | — | — | — | — | — | — | — |
| 32 | 7353 | — | — | — | — | — | — | — | — | — |
| 33 | 4166 | — | — | — | — | — | — | — | — | 2738 |
| 34 | 9444 | — | — | — | — | — | — | — | — | — |
| 35 | — | 9567 | 54 | — | — | — | — | — | — | — |
| 36 | — | 9910 | — | — | — | — | — | — | — | — |
| 37 | 9792 | — | — | — | — | — | — | — | — | — |
| 38 | 6168 | — | — | 100 | — | — | — | — | — | — |
| 39 | 7828 | — | — | — | — | — | — | — | — | — |
| 40 | 6903 | — | — | — | — | — | — | — | — | — |
| 41 | 9022 | — | — | — | — | — | — | — | — | — |
| 42 | 8559 | — | — | — | — | — | — | — | — | — |
| 43 | 8529 | — | — | — | — | — | — | — | — | — |
| 44 | — | 7584 | — | — | — | — | — | — | — | — |
| 45 | 5705 | — | — | — | 4 | 23 | — | — | — | — |
| 46 | 8845 | — | — | — | — | — | — | — | — | — |
| 47 | 7424 | — | — | — | — | — | — | — | — | — |
| 48 | 7757 | — | — | — | — | — | — | — | — | — |
| 49 | 5865 | — | — | — | — | — | — | — | — | — |
| 50 | 9163 | — | — | — | — | — | — | — | — | — |

TABLE 32. PROGRAM:THREE, VERSIONS:27-36, REPLICATIONS:51-100

| REP | VERSION OR DESIGN STATE NUMBER | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| 51 | 5263 | — | — | — | — | — | — | — | — | — |
| 52 | 6836 | — | — | — | — | — | — | — | — | — |
| 53 | 9865 | — | — | — | — | — | — | — | — | — |
| 54 | — | 8410 | — | — | — | — | — | — | — | — |
| 55 | — | 6486 | — | — | — | — | — | — | — | — |
| 56 | — | — | — | — | — | — | — | — | — | — |
| 57 | 7863 | — | — | — | — | — | 2 | — | — | — |
| 58 | 9027 | — | — | — | — | — | — | — | — | — |
| 59 | 9584 | — | — | — | — | — | — | — | — | — |
| 60 | — | 3606 | — | — | — | — | — | — | — | — |
| 61 | 7460 | — | — | — | — | — | — | — | — | — |
| 62 | — | 8932 | — | — | — | — | — | — | — | — |
| 63 | 8249 | — | — | — | — | — | — | — | — | — |
| 64 | 9070 | — | — | — | — | — | — | — | — | — |
| 65 | 8843 | — | — | — | — | — | — | — | — | — |
| 66 | 8533 | — | — | — | — | — | — | — | — | — |
| 67 | — | 5088 | — | — | — | — | — | — | — | — |
| 68 | 9816 | — | — | — | — | 80 | — | — | — | — |
| 69 | — | 5049 | — | — | — | — | — | — | — | — |
| 70 | — | 5202 | — | — | — | — | — | — | — | — |
| 71 | 3604 | — | — | — | — | — | — | — | — | 3671 |
| 72 | 9210 | — | — | — | — | — | — | — | — | — |
| 73 | 7311 | — | — | — | — | — | — | — | — | — |
| 74 | 942 | — | — | — | — | — | — | — | — | — |
| 75 | — | — | — | — | — | — | — | — | — | — |
| 76 | 6650 | — | — | — | — | — | — | — | — | — |
| 77 | — | 9029 | — | — | — | — | — | — | — | — |
| 78 | 8138 | — | — | — | — | — | — | — | — | — |
| 79 | 9221 | — | — | — | — | — | — | — | — | — |
| 80 | 6702 | — | — | — | — | — | — | — | — | — |
| 81 | 3987 | — | — | — | — | — | — | — | — | — |
| 82 | 8926 | — | — | — | — | — | — | — | — | — |
| 83 | 6070 | — | — | — | — | — | — | — | — | — |
| 84 | 4432 | — | — | — | — | — | — | — | — | 2975 |
| 85 | 9574 | — | — | — | — | — | — | — | — | — |
| 86 | 8603 | — | — | — | — | — | — | — | — | — |
| 87 | 6179 | — | — | — | — | — | — | — | — | — |
| 88 | 9712 | — | — | — | — | — | — | — | — | — |
| 89 | 7461 | — | — | — | — | — | — | — | — | — |
| 90 | 5036 | — | — | — | — | — | — | — | — | — |
| 91 | — | 8582 | — | — | — | — | — | — | — | — |
| 92 | 7543 | — | — | — | — | — | — | — | — | — |
| 93 | 7687 | — | — | — | — | — | — | — | — | — |
| 94 | — | 3452 | — | — | — | — | — | — | — | — |
| 95 | 8626 | — | — | — | — | — | — | — | — | — |
| 96 | 9539 | — | — | — | — | — | — | 97 | — | — |
| 97 | 4760 | — | — | — | — | — | — | — | — | — |
| 98 | 8235 | — | — | — | — | — | — | — | — | — |
| 99 | 8547 | — | — | — | — | — | — | — | — | — |
| 100 | 4619 | — | — | — | — | — | — | — | — | — |
| SUM | 546351 | 148825 | 54 | 100 | 4 | 103 | 2 | 97 | 5930 | 16009 |

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15. Supplementary Notes

Langley Technical Monitor: E. Migneault
Langley Contract Monitor: A.O. Lupton

16. Abstract

This report summarizes results of a study undertaken to collect software error data of laboratory quality for use in the development of credible methods for predicting the reliability of software used in life-critical applications. The software error data reported herein were acquired through automated repetitive run testing of three independent implementations of a launch interceptor condition module of a radar tracking problem. The results are based on 100 test replications so that a sufficient sample size for error rate estimation is accumulated. Results based on fewer replications were reported in Dunham and Pierce, NASA CR- 172533, *An Experiment in Software Reliability*, March 1985.

The data collected is used to confirm the results of two Boeing studies by Nagel et al. reported in NASA CR-165836 *Software Reliability: Repetitive Run Experimentation and Modeling*, and NASA CR-172378 *Software Reliability: Additional Investigations into Modeling With Replicated Experiments*, respectively. That is, the results confirm the log-linear pattern of software error rates and reject the hypothesis of equal error rates per individual fault. This rejection casts doubt on the assumption that the program's failure rate is a constant multiple of the number of residual bugs; an assumption which underlies some of the current models of software reliability. Additional analysis of the experiment data raises new questions concerning the phenomenon of interacting faults.

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