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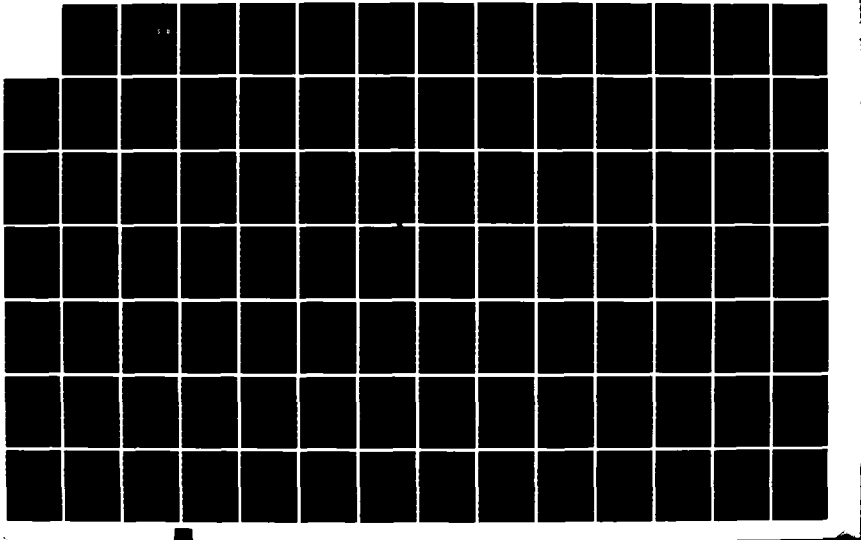

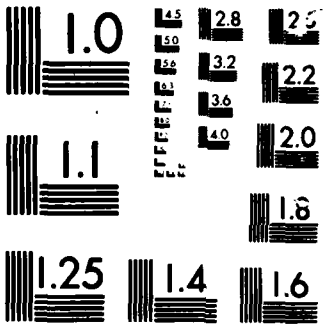

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AN ANALYTICAL METHODOLOGY FOR PREDICTING REPAIR TIME DISTRIBUTIONS OF ADVANCED TECHNOLOGY AIRCRAFT

THESIS

Dennis C. Dietz
Captain, USAF

AFIT/GOR/OS/85D-3

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AN ANALYTICAL METHODOLOGY FOR PREDICTING REPAIR TIME DISTRIBUTIONS OF ADVANCED TECHNOLOGY AIRCRAFT

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Operations Research

Dennis C. Dietz, B.S.
Captain, USAF

December 1985

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The applicability of the analytical method is examined by comparing analytical repair time distributions with distributions produced by Monte Carlo simulation. Using the Advanced Tactical Fighter as an example, comparisons are performed over a wide range of relevant factors. Overall aircraft reliability emerges as the single critical factor determining the applicability of the method.

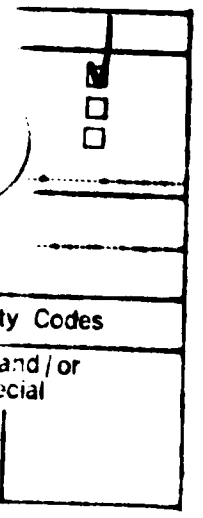
A simple model is presented for translating the aircraft repair time distribution into measures of aircraft operational effectiveness (availability and sortie generation rate) under a specified concept of operations. The translation model demonstrates how the analytical method for forming a repair time distribution could be used to heuristically determine how to best allocate a reliability and maintainability "budget" to various subsystems as an aircraft design is developed.

Preface

The operational effectiveness of a military aircraft is partly determined by the amount of time needed to repair the aircraft when it fails. This project developes an analytical method for forming a probability distribution of repair time for an advanced technology aircraft. The repair time distribution is then translated to measures of aircraft operational effectiveness. The project methodology provides a simple alternative to the complex simulation models currently in use, and is particularly applicable to aircraft in the early stages of development, such as the Advanced Tactical Fighter.

This effort could not have been completed without the assistance of others. I am particularly indebted to Maj George Orr, formerly of the ATF System Program Office, for kindling my interest providing valuable insight. I also wish to thank Dr. Albert Moore and Lt Col Charles Ebeling for their assistance with specific aspects of the project. My faculty advisor, Maj William Rowell, provided the perfect mix of critical review and positive reinforcement. Finally, I wish to sincerely thank my wife, Lynda, and my three daughters, Chelsea, Tiesha, and Brittney, for their unwavering patience and support throughout the ordeal.

Dennis C. Dietz



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List of Symbols

E(*) = Expected Value of random variable *

F(*) = Cumulative Distribution Function (CDF) of a random variable with respect to the independent variable *

f(*) = Probability density function (pdf) of a random variable with respect to the independent variable *

G = Proportion of aircraft repaired within a specified time period

g = Sample proportion of aircraft repaired within a specfied time period

H = Proportion of aircraft *not* repaired within a specified time period (1-G)

h = Sample proportion of aircraft *not* repaired within a specified time period (1-g)

K = Analytical CDF correction factor

L = Lognormally distributed random variate

M = Maximum difference between analytical and simulation CDFs (Kolomgornov-Smirnov statistic)

m = Mean number of sorties between failures (MSBF)

N = Total number of aircraft subsystems

n = Simulation sample size

P(*) = Probability of occurrence of event *

p = Probability of subsystem failure

q = Probability a particular maintenance action is required given subsystem failure

R = Random number distributed uniformly on the interval (0,1)

R^2 = Coefficient of determination

r = Sortie reliability

S = Exponentially distributed random variate

s = Number of sorties to failure

T = Repair time

t = Time

$u(\theta)$ = Probabilty density of a joint probability density parameter θ

V = Uniformly distributed random variate on the interval $(-1,1)$

X = Standard normal random variate

Y = Normally distributed random variate

z_α = Percentage point of the standard normal distribution for cumulative probability $1-\alpha$

α = Probability of Type I statistical error or probability that a confidence interval around a parameter estimator does not contain the parameter

γ^2 = Repair time variance

δ = Coefficient of variation (standard deviation/mean)

θ = Joint probability density parameter

λ = Parameter of an exponential distribution

μ = First parameter of a normal/lognormal distribution

σ^2 = Second parameter of a normal/lognormal distribution

τ = Mean repair time

χ^2 = Chi-squared random variable

$\Phi(\$)$ = CDF for a standard normal random variable with respect to the independent variable $

Experimental Design Factor Symbols

A = Overall aircraft reliability
B = Variation of subsystem reliabilities
C = Subsystem repair time variances
D = Subsystem mean repair times

Abstract

Classical probability theory is applied to analytically combine known or hypothesized subsystem reliability and maintainability characteristics into an aggregate probability distribution for repair time of an advanced technology aircraft. While repair time of a weapon system is determined by a complex interaction of many factors, the relatively high reliability predicted for advanced technology aircraft justifies several simplifying assumptions which permit an analytical approach.

The applicability of the analytical method is examined by comparing analytical repair time distributions with distributions produced by Monte Carlo simulation. Using the Advanced Tactical Fighter as an example, comparisons are performed over a wide range of relevant factors. Overall aircraft reliability emerges as the single critical factor determining the applicability of the method.

A simple model is presented for translating the aircraft repair time distribution into measures of aircraft operational effectiveness (availability and sortie generation rate) under a specified concept of operations. The translation model demonstrates how the analytical method for forming a repair time distribution could be used to heuristically determine how to best allocate a reliability and maintainability "budget" to various subsystems as an aircraft design is developed.

AN ANALYTICAL METHODOLOGY FOR PREDICTING REPAIR TIME DISTRIBUTIONS OF ADVANCED TECHNOLOGY AIRCRAFT

I. Introduction

Backround

Motivation. The Air Force is dramatically increasing its emphasis on the reliabiliity and maintainability of new weapon systems. In a September 1984 joint memo to commanders, Secretary of the Air Force Verne Orr and Air Force Chief of Staff General Charles A. Gabriel mandated:

> For too long, the reliability and maintainability of our weapon systems have been secondary considerations in the acquisition process. It is time to change this practice and make reliability and maintainability primary considerations (12:1).

This statement is evidence of high-level recognition that the reliability and maintainability (R&M) of weapon systems are crucial factors in determining their operational effectiveness. On 14 February 1985, Secretary Orr announced a program aimed at accelerating the improvement of R&M in Air Force weapon systems entitled "R&M 2000." The program "calls for managers of new system procurements ... to consider R&M equally with cost, schedule and performance factors." (48:1) The need for this elevation in the priority of R&M is explained by General Robert D. Russ, former Air Force deputy chief of staff for Research, Development, and Acquisition and now commander of the Tactical Air Command (TAC):

> We need R&M by design, not chance. If the engineers don't design it in during development, where it's most efficient, they have to redesign it in production, or add it as a modification. That can be disruptive and very expensive. (31:10)

Reliability and maintainability factors must thus be considered from the very earliest stages of weapon system development. Brigadier General Frank S. Goodell, Air Staff Special Assistant for R&M, has expressed the view that the vast majority of R&M design should be accomplished prior to full scale development of a system (33).

One major weapon system currently in the early stages of development is the Advanced Tactical Fighter (ATF). While the ATF concept must yet undergo about three years of demonstration and validation before its requirements and technologies are firmly fixed, some R&M goals have already been set as part of the ATF concept definition. For example, the ATF sustained sortie rate must be at least twice that of the F-15 (55:2). Major General John M. Loh, TAC Deputy Chief of Staff for Requirements, has acknowleged the need to "give up some performance, to a point, in order to achieve reliability and maintainability of the ATF." (7:58) Reliability and maintainability will thus truly be primary design considerations for this aircraft.

Definitions. The Department of Defense defines *reliability* as the probability that an item can perform its intended function for a specified interval under stated conditions." (14:8) *Maintainability* is expressed as "the

probability that an item will be retained in, or restored, to a specified condition within a given period if prescribed procedures and resources are used." (9:Sec III,1) Together, the reliability and maintainability features of a system combine to determine the system's *operational readiness*, often measured by *availability*. Availability is simply "a measure of the degree to which an item is in an operable and commitable state at the start of a mission when the mission is called for at a random point in time." (9:Sec IV,1) For an aircraft, another important measure of operational capability is the "sortie generation rate," which is simply the number of sorties per aircraft launched by a operational unit within a specified time period under specified conditions. A major goal of ATF design engineers will be to allocate the ATF reliability and maintainability "budget" to various subsystems in such a way as to maximize the operational effectiveness of the ATF as measured by availability and the sortie generation rate (50).

Problem. An important step in evaluating the potential availability and sortie generation capability of an aircraft is determination of the effect of subsystem characteristics on the amount of time needed to restore the aircraft to an operable condition when it fails (16:1). This repair time can be expressed as a continuous probability distribution, such as that shown in Figure 1.1. The repair time distribution can be used to specify the probability that a

failed aircraft's repair time will fall within any particular interval of possible repair times. In Figure 1.1, the darkened area under the curve represents the cumulative probability that a failed aircraft will be repaired in two hours or less.

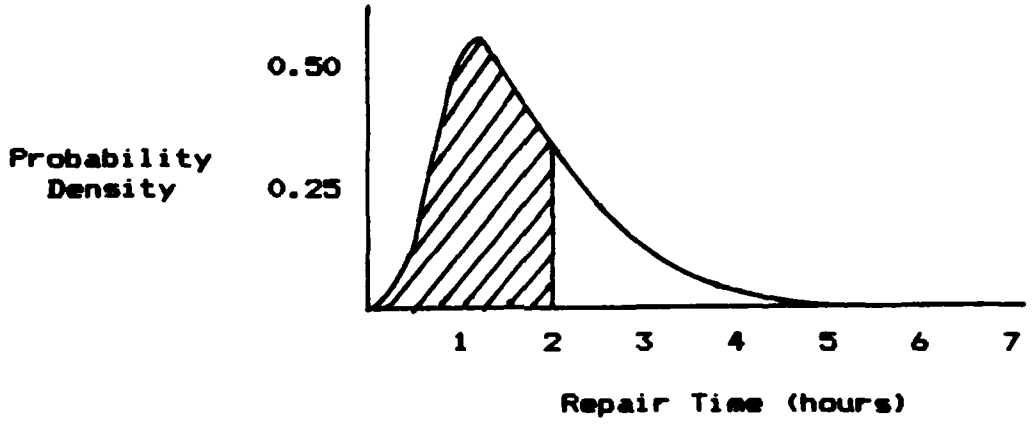

Figure 1.1. *Typical Probability Distribution for Repair Time of an Aircraft*

The shape and parameters (mean repair time, variance, etc.) of the repair time distribution can be determined by aggregating reliability and repair time estimates of major subsystems that together comprise the entire weapon system. A typical military aircraft consists of twenty to thirty major subsystems such as airframe, engines, fuel, and hydraulics. For current aircraft, the process of aggregating subsystem characteristics to form a repair time distribution for the entire system is quite complex because of the possibility that more than one subsystem may fail before repair efforts are begun on the aircraft (51:111).

If repairs on each failed subsystem are conducted simultaneously, the aircraft repair time will reflect the longest time required to repair a single subsystem rather than the sum of the subsystem repair times. The need to model this effect makes the prediction of overall aircraft repair time a mathematically intractable problem that currently requires the use of simulation modeling. Unfortunately, simulation generally requires a large number of computer runs, provides no guaranteed level of accuracy, and does not provide full analytical insight into the effects of the input variables (61:13). For these reasons, many analysts argue that "before simulation is chosen as the solution method, every effort should be made to solve the problem mathematically." (2:19)

The predicted high reliability of advanced technology aircraft introduces the possibility that a modeling method other than simulation can be developed to determine aggregate repair time distributions. Unlike current aircraft, advanced technology aircraft are predicted to be so reliable that the probability of two or more subsystems failing before one can be repaired may be negligible. This high reliability eliminates the need to model simultaneous subsystem repairs, making the repair time distribution problem much more mathematically tractable. Through the use of an appropriate analytical methodology, the effect of subsystem proposals on the repair time distribution could be

quickly and accurately measured and evaluated as the aircraft design is developed.

Objective

The primary objective of this project is to develop an analytical methodology for aggregating subsystem reliability and maintainability estimates to form a repair time distribution for the Advanced Tactical Fighter and other highly reliable advanced technology aircraft. The project also determines the level of overall aircraft reliability necessary for the methodology to be applicable. Finally, the project demonstrates how the methodology can contribute to reliability and maintainability allocation decisions. These objectives are accomplished through the following steps:

1) Development of an analytical method for aggregating subsystem repair time distributions based on the assumption that only one subsystem will fail before repair is initiated.

2) Development of a simulation model that forms an aggregate repair time distribution with multiple subsystem failures and repairs permitted.

3) Comparison of the analytical and simulation models for computational efficiency and disparity of results when estimates of ATF subsystem characteristics are used as input data.

4) Determination of the level of subsystem

reliabilities required in order for the analytical model to produce results similar to those produced by the simulation model. This step determines the reliability levels under which the analytical model can reasonably be applied. The effects of other factors, such as the subsystem maintainability characteristics, are also examined. Since many different subsystems could have widely varying reliability and maintainability characteristics, a thorough understanding of the relationship between the results of the two models over a wide range of subsystem characteristics is essential.

5) Demonstration of how the aggregate repair time distribution can contribute to determination of the predicted operational effectiveness of an aircraft as measured by characteristics such as availability and sortie generation capability. A by-product of this step is an indication of how differences in system repair time distributions relate to differences in measures of operational effectiveness.

Scope and Assumptions

The project deals with the effect of major subsystems on the repair time distribution for an entire aircraft. Failure of any subsystem is assumed to have no effect on the probability of failure of any other subsystem. This is an appropriate approach for a system in the earlier stages of

development, when many design details are unknown. Only unscheduled maintenance is addressed and is assumed to be independent of scheduled maintenance. Also, repair time for any form of battle damage repair is not addressed. While ease of anticipated battle damage repair is a possible design consideration, it is dominated by the need to design the aircraft for overall survivability. This project therefore separates battle damage repair concerns from reliability and maintainability allocation decisions.

Subsystem Characteristics. No actual ATF hardware yet exists, so subsystem characteristics must be hypothesized. Table 1.1 displays reliability and maintainability estimates that have been provided by the ATF System Program Office for each of the twenty-four major ATF subsystems. The subsystem work-unit-codes (WUC) in Table 1.1 correspond to the following subsystem descriptors:

11)	Airframe	49)	Miscellaneous Utilities
12)	Crew Station	51)	Flight Instruments
13)	Landing Gear	55)	Malf. Analysis Recorder
14)	Flight Controls	62)	VHF Communications
23)	Engine	63)	UHF Communications
24)	Auxiliary Power Plant	64)	Interphone
41)	Environmental Control	65)	IFF Transponder
42)	Electric Power	71)	Radio Navigation
44)	Lighting	74)	Fire Control
45)	Hydraulics/Pneumatics	75)	Penetration Aids/ECM
46)	Fuel	76)	Gun
47)	Oxygen	97)	Weapons/Delivery/Radar

The subsystem reliability estimates are expressed in Mean Sorties Between Failures (MSBF) and are based on current reliability data for the F-15 Air Superiority Fighter which

have been adjusted to reflect predicted technological advances and ATF reliability requirements.

Table 1.1

ATF Subsystem Reliability and Maintainability Estimates

		Repair Time Data (hours)								
		Remove and Replace			Repair in Place			Can Not Duplicate		
Subsystem WUC	Subsystem MSBF	Cond. Prob.	Mean Time	Var-iance	Cond. Prob.	Mean Time	Var-iance	Cond. Prob.	Mean Time	Var-iance
11	133.00	0.030	1.27	0.37	0.966	2.22	0.64	0.004	3.13	0.91
12	241.00	0.278	2.72	0.79	0.662	1.70	0.49	0.060	0.70	0.20
13	149.00	0.544	2.08	0.60	0.386	2.05	0.59	0.070	2.18	0.63
14	141.00	0.456	2.33	0.68	0.299	2.43	0.70	0.245	1.53	0.44
23	165.00	0.428	3.12	0.90	0.494	1.48	0.43	0.078	2.11	0.61
24	207.00	0.490	2.83	0.82	0.436	2.26	0.66	0.074	2.22	0.64
41	417.00	0.442	3.31	0.96	0.199	1.72	0.50	0.359	2.35	0.68
42	265.00	0.803	1.32	0.38	0.173	2.97	0.86	0.024	2.90	0.84
44	700.00	0.618	1.20	0.35	0.333	1.52	0.44	0.049	2.57	0.75
45	450.00	0.327	3.11	0.90	0.587	2.20	0.64	0.086	1.45	0.42
46	168.00	0.428	3.08	0.89	0.421	2.78	0.81	0.151	1.78	0.52
47	1000.00	0.523	1.80	0.52	0.315	1.71	0.50	0.162	1.48	0.43
49	3300.00	0.857	3.23	0.94	0.000	0.00	0.00	0.143	1.00	0.29
51	480.00	0.583	1.51	0.44	0.183	1.04	0.30	0.234	1.02	0.30
55	7200.00	0.389	1.12	0.32	0.222	1.13	0.33	0.389	0.37	0.11
62	2000.00	0.298	1.03	0.30	0.386	1.27	0.37	0.316	0.95	0.28
63	475.00	0.329	1.19	0.35	0.309	0.95	0.28	0.362	1.18	0.34
64	975.00	0.220	1.70	0.49	0.381	1.31	0.38	0.399	0.89	0.26
65	1600.00	0.685	1.29	0.37	0.137	0.92	0.27	0.178	0.84	0.24
71	622.00	0.497	1.26	0.37	0.222	0.97	0.28	0.281	1.12	0.32
74	36.50	0.359	1.35	0.39	0.094	1.26	0.37	0.547	1.04	0.30
75	80.00	0.274	1.63	0.47	0.089	1.68	0.49	0.637	1.01	0.29
76	295.00	0.635	2.28	0.66	0.184	1.71	0.50	0.181	1.48	0.43
97	11000.00	0.867	2.57	0.75	0.133	2.10	0.62	0.000	0.00	0.00

The ATF subsystem repair time estimates in Table 1.1 are also based on F-15 data. The estimates include mean repair times and repair time variances for each of three

possible maintenance actions on each subsystem: remove and replace, repair in place, and "can not duplicate." The "can not duplicate" action refers to a situation in which the cause of a reported intermitent malfunction can not be found and no corrective action is possible after exhaustive troubleshooting and testing. The estimates in Table 1.1 also include the conditional probability associated with each maintenance event (given subsystem failure).

Elements of Repair Time. The repair time estimates include all the activities associated with "active" repair, including fault detection, location, diagnosis, correction and verification. An important factor deliberately excluded is the possible presence of delays caused by queuing for scarce resources such as manpower and replacement parts which must be delivered from distant locations or cycled through various maintenance shops. There is considerable evidence that such delays will be less significant for advanced technology weapon systems than for current systems. For example, ATF reliability estimates predict an aircraft engine failure rate of one every 165 sorties. A failed engine would require removal and replacement with probability 0.428. Thus, a squadron of twenty-four single engine aircraft, each flying six two-hour sorties per day, would require a replacement engine an average of only once every 2.57 days. A very small number of on-hand replacement engines would therefore ensure that virtually no substantial

queuing delays for engines occur. Furthermore, the effect of queuing delays on operational effectiveness will depend as much on the concept of maintenance employed (number of maintenance specialists per aircraft, number of spare parts per aircraft, etc.) as on the inherent reliability and maintainability characteristics of the aircraft. Rather than attempt to consider an intractable number of undetermined variables at early stages of weapon system development, this project supports reliability and maintainability allocation decisions on the basis of their effect on the inherent operational effectiveness of an aircraft under an anticipated concept of operations. Chapter VII discusses the possibility that the analytical methodology could be extended to include queuing effects as more details about the system design and concept of maintenance become established.

II. Literature Review

Overview

The military application of the mathematical theory of reliability and maintainability began shortly after World II as an outgrowth of experience with complex electronic equipment (56:56). By 1950, R&M shortcomings of electronic aerospace systems had become so significant that the Air Force formed an *ad hoc* Group on Reliability of Electronic Equipment to recommend measures to improve reliability and reduce maintenance. In late 1952, the Department of Defense established the Advisory Group on Reliability of Electronic Equipment (AGREE), which published its first report in 1957 (3:16). This report included reliability testing requirements and acceptability limits for new acquisitions.

Since the first AGREE report, the Department of Defense and the Air Force have been increasingly concerned with the impact of reliability and maintainability on the cost of operating weapon systems and components (43:52). Numerous specific guidelines for the consideration of R&M factors in military systems are provided in MIL-STD-785B, *Reliability Program for Systems and Equipment Development and Production* (23), and MIL-STD-470A, *Maintainability Program for Systems and Equipment* (17). A literature review conducted by the "R&M 2000" Action Plan Development Team identifies over 1,000 current Air Force documents that directly address R&M issues (13:Sec F,17). While many of

these documents are oriented toward the life-cycle costs of systems, the 1980s have brought increasing emphasis on the direct impact of reliability and maintainability on system operational readiness (11:33). A current dominant objective of senior Air Force leaders is to keep the maximum possible portion of forces ready for action and to ensure the capability to sustain these forces through intense periods of operation (33).

Two specific segments of the current reliability and maintainability literature are of particular importance to this project and are reviewed below. The first segment deals with existing models that have been employed to assess the impact of R&M allocation decisions on aircraft operational effectiveness. The second segment deals with the theoretical and experimental work that has been directed toward determining and predicting the repair time distributions of weapon system components. Since the objective of the project methodology is to aggregate subsystem repair time distributions into an overall repair time distribution, a understanding of the potential forms of the subsystem distributions is essential.

Current Models

In recent years, numerous models have been developed or adapted to assess the impact of system reliability and maintainability characteristics on aircraft operational

effectiveness. One of the most widely accepted of these is the Logistics Composite Model (LCOM) (9:Sec IV,8). Written in Simscript II.5, LCOM employs Monte Carlo simulation for the primary purpose of analyzing support requirements for complete weapon systems. For new aircraft, LCOM is specifically used to determine manpower requirements and to verify supportability and maintainability requirements (57:1). The model can be configured to determine the resource requirements needed to support a concept of operations or to determine the operational effectiveness realized under specified conditions. Necessary inputs to the model include daily mission schedules, service and repair networks (defining tasks, times, and resources required), subsystem failure rates, and total resources available (57:2). The resources include personnel by specialty and shift, spare parts, and support equipment.

While the LCOM model is very flexible, it is designed for use with highly detailed input data and can only be operated in a batch mode. It is therefore not well suited for use in the evaluation of many alternative reliability and maintainability allocation strategies early in the process of weapon system development. Accordingly, two additional models have been developed for "first cut" looks at design options: the Expected Value Model (EVM) and the Reliability and Maintainability Model (R&M).

EVM and R&M are both average value models that compute

expected values for reliability, maintenance man-hours, and required resources by working through every path of a maintenance action network and multiplying the probabilities of tasks on each path. The EVM and R&M models do not consider queueing effects caused by constraints on resources. However, users of the model at the Air Force Aeronautical Systems Division argue that the impact of these effects "need only be assessed for the final [design] decision. The EVM and R&M models are designed to provide quick turnaround answers to isolate details, decision differences and exploratory tradeoffs." (49:35)

A major limitation of the EVM and R&M models for evaluation of aircraft operational effectiveness is that they compute overall expected maintenance man-hours to repair rather than expected system down-time. System down-time is equivalent to average maintenance man-hours divided by average personnnel required, but only if there are no simultaneous subsystem repairs or no multiple subsystem failures. Another limitation of the the EVM and R&M models is that they can provide only an expected value of maintenance man-hours rather than a complete probability distribution. One maintainability expert observes:

> Military commanders are not interested in knowing that a system will be down a certain length of time "on the average"; they want assurance that it will not be down more than a specified amount of time. (40:105)

Thus, the ability of the EVM and R&M models to fully capture the full impact of reliability and maintainability

allocation decisions on system operational effectiveness is limited.

Many other models have been used to relate reliability and maintainability characteristics to the generation of aircraft sorties. One typical example is a simulation model developed at the Air War College to evaluate the effect of weapon system accuracy, reliability, and maintainability allocation decisions on aircraft effectiveness in peacetime and wartime environments (53). Significant results obtained from the model include the observations that maintainability characteristics are more important in wartime than in peacetime and that many simple, less accurate aircraft are more effective in combat than a few complex, highly accurate aircraft (53:58). Another example of the many simulation models currently in use is the TSAR sortie generation model, developed in 1982 by the Rand Corporation to assess force generation and logistical support in a combat environment (26). This model is unique in that it analyzes aircraft maintenance under the impact of a "surge" flight program, extensive aircraft battle damage, and "the highly irregular patterns of damage to essential base facilities that would be experienced during airbase attacks" (26:3). While models such as TSAR and the Air War College model are useful for the purposes for which they are designed, they have limited applicability to early R&M allocation decisions because they require detailed input

information not known in the early stages of weapon system development. Furthermore, since these models employ Monte Carlo simulation to produce their results, they possess the accompanying disadvantages of long run times and limited accuracy.

Forms of Subsystem Repair Time Distributions

Many current simulation models and the analytical model proposed by this project require information about the forms of repair time distributions for aircraft subsystems. For existing aircraft, the distributional forms can be obtained from empirical data. However, in the early stages of weapon system development, theoretical distributions for repair times must be assumed (25:20). The distributions appearing most frequently in maintainability literature are the exponential and lognormal distributions (40:106). These distributions are illustrated in Figure 2.1.

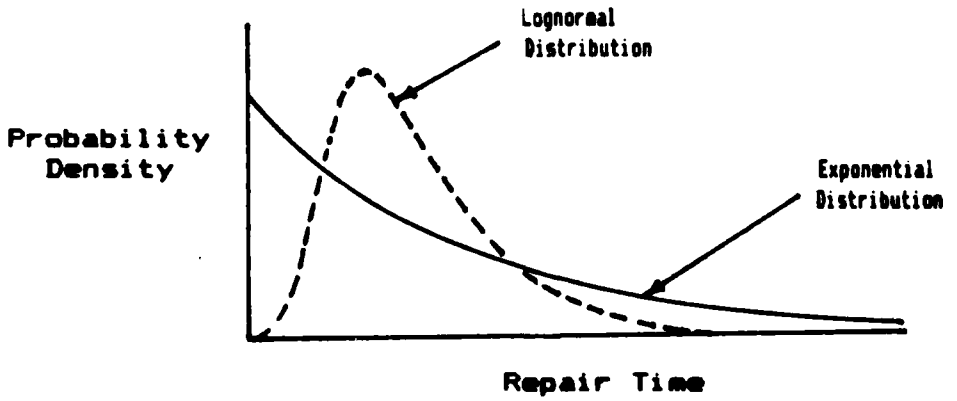

Figure 2.1. Exponential and Lognormal Repair Time Distributions

The exponential distribution has the probability density function (pdf)

$$f(t) = (1/\tau) \exp(-t/\tau), \; t \geq 0 \qquad (2.1)$$

where t is time and τ is the mean repair time. A property of the exponential distribution making it unique among continuous distributions is that it is "memoryless" (4:105). If the repair time for a subsystem is exponentially distributed, then the probability that an ongoing repair will consume an additional Δt units of time will be the same no matter how long the subsystem has been worked on. The exponential distribution applies to simpler types of equipment that normally require adjustments of a very short duration or quick removal and replacement, and only occasionally require much longer repair times (32:46). For existing aircraft, the exponential distribution is rarely applicable to major subsystems because of their complexity. However, advanced technology aircraft such as the ATF are expected to consist largely of modularized components which can be quickly tested and replaced (7:58). Thus, the exponential distribution may apply to some major ATF subsystems, particularly those which are primarily electronic (11:33).

Unlike the exponential distribution, the lognormal distribution describes the repair time for a wide variety of complex equipment and can generally be fit to empirical

repair time data (32:51; 10:56). In MIL-STD-471A, *Maintainability Verification/Demonstration/Validation*, the lognormal distibution is the only parametric family of distributions for which test plans are given (27:13; 18).

A lognormally distributed repair time T has the probability density function

$$f(t) = \{1/[t\sigma(2\pi)^{1/2}]\} \exp[-(\ln t - \mu)^2/2\sigma^2]dt, \quad t>0 \qquad (2.2)$$

where μ and σ^2 are the mean and variance of a normally distributed random variable which is the logarithm of T (1:8). Figure 2.2 illustrates the fit of a lognormal distribution to empirical repair time data for a particular type of aircraft radar, which is representative of several subsystems analyzed by the ARINC research corporation (32:62). The dashed line in Figure 2.2 plots the theoretical Cumulative Distribution Function (CDF) for a lognormal distribution with a mean of 1.008 hours and a standard deviation of 0.5891 hours. The value of the theoretical CDF at any time t is the integral of the pdf at t and represents the probabiltiy that repair is completed by t. The solid line in Figure 2.2 plots the empirical CDF.

In addition to empirical evidence, the literature presents some theoretical justification for use of the lognormal distributions in modeling the repair times of complex subsystems. It has been shown that whenever the change in a variable at any step in a process is a random

proportion of the previous value of the variable, then the variable is lognormally distributed (1:22). The time required to locate and correct a fault in a complex subsystem exhibits this behavior, since the next step in any repair process often depends on the outcome of the previous step.

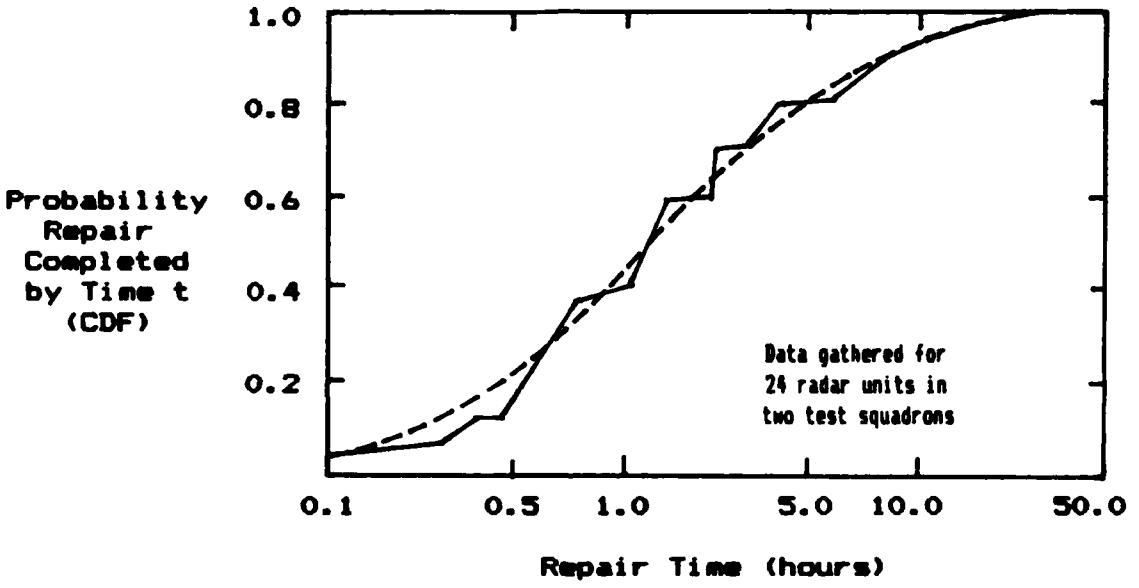

Figure 2.2. Empirical and Theoretical Repair Time CDFs (adapted from 32:51)

A number of maintainability prediction methods which assume lognormal distributions are described in MIL-HDBK-472, *Maintainability Prediction* (16). One procedure uses an "elemental activity approach" by synthesizing all of the specific tasks involved in each possible repair. Basic repair time distributions are provided for each standard task; the task times are then aggregated using a manual Monte

Carlo technique (16:Sec I,19). The times for each task are assumed to be lognormally distributed, except for very specific activities (such as opening an aircraft radome), which are assumed to be normally distributed. Another MIL-STD-472 procedure involves the determination of repair times required to attain particular cumulative probabilities of repair. These cumulative probabilities are then used to determine the parameters of an associated lognormal distribution according to a procedure described by Kline (40:106).

While the maintainability prediction methods described in MIL-STD-472 are most useful at relatively late stages of the weapon system acquisition process, they can be applied to some extent in very early stages. Experience with existing weapon systems can often be adapted to produce usable estimates. In a recent R&M study, the Institute for Defense Analysis concluded that the military services should institute programs to improve the accuracy of maintenance data to better facilitate maintainability prediction (58:Sec II,11). The prospect for future improvement in subsystem maintainability prediction is of considerable significance to this project, since subsystem repair time characteristics are principal inputs to the analytical methodology presented in the following chapter.

III. Analytical Method

Theoretical Development

The form of the aggregate repair time distribution for an aircraft depends on the forms of its subsystem repair time distributions and also on the relative frequency with which different subsystem failures occur. At any point in time, an item (aircraft or subsystem) can either be in an acceptable state or an unacceptable state. A failure occurs when an item moves from an acceptable state to an unacceptable state. Time to failure can be specifically defined in several ways; four definitions presented by Graves and Keilson (35:175) are paraphrased below:

1) Failure Time from the Perfect State: The time until an item reaches an unacceptable state from a state in which all components are *new* and working.

2) Post-Recovery Failure Time: The time until an item returns to an unacceptable state after it has just moved from an unacceptable state to an acceptable state.

3) Ergodic Failure Time: The time until an item reaches an unacceptable state when nothing is known about the past performance of the item except that the item is currently in an acceptable state.

4) Quasi-Stationary Failure Time: The time until an item reaches an unacceptable state from an acceptable state when the item has been in an acceptable state for as

long as anyone can remember. This differs from the ergodic failure time in that for the ergodic failure time the possibility of one or more recent item failures is not dismissed.

The definition most relevant to this project is Post-Recovery Failure Time, which can alternatively be described as "time between failures." Failure Time from the Perfect State and Quasi-Stationary Failure Time are inappropriate definitions because they apply only to particular classes of aircraft rather than a general population. Ergodic Failure Time is an inappropriate definition because it does not make use of known information about the past performance of aircraft.

In order to form an aggregate repair time distribution for an aircraft, it is necessary to determine the distributional forms of Post-Recovery Failure Time for each subsystem. Keilson shows that Quasi-Stationary Failure Time is always distributed as a pure exponential, and that both Ergodic Failure Time and Failure Time from the Perfect State are exponential in the limit as item reliability increases (38:90,143). The limiting behavior of Post-Recovery Failure Time is complicated by the presence of *jitter*, which occurs when an item, having just recovered from an unacceptable state, tends to oscillate between acceptable and unacceptable states before entering the acceptable state for an extended period. For highly

reliable systems with a high probability of successful repair, the amount of jitter is very small, and the Post-Recovery Failure Time approaches an exponential form as item reliability increases (35:187). This suggests that, for highly reliable aircraft such as the Advanced Tactical Fighter, subsystem failure time distributions can be accurately modeled with exponential forms.

Throughout this project, time to failure for an aircraft or subsystem is expressed in terms of a number of time-limited operational sequences (sorties) until failure. The exponentiality of subsystem failure time distributions for highly reliable aircraft thus permits calculation of subsystem sortie reliabilities which remain constant for each sortie flown. Subsystem sortie reliabilities can be calculated as

$$r_i = P(s_i > 1) = 1 - \int_0^1 (s_i/m_i)\ \exp(-s_i/m_i)ds_i$$

$$= 1 - [-\exp(-1/m_i) + 1]$$

$$= \exp(-1/m_i) \qquad (3.1)$$

where r_i is the sortie reliability of subsystem i, s_i is the number of sorties to failure, and m_i is the mean number of sorties between failures. Since the exponential distribution has the memoryless property, the subsystem reliabilities can be applied to each sortie independent of the failure history of previous sorties.

By assuming that a failed aircraft will arrive with only one failed subsystem, conditional probabilities p_i can be computed to represent the probability that any subsystem has failed given the aircraft has failed. For an aircraft with N total subsystems, the conditional probability of failure for any subsystem i can be expressed as

$$p_i = (1-r_i) / \sum_{i=1}^{N} (1-r_i) \tag{3.2}$$

The probabilities p_i can be used to form a probability density function (pdf) for the aircraft repair time as a function of the known subsystem repair time density functions. Feller (29:52) states that if we let F be a cumulative distribution function (CDF) depending on parameter θ which has a probability density u, then

$$F(t) = \int_{-\infty}^{\infty} F(t,\theta)u(\theta)d\theta \tag{3.3}$$

is a monotone function of t increasing from zero to one and hence a CDF itself. If $F(t,\theta)$ has a continuous probability density function $f(t,\theta)$, then F(t) has a density function f(t) given by

$$f(t) = \int_{-\infty}^{\infty} f(t,\theta)u(\theta)d\theta \tag{3.4}$$

Feller further states that instead of integrating with respect to density u we can sum with respect to a discrete probability distribution. If discrete $\theta_1, \theta_2, \ldots, \theta_N$ exist such that $p_i \geq 0$ for all i and $\sum_{i=1}^{N} p_i = 1$, then

$$f(t) = \sum_{i=1}^{N} f(t, \theta_i) p_i \qquad (3.5)$$

defines a new new probability density. The summation process is described as *randomization* and the resultant probability density function is termed a *mixture* (29:53).

In the repair time problem, the single failure assumption makes the subsystem failures mutually exclusive because only one subsystem will fail given the aircraft has failed. The subsystems thus represent discrete θ_i with associated probabilities p_i. If we write the subsystem probability densities $f(t, \theta_i)$ as simply $f_i(t)$, the aircraft repair time pdf can thus be written as a probabilistic mixture

$$f(t) = \sum_{i=1}^{N} p_i f_i(t) \qquad (3.6)$$

The concept can be extended to include the three types of maintenance actions (remove and replace, repair in place, and can not duplicate), which are also mutually exclusive. Thus,

$$f(t) = \sum_{i=1}^{N} p_i \left[\sum_{j=1}^{3} q_{ij} f_{ij}(t) \right] \qquad (3.7)$$

where q_{ij} is the probability that maintenance action j is required given subsystem i has failed and $f_{ij}(t)$ is the repair time pdf for maintenance action j on subsystem i. Alternatively, Eq (3.7) can be written as

$$f(t) = \sum_{i=1}^{N} \sum_{j=1}^{3} p_{ij} f_{ij}(t) \qquad (3.8)$$

where $p_{ij}=p_i q_{ij}$. It is important to note that this concept could be applied to sub-components of subsystems as well as to different maintenance actions. In fact, components at any level of detail could be aggregated provided the overall system reliability is sufficient to warrant the single failure assumption.

To translate the closed form aircraft repair time pdf into more useful information, we can analytically compute a mean and higher order moments. The mean repair time τ is the expected value of the aircraft repair time T and can be calculated as

$$\begin{aligned}
\tau = E(T) &= \int_{-\infty}^{\infty} t f(t)\,dt \\
&= \int_{-\infty}^{\infty} t \sum_{i=1}^{N} \sum_{j=1}^{3} p_{ij} f_{ij}(t)\,dt \\
&= \int_{-\infty}^{\infty} t p_{11} f_{11}(t)\,dt + \int_{-\infty}^{\infty} t p_{11} f_{11}(t)\,dt + \ldots \\
&\qquad + \int_{-\infty}^{\infty} t p_{N3} f_{N3}(t)\,dt \\
&= p_{11}E(T_{11}) + p_{12}E(T_{12}) + \ldots + p_{N3}E(T_{N3}) \\
&= \sum_{i=1}^{N} \sum_{j=1}^{3} p_{ij} \tau_{ij}
\end{aligned} \tag{3.9}$$

or the weighted sum of the mean repair times τ_{ij} for each action j on each subsystem i. Higher order moments of the aircraft repair time distribution can be similarly calculated as the weighted sum of the subsystem higher order moments.

To calculate the second *central* moment or variance γ^2 of T, we can use the computational formula

$$\gamma^2 = E(T^2) - [E(T)]^2 \tag{3.10}$$

Thus,

$$\gamma^2 = \int_{-\infty}^{\infty} t^2 f(t)dt - [E(T)]^2$$

$$= \sum_{i=1}^{N} \sum_{j=1}^{3} p_{ij} E(T_{ij}^2) - [E(T)]^2 \tag{3.11}$$

or the weighted sum of the second moments minus the mean aircraft repair time squared. The method for computing the needed second moments will vary with the particular forms of the subsystem distributions. While Eq (3.11) could be used to aggregate any number of distributional forms, we are particularly interested in the lognormal and exponential forms.

For a lognormal subsystem repair time distribution, the kth moment can be written explicitly as

$$E(T_{ij}^k) = \exp(k\mu_{ij} + k^2\sigma_{ij}^2/2) \tag{3.12}$$

so the second moment is

$$E(T_{ij}^2) = \exp(2\mu_{ij} + 2\sigma_{ij}^2) \tag{3.13}$$

(1:8) where μ_{ij} and σ_{ij}^2 are the distribution parameters. These parameters are not the mean and variance of the lognormal distribution itself. The mean τ_{ij} is the first

moment $\exp(\mu_{ij}+\sigma_{ij}^2/2)$ and the variance γ_{ij}^2 is $\exp(2\mu_{ij}+2\sigma_{ij}^2)-\tau_{ij}^2$. The parameters μ_{ij} and σ_{ij}^2 are easily obtained from a given mean and variance by using the formulas

$$\mu_{ij} = \ln [\tau_{ij}^2(\gamma_{ij}^2 + \tau_{ij}^2)^{1/2}] \quad (3.14)$$

$$\sigma_{ij}^2 = \ln [(\gamma_{ij}^2 + \tau_{ij}^2)/\tau_{ij}^2] \quad (3.15)$$

(41:260).

To calculate moments for an exponential repair time distribution, we must use the moment generating function $M(t)=\lambda_{ij}/(\lambda_{ij}-t^2)$ where λ_{ij} is the reciprocal of the mean (4:406). The second moment is the second derivative of the moment generating function evaluated at t=0.

$$M'(t) = \lambda_{ij}/(\lambda_{ij} - t)^2 \quad (3.16)$$

$$M''(t) = 2\lambda_{ij}/(\lambda_{ij} - t)^3 \quad (3.17)$$

$$E(T_{ij}^2) = M''(0) = 2/\lambda_{ij}^2 = 2\tau_{ij}^2 \quad (3.18)$$

The second moments calculated in Eqs (3.13) and (3.18) can be substituted into Eq (3.11) to calculate the variance of the aircraft repair time distribution.

In addition to the distribution mean and variance, other information of interest is the probability that a failed aircraft will be repaired within a particular period of time (30 minutes, 1 hour, 6 hours, etc.). This information can be provided by the aircraft repair time

cumulative distribution function. Unfortunately, the aicraft repair time CDF does not have a closed form because it is a mixture including lognormal distributions, which have no closed form (41:164). However, the CDF F(t) can be described by the equation

$$F(t) = \int_{-\infty}^{t} f(t)dt$$

$$= \int_{-\infty}^{t} \sum_{i=1}^{N} \sum_{j=1}^{3} p_{ij} f_{ij}(t)dt$$

$$= \int_{-\infty}^{t} p_{ij} f_{ij}(t)dt + \int_{-\infty}^{t} p_{ij} f_{ij}(t)dt + \ldots + \int_{-\infty}^{t} p_{ij} f_{ij}(t)dt$$

$$= \sum_{i=1}^{N} \sum_{j=1}^{3} p_{ij} F_{ij}(t) \qquad (3.19)$$

where $F_{ij}(t)$ are the cumulative distribution functions of the subsystem repair time distributions. The exponential subsystem CDFs have the closed form

$$F_{ij}(t) = 1 - \exp(-t/\tau_{ij}), \quad t \geq 0 \qquad (3.20)$$

and the lognormal components can be computed as definite integrals of the form

$$F_{ij}(t) = \int_{0}^{t} \{1/[t\sigma_{ij}(2\pi)^{1/2}]\} \exp[-(\ln t - \mu_{ij})^2 / 2\sigma_{ij}^2]dt, \quad t \geq 0 \qquad (3.21)$$

(1:8). Implementation of Eq (3.21) on a computer would require the use of a numerical integration technique to

calculate the probability of repair within a particular time period. A more efficient approach would be to take advantage of the fact that the CDF $F_{ij}(t)$ of a lognormally distributed subsystem repair time T_{ij} can be expressed in terms of the standard normal CDF. If X is a random variable distributed normally with mean 0 and variance 1, then

$$\begin{aligned} F_{ij}(t) &= P[\exp(X) \leq t] \\ &= P(X \leq \ln t) \\ &= F_{ij_X}(\ln t) \\ &= \phi[(\ln t - \mu_{ij})/\sigma_{ij}] \end{aligned} \qquad (3.22)$$

where ϕ represents the standard normal CDF (4:160). A subroutine for returning ϕ for any values of t of interest could thus be used in place of a time-consuming numerical integration routine.

Computer Implementation

The first part of the Repair Time Distribution Model listed in Appendix B implements the analytical method for forming an aggregate repair time distribution. The program analytically computes aircraft reliability, mean repair time, and repair time variance. It also computes and plots values for the analytical repair time pdf and CDF at user-specified time intervals up to a user-specified maximum time. Appendix A thoroughly describes the logic of each applicable subroutine and function.

Several algorithms were considered for use in function SNORM, which returns standard normal cumulative probabilities for use in determining the values of lognormal CDFs. One algorithm recommended by the Association for Computing Machinery computes a definite integral with the aid of Simpson's formula (8:Sec 226,2). This method would seem to offer no speed advantage over a direct numerical integration of the subsystem distribution itself. Another algorithm, developed by Thatcher (62:315), computes the integral using a Taylor series expansion. This method is very accurate but is not as fast as a method developed by Ibbetson (37:616). The Ibbetson algorithm calculates the cumulative probability through the use of a ninth order polynomial approximation if $|X|/2 < 1.0$ and a thirteenth order polynomial approximation if $|X|/2 \geq 1.0$. The algorithm is reasonably accurate, and very fast, making it the most suitable method for our purposes since the input data is of limited accuracy (8:Sec 226,2).

IV. Simulation Model

General Approach

This project employs a simulation model in a somewhat unique fashion. Although simulation is empirical in nature and therefore inherently inexact, a simulation model is used to produce a baseline repair time distribution against which an analytical distribution is compared. The analytical distribution is known to be an approximation of the "real solution" since it is based on the single failure assumption. Unfortunately, simulation can also only produce an approximation of the "real solution," and there is no way to positively measure the degree of imprecision (61:13). However, statistical theory asserts that the accuracy of the repair time distribution produced by a simulation model will increase as the number of observations contributing to the distribution increases. We can place tight limits on the parameters of the real distribution with a high level of confidence by making a very large number of observations; that is, by passing a large number of aircraft through the simulation. Unfortunately, this requires a large amount of computer time. A primary objective of the design of the simulation model then is to minimize the amount of computer time needed to process a large number of observations. This objective must be accomplished both to produce a reasonably precise repair time distribution based on multiple subsystem failures and to ensure a fair comparison of the analytical

and simulation methods for computational efficiency.

The requirement for a "fast" simulation demands careful attention to the manner in which the model is constructed. Computer languages specifically designed for simulation offer considerable flexibility and ease of programming but do not always use the most efficient methods for specific purposes. For example, the method used for generating lognormal random variates in the Simulation Language for Alternative Modeling language (SLAM) has been shown to be much slower than newer, more elegant methods (54:590, 39:895). For this reason, a unique simulation model is developed in this project and implemented in the FORTRAN computer language.

Model Accuracy and Sample Size

The assumption that the time between failures for all subsystems have exponential distributions is extremely helpful in producing a precise output distribution. The memoryless property of the exponential distribution effectively makes each observation independent of any that precede or follow it. We can therefore place confidence limits on parameters of the output repair time distribution based on multiple independent observations within a single run of the simulation. For a large sample size, confidence limits for the mean repair time can be approximated as

$$\bar{T} \pm z_{\alpha/2}(\hat{\gamma}/n^{1/2}) \qquad (4.1)$$

with confidence $1-\alpha$ where $\bar{T}$ is the sample mean, $z_{\alpha/2}$ is the percentage point of the standard normal distribution for cumulative probability $1-\alpha/2$, $\hat{\gamma}$ is the sample standard deviation, and n is the number of observations (45:310). Confidence limits for the variance of the repair time distribution can be approximated as

$$[\ (n-1)\hat{\gamma}^2/\chi^2_U,\ (n-1)\hat{\gamma}^2/\chi^2_L\ ] \qquad (4.2)$$

where χ^2_L and χ^2_U are percentage points of the Chi-squared distribution as shown in Figure 4.1 (45:329). For a sample size greater than thirty, the expression $(2\chi^2)^{1/2}-(2n-1)^{1/2}$ has approximately a standard normal distribution (6:233). Thus, a needed percentage point of a Chi-squared distribution can be computed according to the formula

$$\chi^2_\alpha = [z_\alpha + (2n-1)^{1/2}]^2 \qquad (4.3)$$

where z_α is the percentage point of the standard normal distribution for cumulative probabilty $1-\alpha$.

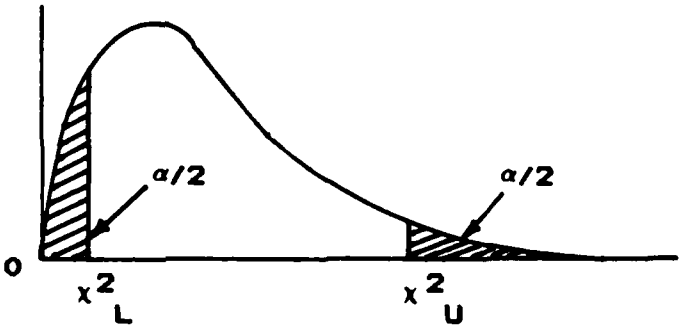

Figure 4.1. Locations of χ^2_L and χ^2_U on the Chi-squared Distribution

Confidence limits for the proportion of repairs completed within a particular period of time can also be established. The value of a CDF at any repair time is simply the proportion of failed aircraft that will be repaired within that time. If n is the total number of failed aircraft in a sample and G is the underlying (but unknown) proportion that will be repaired with a specified time period, then the sample proportion g will be approximately normally distributed with mean G and standard error equal to $(GH/n)^{1/2}$ where H=1-G (30:13). An approximate $100(1-\alpha)\%$ confidence interval for a value of a CDF therefore consists of all those values of G satisfying

$$[|g - G| - 1/(2n)] \; / \; (GH/n)^{1/2} \leq z_{\alpha/2} \qquad (4.4)$$

where g is the sample proportion, 1/(2n) is a correction for continuity, and $z_{\alpha/2}$ denotes the percentage point of the standard normal distribution for cumulative probability $1-\alpha/2$ (30:14). The limits of this interval are found by solving the quadratic equation obtained by setting the square of the left-hand side of Eq (4.4) equal to $z_{\alpha/2}^2$. Defining g=1-h, the lower limit is given explicitly by

$$G_L = \frac{(2ng+z_{\alpha/2}^2-1) - z_{\alpha/2}[z_{\alpha/2}^2-(2+ 1/n)+4g(nh+1)]^{1/2}}{2(n + z_{\alpha/2}^2)} \qquad (4.5)$$

and the upper limit by

$$G_U = \frac{(2ng+z_{\alpha/2}^2-1) - z_{\alpha/2}\left[z_{\alpha/2}^2+(2-1/n)+4g(nh+1)\right]^{1/2}}{2(n+z_{\alpha/2}^2)} \quad (4.6)$$

Differentiation of the expression for G_U-G_L with respect to g reveals that the widest confidence interval occurs at g=0.5.

It is desirable to select a sample size n that will provide a reasonably small confidence interval for simulation CDF values without expending excessive computer time. Figure 4.2 presents a plot of the maximum width of the confidence interval as a function of sample size. It is apparent from the plot that a decrease in the width of the interval becomes very expensive once the sample size increases beyond 40,000 failed aircraft. This sample size, which provides a maximum confidence interval width of less than 0.01 with 95% confidence, is used throughout the project.

Model Construction

For every aircraft sortie generated in the simulation model, each aircraft subsystem must be examined for possible failure. Thus, for each subsystem i, a random variate S_i from an exponential distribution must be generated to determine the number of sorties until failure of the subsystem. The fastest method for generating the required exponential random variates in FORTRAN is the inverse-transform method (41:254). This method is based on equating a random number R distributed uniformly from 0 to 1 with a

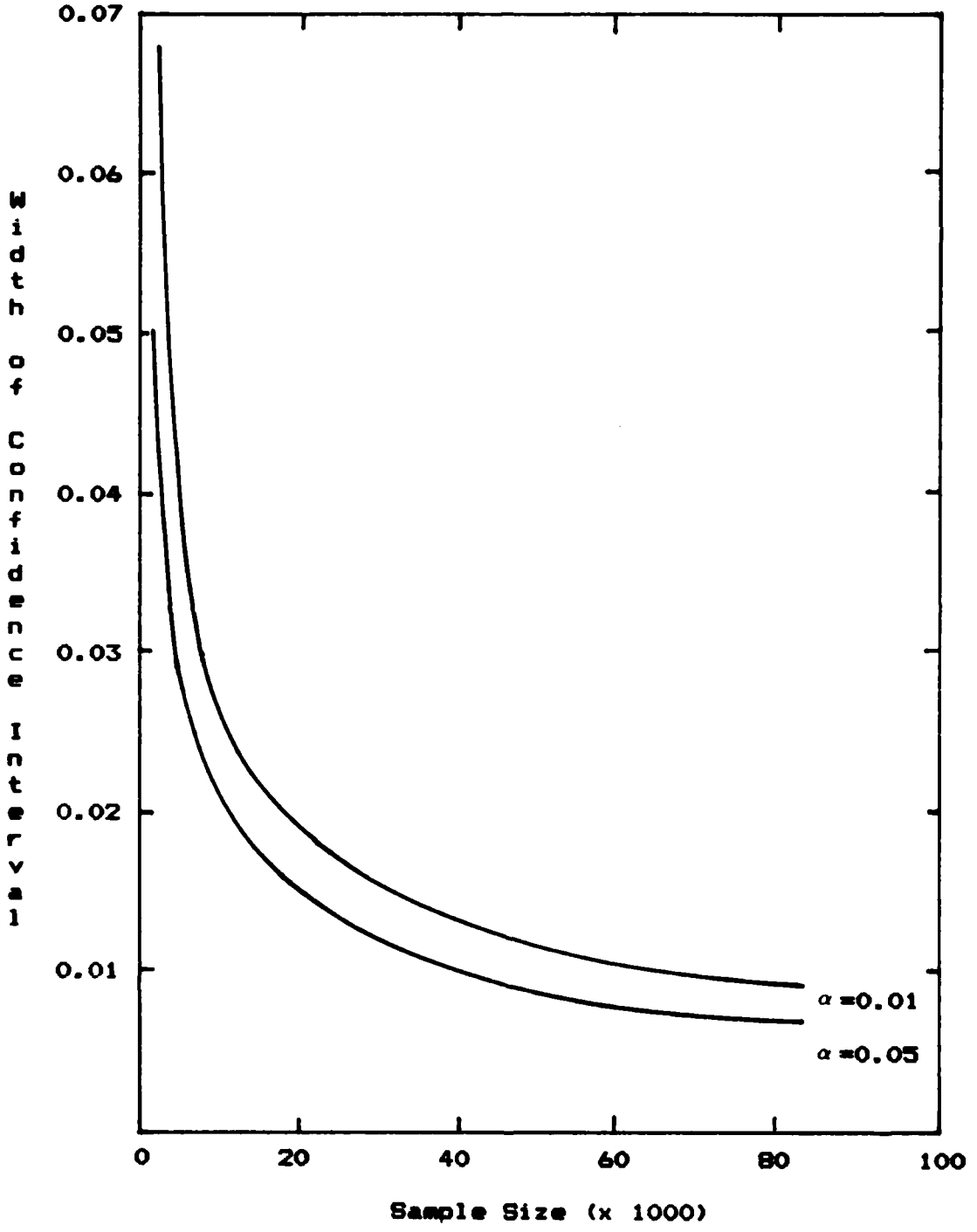

Figure 4.2. Confidence Interval Width vs. Sample Size

cumulative distribution function $F_i(s_i)$ of an exponential distribution as follows:

$$R = F_i(s_i) = 1 - \exp(-s_i/m_i) \tag{4.7}$$

where m_i is the mean of the distribution. It follows that

$$\begin{aligned} \exp(-s_i/m_i) &= 1 - R \\ -s_i/m_i &= \ln(1-R) \\ s_i &= -m_i \ln(1-R) \end{aligned} \tag{4.8}$$

Since R and (1-R) have the same distribution, a subtraction operation can be eliminated by simply generating the exponential random variate S_i according to the equation

$$S_i = -m_i \ln(R) \tag{4.9}$$

If S_i is less than 1.0 in the simulation, a failed subsystem has been found and another random number must be obtained to determine which maintenance action is required. If q_{ij} is the probability action j is required where j=1,2, or 3, then another random number R can be used to determine which action is required according to Table 4.1. Once the appropriate action is determined, the subsystem repair time must be determined by obtaining a random variate from the repair time distribution for action j on subsystem i. If the repair time distribution is exponential, the repair time can be determined using the inverse-transform method. If the repair time distribution is lognormal, a more

complicated procedure must be used.

Table 4.1.

Relationship between Random Number R and Required Maintenance Action

$R \leq q_{i1}$	=>	action 1 (remove and replace)
$q_{i1} < R \leq q_{i1} + q_{i2}$	=>	action 2 (repair in place)
$R > q_{i1} + q_{i2}$	=>	action 3 (can not duplicate)

Since a lognormal variate is a random variate whose logarithm is distributed normally, then if Y is distributed normally with mean μ and variance σ^2, it follows that exp(Y) is distributed lognormally with parameters μ and σ^2. We can thus generate a lognormal random variate L from a normal random variate Y using the equation L=exp(Y). Further, given X distributed normally with mean 0 and variance 1, we can obtain Y by applying the transformation $Y=\mu+\sigma X$ (41:258). We can therefore generate a lognormal random variate L with parameters μ and σ^2 from a standard normal random variate X using the relationship

$$L = \exp(\mu + \sigma X) \qquad (4.10)$$

Since the cumulative distribution function of the standard normal distribution does not have a closed form, the inverse transform method can not be used to generate X from a random number R. Consequently, many alternative methods have been

developed for generating standard normal random variates. Traditional methods considered for use in this project include the Box-Muller method (2:315) and the "polar" method (41:260), which are simple and reasonably efficient. Recently, faster methods have been developed by Marsaglia and Bray (42:260), and Kinderman and Ramage (39:893). These methods use very simple procedures to return approximate standard normal variates most of the time, occassionally employing sophisticated correcting operations. Still another approach, developed by Beasley and Springer, uses a simple numerical approximation to the standard normal CDF. Beasley and Springer argue that while elegant approaches such as the Marsaglia-Bray and Kinderman-Ramage methods are dominant when programmed in machine language, a numerical method is comparable for speed when working in a higher level language such as FORTRAN (5:120).

When the five methods mentioned above are implemented on the VMS/VAX computer employed by this project, the Beasley-Springer numerical method emerges as the most efficient. It should be pointed out that the relative speeds of the different methods are highly dependent on the particular random number generator employed since the methods require varying quantities of random numbers to generate standard normal random variates. VMS FORTRAN has a built-in random number generator function RAN, which originated with IBM's old scientific package (63:Sec D,12). Because this

random number generator is coded in machine language, it is very fast, and the sophisticated methods of Marsaglia-Bray and Kinderman-Ramage are favored when it is employed. Unfortunately, this particular generator has been shown to have some undesirable statistical properties, and it is therefore unusable (41:225). The random number generator used in this project is a fast FORTRAN multiplicative generator RAND developed by Schrage and recommended by Law and Kelton (41:227). Using this random number generator, the Beasley-Springer method for producing standard normal variates is about 17 per cent faster than the Kinderman-Ramage method.

The method developed by Beasley and Springer approximates the standard normal CDF curve with rational approximations over two regions. Where $|x| < 0.42$, the curve is approximated by $x = Q\ A(Q^2)/B(q^2)$ where $Q = R - 0.5$ and A and B are polynomials of degrees 3 and 4 respectively. For the tail region, x is formed as $x = \pm C(v)/D(v)$ where v is an auxiliary variable $v = [\ln (0.5 - |Q|)]^{1/2}$ and C and D are polynomials of degrees 3 and 2 respectively. In a test of 10,000 random variates, a maximum error of 0.00000114 was produced (5:119). Thus, the numerical approximation accurately produces standard normal random variates, which are then used in the simulation to generate lognormally distributed subsystem repair times.

The subsystem repair times generated from random

variates are used to produce an empirical probability density function and cumulative distribution function for aircraft repair time. In forming the multiple failure distribution, the repair time for each failed aircraft is simply the maximum repair time of all failed subsystems. We can concurrently form a single failure repair time distribution by storing the repair time of the subsystem that failed "first"; that is, the subsystem with the smallest number of sorties (less than 1.0) until failure. The single failure distribution is useful for comparison with the analytical distribution to verify that the simulation is functioning properly and to present information about the amount of random error in the simulation.

Computer Implementation

The second phase of the Repair Time Distribution Model listed in Appendix B implements the simulation method. Appendix A provides a detailed description of each routine. In order to obtain the smallest possible confidence intervals on the output repair time parameters (mean, variance, and CDF values), two different implementation strategies should be considered. Confidence limits can be established from a single long run of the model, or from multiple shorter runs. Using the ATF reliability and maintainability data in Table 1.1, a single long run of 40,000 observations consumes 19.86 minutes of CPU time and

four multiple runs of 10,000 observations require a combined total of 24.13 CPU minutes. While the total run times are comparable, the maximum CDF confidence interval width produced by the single long run for (0.00983) is less than half that resulting from the four short runs (0.0249) for α=0.05.

To verify that the implementation is functioning properly, the single failure distribution produced by the simulation can be compared with the analytical single failure distribution. The sample output in Appendix C indicates almost exact conformity between the two single failure results for distribution mean, variance, and CDF values. The simulation multiple failure distribution has a slightly higher mean, and thus appears to provide a valid basis against which the analytical distribution can be compared.

V. Comparison of Analytical and Simulation Results

Comparison Criteria

To determine the accuracy and applicability of the analytical method, the results of the analytical method must be compared with the results of the simulation method over a wide range of subsystem reliability and maintainability characteristics. Several alternate approaches are possible for comparing the analytical single failure distribution and the simulation multiple failure distribution for overall aircraft repair time. One approach is to compare central moments of the distributions (mean, variance, skewness, Kurtosis, etc.). Unfortunately, higher order central moments would be extremely difficult to calculate for the analytical distributions. Another approach, which is perhaps more meaningful, is to compare the cumulative distribution functions of the two distributions over the full range of possible repair times. The cumulative distribution function has a practical meaning in that it represents the percentage of aircraft that can be repaired in a particular time period.

Comparison of the two CDFs under varying conditions would be most meaningful if the difference between them could be described in terms of a single numerical index. Whenever theoretical and empirical distributions are compared, an accepted practice is to use a test statistic

for goodness-of-fit as a measure of disparity. Candidate test statistics include the Chi-squared statistic, Kolomgornov-Smirnov (KS) statistic, Anderson-Darling (AD) statistic, and Cramer-von Mises (CvM) statistic (64:241). The Kolomgornov-Smirnov statistic provides the following advantages over the others.

1) The KS statistic uses ungrouped data so that every observation represents a point of comparison, while the Chi-squared test requires the data to be grouped in arbitrary cells. The choice of group boundaries would introduce an element of variability between comparisons using different maintainability characteristics.

2) The KS statistic uniformly weights deviations over the full range of the repair time distribution, while the AD statistic increases weighting in the tails. Since the tails of the distribution have no more practical significance than the center, the weighting appears undesirable for the purposes of this project.

3) The KS statistic can be used to measure deviations in a given direction, while the Chi-squared, AD and CvM statistics can be used only for deviations in both directions (25:22). Since for any repair time the value of the corresponding multiple failure cumulative probability should always be less than the single failure cumulative probability, the KS statistic will provide a stronger indication of disparity.

4) The KS statistic has a practical meaning in that it represents the maximum difference between the CDFs of the two distributions over the full range of repair times. While the CvM statistic also has a recognizable meaning in that it is based on the sum of the squared differences between distributions at each observation, the meaning of the KS statistic is more obvious and practically significant.

Based on the above reasons, the Kolomgornov-Smirnov statistic (maximum difference between CDFs) is used to compare the analytical and simulation repair time distributions. This statistic is comprised of the sum of the actual maximum difference between CDFs and an error term introduced by the empirical nature of the simulation distribution. The error term, however, is minimal due to the large sample size employed by the simulation model.

Experimental Design and Analysis

Relevant Factors. To determine how the disparity between single and multiple failure distributions is influenced by reliability and maintainability characteristics, multiple computer runs of the analytical and simulation models must be performed using different levels of various relevant factors. The most obvious factor that would influence the disparity between distributions is the overall reliability of the aircraft. Lower subsystem reliabilities increase the probability of multiple failures,

and thus the potential magnitude of disparity between distributions. Another factor to be considered is the variability of subsystem reliabilities. An aircraft with a given overall reliability could have subsystem reliabilities that are similar or that vary over a wide range. This variability could influence the amount of disparity between single and multiple failure distributions. Still another potentially influential consideration is the nature of the subsystem repair time distributions. If all subsystem distributions had the same mean and zero variance, any multiple failure repair time would be exactly the same as any single failure repair time. However, when system repair time can vary significantly from repair to repair, a substantial disparity between the single and multiple failure repair time distributions is possible. Variability of overall system repair time can be modeled by varying the subsystem repair time variances over a wide range.

Screening Design. Three factors have been identified as potentially relevant to the amount of disparity between the analytical single failure distribution and the simulation multiple failure distribution:

A) Overall system reliability

B) Variability among subsystem reliabilities

C) Variances of subsystem repair time distributions

Because of the relatively long run time required to produce a reasonably accurate simulation distribution, the number of

factor levels that can be examined and the number of replications that can be produced are limited. Fortunately, it is reasonable to expect changes in any factor level in one direction to always impact the KS statistic in the same direction. For example, a decrease in overall reliability would be expected to always cause an increase in the KS statistic regardless of the original reliability level. It is therefore reasonable to screen the potentially relevant factors for significance by measuring the KS statistic at various combinations of two extreme factor levels. A 2^3 factorial design accomplishes this most efficiently.

Implementation of the factorial design measures the three main factor effects (A, B, C) and also four interaction effects (AB, AC, BD, and ABC). In order to test the effects for statistical significance without assuming any effects to be negligible *a priori*, some replication of the design is necessary. A twin replication can be used to introduce another factor that need not impact the amount of disparity between CDFs but has a significant impact on measures of operational effectiveness, namely:

D) Means of subsystem repair time distributions

If the high and low levels of the subsystem repair time variances are specified as multiples or proportions of the mean repair times, uniform scaling of the mean repair times will have no impact on the amount of disparity between single and multiple failure CDFs. Thus, sets of computer

runs at high and low levels of factor D can be treated as replications for determining significance of factor effects on the KS statistic. However, the computer model used to implement the factorial design includes a post-processor, discussed in Chapter VI, which translates the analytical and simulation CDFs into aircraft availabilities and sortie generation rates. These parameters are sensitive to subsystem mean repair times, and are used later in the project to identify the degree of disparity between distributions necessary to produce noticable differences in measures of operational effectiveness.

Production of twin replications of the 2^3 factorial design requires sixteen computer runs. It is important to note that runs for low reliability levels expend considerably less computer time than runs for high reliability levels because fewer total aircraft must be processed in the simulation to produce the required sample size of 40,000 failed aircraft.

Screening Factor Levels. The factor levels used in the design runs are set at extreme values of their relevant ranges. The proposed ATF reliability levels are an order of magnitude above the subsystem reliabilities of current aircraft and are used as an upper bound. A logical lower bound for this factor is current reliability data for the operational F-15 and F-16 fighters. We would expect the actual ATF subsystem reliability levels to lie somewhere

between these extremes as the design is developed. Table 5.1 compares the ATF and F-15/16 reliability data.

Table 5.1

Mean Sorties Between Failures for F-15/16 and ATF Subsystems

Subsystem Code	F-15/16 MSBF	ATF MSBF
11	13.20	133.00
12	23.77	241.00
13	14.76	149.00
23	13.94	141.00
24	16.34	165.00
41	41.17	207.00
42	26.18	417.00
44	68.87	700.00
45	44.74	450.00
46	16.66	168.00
47	102.40	1000.00
49	334.10	3300.00
51	47.35	480.00
55	710.20	7200.00
62		2000.00
63	46.76	475.00
64		975.00
65	115.70	1600.00
71	61.42	622.00
74	3.60	36.50
75	7.84	80.00
76	29.14	295.00
97	1136.00	11000.00
Mean	133.39	1337.48
Variance	71370.39	6308276.78
Std. Dev.	267.15	2511.63
δ	2.00	1.88

Determining extreme levels for factor B, the variability between subsystem reliabilities, presents a more difficult problem. A low factor level of zero variability

can be obtained by making all subsystem reliabilities equal. The subsystem mean sorties between failures (MSBF) can be set to a common value that produces an overall aircraft MSBF equivalent to the MSBF resulting from the actual varied subsystem reliabilities. This common value m_c is not the simple mean of the subsystem MSBFs but can be calculated as

$$m_c = -1 \; / \; \{\ln[\prod_{i=1}^{N} \exp(-1/m_i)]\} \qquad (5.1)$$

where N is the number of subsystems and m_i is the MSBF for subsystem i. For the high level of factor B, it is desirable to find a way of indexing the variability so that the ATF and F-15/16 factors are in some sense "equivalent" at their high levels. Table 5.1 shows that the variability for the two data sets is in no way equivalent when measured by conventional indexes such as variance or standard deviation. However, it is apparent that the coefficients of variation (δ=standard deviation/mean) are similar. Note also that the F-15/F-16 data does not include MSBF estimates for subsystems 62 and 64 because most operational aircraft do not have these subsystems. By using dummy values of 231.63 and 112.92 for MSBFs of subsystems 62 and 64, the coefficients of variation for two data sets can be made identical (δ=1.88).

The high and low levels of factor C, subsystem repair time variances, are set to encompass a very wide range of values. While the variances among subsystem repair times for current weapon systems (relative to their means) have

been shown to be fairly consistent, exceptions have been identified (32:56). The future variances of ATF subsystem repair times are therefore somewhat uncertain. To ensure adequate range of this factor in the screening design, factor C is varied an order of magnitude above and below the ATF estimates in Table 1.1. For the high level of factor C, variance values of ten times the subsystem mean repair times are used. For the low factor level, values of one-tenth the mean repair times are used. To permit manipulation of the variances, all subsystem repair time distributions are assumed to be lognormal.

The subsystem mean repair times provided in Table 1.1 reflect current F-15 data and are used to represent the high level of factor D, subsystem mean repair times. To allow for the possibility of substantial improvements in the maintainability of ATF subsystems, the low level for factor C is obtained by setting the subsystem mean repair times to one-fourth the values provided in Table 1.1. This range of values will provide an indication of the impact of subsystem mean repair times on measures of operational effectiveness.

Screening Results. To produce the sixteen data bases required by the experimental design, a special FORTRAN program is used to transform a single master data set into the sixteen input data files. Then the Repair Time Distribution Model listed in Appendix B is run using each data file to produce and compare analytical and simulation

repair time distributions. The results of the sixteen required runs are shown in Table 5.2. The small letters in the "Factor Levels" column indicate which factors are set at their high level for the corresponding run. For Run 1, all factors are set at their low levels, as indicated by the convention "(1)."

Table 5.2

Screening Design Results

Replication 1			Replication 2		
Run	Factor Levels	Maximum CDF Difference	Run	Factor Levels	Maximum CDF Difference
1	(1)	0.1304	9	d	0.1308
2	a	0.0110	10	cd	0.0150
3	b	0.1150	11	bd	0.1165
4	ab	0.0121	12	abd	0.0099
5	c	0.1232	13	cd	0.1293
6	ac	0.0147	14	acd	0.0156
7	bc	0.1181	15	bcd	0.1169
8	abc	0.0108	16	abcd	0.0165

From the results in Table 5.2, it is apparent that the reliability characteristics of the systems examined have a far more significant impact than the subsystem repair time variances since the results appear very similar for each group of four runs within each replication (1-4, 5-8, 9-12, 13-16). These groups represent different levels of factors C and D. The dominant effect of factors A and B is confirmed by a formal analysis of variance (ANOVA), which

determines factor effects and tests them for statistical significance. Significance of an effect is determined by calculating the ratio of the mean square error due to factor effects over the mean square error due to random error. As discussed in Montgomery (46:50), this ratio has an F distribution and is therefore a test statistic for the hypothesis of no difference in factor level means. The ANOVA results, shown in Table 5.3, indicate that factor A, factor B, and the AB interaction effects are highly significant with factor C and its interactions having virtually no effect over the ranges examined. The critical values of the F statistic for α=0.01 and α=0.05 are listed at the bottom of the table.

Table 5.3

Factor Effects and ANOVA for Screening Design

Source	Effect	Sum of Squares	DOF	Mean Square Error	F Statistic
A	-0.1042	0.0434	1	0.0434	268369.6330 *
B	-4.4625E-03	7.9657E-05	1	7.9655E-05	492.0964 *
AB	5.7625E-03	1.3283E-04	1	1.3289E-04	820.5700 *
C	-1.3750E-04	7.5625E-08	1	7.5625E-08	0.4672
AC	1.8750E-04	1.4063E-07	1	1.4063E-07	0.8687
BC	-2.6250E-04	2.7562E-07	1	2.7563E-07	1.7028
ABC	2.1250E-04	1.8063E-07	1	1.8063E-07	1.1159
Error		1.2950E-06	8	1.6187E-07	
Total		0.04365	15		

* F(0.01) = 11.26
F(0.05) = 5.12

Graphic Analysis. Since only factors A and B have a statistically significant impact, it is possible to graphically illustrate the effect of these factors on the amount of disparity between the analytical and simulation distributions. If the effects were strictly linear, a thoroughly descriptive plot could be constructed using output from completed simulation runs. However, knowledge of the nature of the factor effects could be improved by making additional runs at additional factor levels. One approach would be to make additional runs involving third levels of both factors A and B. Five new runs could be used in addition to the existing runs to provide runs at all $3^2=9$ combinations of factor levels. However, Table 5.3 indicates that factor A has a far more significant effect than Factor B. For this reason, new runs are made at three new levels of factor A and no new levels of factor B. The runs at new levels of factor A are made at existing high and low values of factor B for a total of six new runs. Factors C and D are set at the representative values shown in Table 1.1.

For each new level of factor A, it is necessary to determine subsystem MSBFs associated with that factor level. A constant level of the coeffienct of variation (factor B) can be maintained by multiplying all subsystem MSBF by some constant. Table 5.1 indicates that the F-15/16 subsystem MSBFs are all reasonably close to one-tenth of the ATF subsystem MSBFs. A new level of factor A can therefore be

determined without changing the high level of Factor B by multiplying ATF subsystem MSBFs by a constant having a value between 0.1 and 1.0. Values of 0.3, 0.5, and 0.75 are chosen to define the three new levels. To determine subsystem MSBFs for the low level of Factor B, Eq (5.4) can again be applied to determine a common MSBF for all subsystems.

Table 5.4 summarizes the results of the six new runs using the new combinations of factor levels. These results are plotted with the results of the previous runs in Figure 5.1. In the previous runs, the low level of factor A corresponds to an overall system MSBF of 0.9415 sorties and the high level of factor A corresponds to a MSBF of 9.5324. The two lines in Figure 5.1 represent the two levels of factor B. Note that while the effect of factor B is statistically significant when measured at two factor levels, in Figure 5.1 it appears to have little practical impact compared to the impact of Factor A. This is

Table 5.4

Results of Additional Runs

Run	Aircraft MSBF (factor A)	δ (factor B)	Maximum CDF Difference
17	2.8597	0.00	0.0455
18	4.7662	0.00	0.0267
19	7.1943	0.00	0.0196
20	2.8597	1.88	0.0416
21	4.7662	1.88	0.0244
22	7.1943	1.88	0.0167

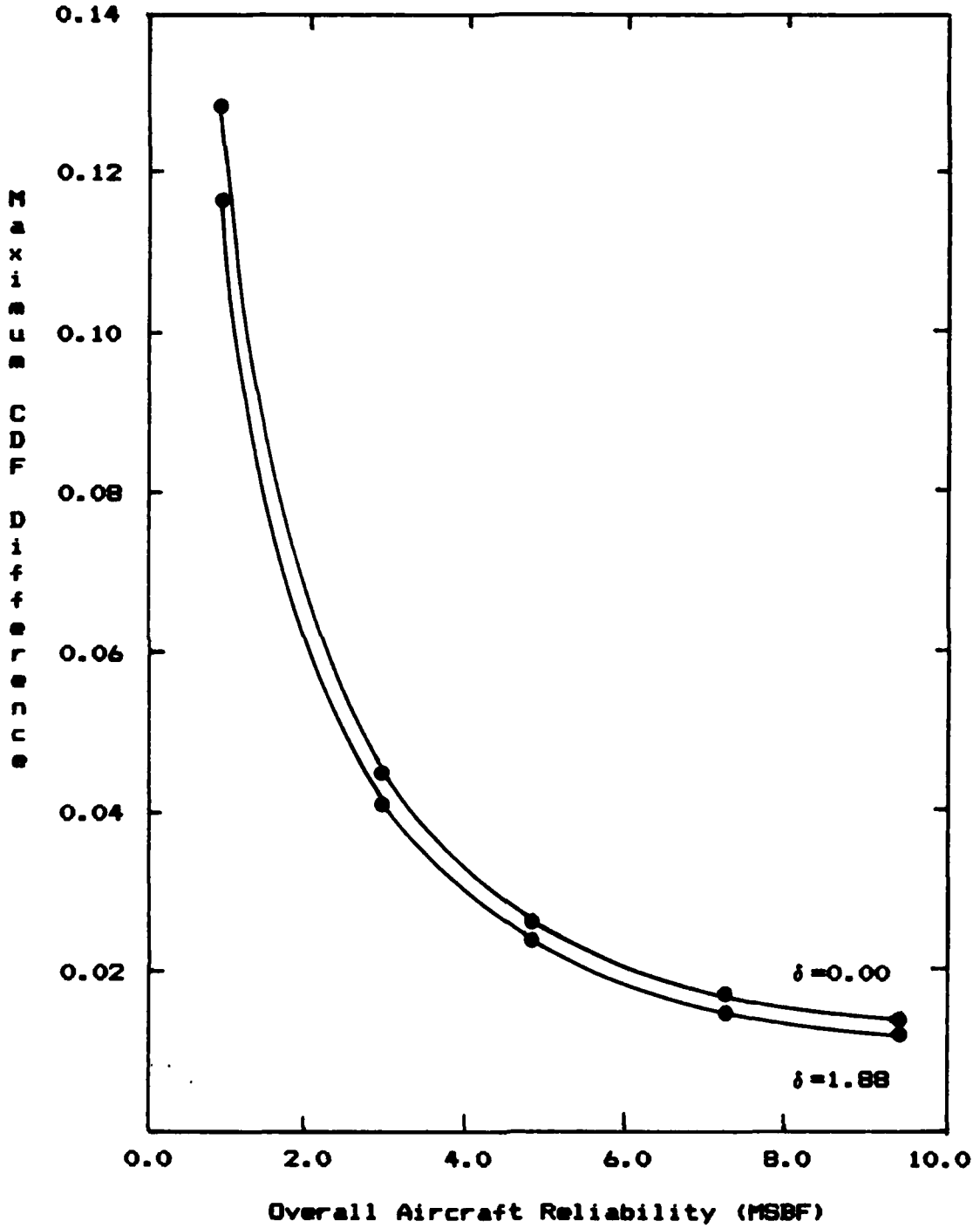

Figure 5.1. Maximum CDF Difference vs. Aircraft MSBF

especially true considering the fact that the effect of factor B is measured over a very wide range.

As a point of interest, the critical value of the KS statistic for a sample size of 40,000 with α=0.01 is 0.00815. Thus, the single failure and multiple failure distributions are statistically different even at the high system reliability levels. However, a statistically significant difference between CDFs for this large sample size need not necessarily translate into a practically significant difference in measures of operational effectiveness, as discussed in Chapter VI.

Sensitivity Analysis

There are two possible variations in the ATF subsystem characteristics not treated in the previous analysis. One of these variations is the potential form of the subsystem repair time distributions. While the mean and variance of the distributions have been varied, the higher order moments or forms of the distributions have not been changed. It is therefore important to determine how well the plot in Figure 5.1 predicts the maximum CDF difference when different distributional forms are used.

To perform this sensitivity analysis, it is assumed that the subsystem distributions have an exponential form rather than a lognormal form. One computer run is made at high levels of Factors A and B, and another run is made at low levels of these factors. The results for both

distributional forms are summarized in Table 5.5. The values shown for the lognormal form represent the range of values for the four runs made at each combination of factor levels for factors A and B.

Table 5.5

Sensitivity to Form of Repair Time Distributions

	Maximum CDF Difference	
	Lognormal	Exponential
Factors A and B low	0.1232 -- 0.1308	0.1273
Factors A and B high	0.0099 -- 0.0165	0.0147

Table 5.5 indicates that there is no substantial difference between the results using the exponential vs. the lognormal form for subsystem repair time distributions. The exponential results fall well within the ranges of results for lognormal distributions, indicating that any change caused by the exponential forms is of a magnitude no greater than the level of random error in the simulation. Since the exponential distribution is shaped differently than the lognormal distribution, there is no reason to believe the results shown in Figure 5.1 are particularly sensitive to forms of the subsystem repair time distributions.

Another variable that might be of interest is the amount of "grouping" of the subsystem reliabilities. While the effect of changes in the variability of subsystem

reliabiliities has been previously examined, a constant "spread" of this variablity between subsystems has been maintained. To examine the effect of grouping, the subsystems can be randomly divided into two groups: one group with high reliabilities (m_i=5000.0) and one group with low reliabilities (m_i=50.0). An additional computer run using these subsystem reliabilities yields an overall aircraft reliability of 4.1254 MSBF and a maximum CDF difference of 0.0300. Since the grouped reliabilities have a coefficient of variation of 0.9802, interpolation using Figure 5.1 yields an expected maximum CDF difference of about 0.029. This compares very favorably to the 0.030 maximum CDF difference obtained from the grouped data, and the results summarized in Figure 5.1 are apparently insensitive to grouping in subsystem reliabilities.

Correction Factor

The previous analysis indicates that the applicability of the single-failure analytical method can be determined with reasonable confidence simply by determining the overall reliability of the weapon system. The effects of maintainability characteristics (mean and variance of subsystem repair time distributions) are statistically insignificant over a wide range in a factorial analysis. While the effect of variability between subsystem reliabilities is statistically significant, it has no

practical impact compared to the impact of overall system reliability. The possibility therefore exists that the analytical method could be applied to less reliable systems by performing some adjustment operation on a single failure CDF for the system. This adjustment need only reflect the overall system reliability.

The results summarized in Figure 5.1 indicate a nonlinear strictly-convex relationship between overall aircraft MSBF the maximum difference between the analytical and "actual" CDFs. The shape of the curve suggests that an approximate linear relationship may exist between the maximum CDF difference and a logarithmic or reciprocal transformation of the aircraft MSBF. Another possibility worth investigating is the relationship between the maximum CDF difference and the aircraft reliability r (probability of no subsystem failures). Figure 5.2 illustrates the most linear of these relationships: the maximum CDF difference vs. the reciprocal of the aircraft MSBF. The relationship can be approximated nicely with a least-squares linear regression equation:

$$M = 0.00141 + 0.1086\ (1/m) \qquad (5.2)$$

where M is the maximum CDF difference and m is the overall aircraft MSBF. Only the results for runs at the high level of factor B are used in the regression since the high level is representative of the data for existing weapon systems

and also for the ATF. The low level of zero is extreme and serves only to demonstrate the lack of substantial influence of the factor. The linear fit is performed by applying a regression program of the BMDP statistical package (24:283) to the results of runs 3, 4, 7, 8, 11, 12, 15, 16, 17, 18, and 19. The coefficient of determination (R^2) for the resulting equation is 0.99854, indicating an excellent fit to the data (47:241).

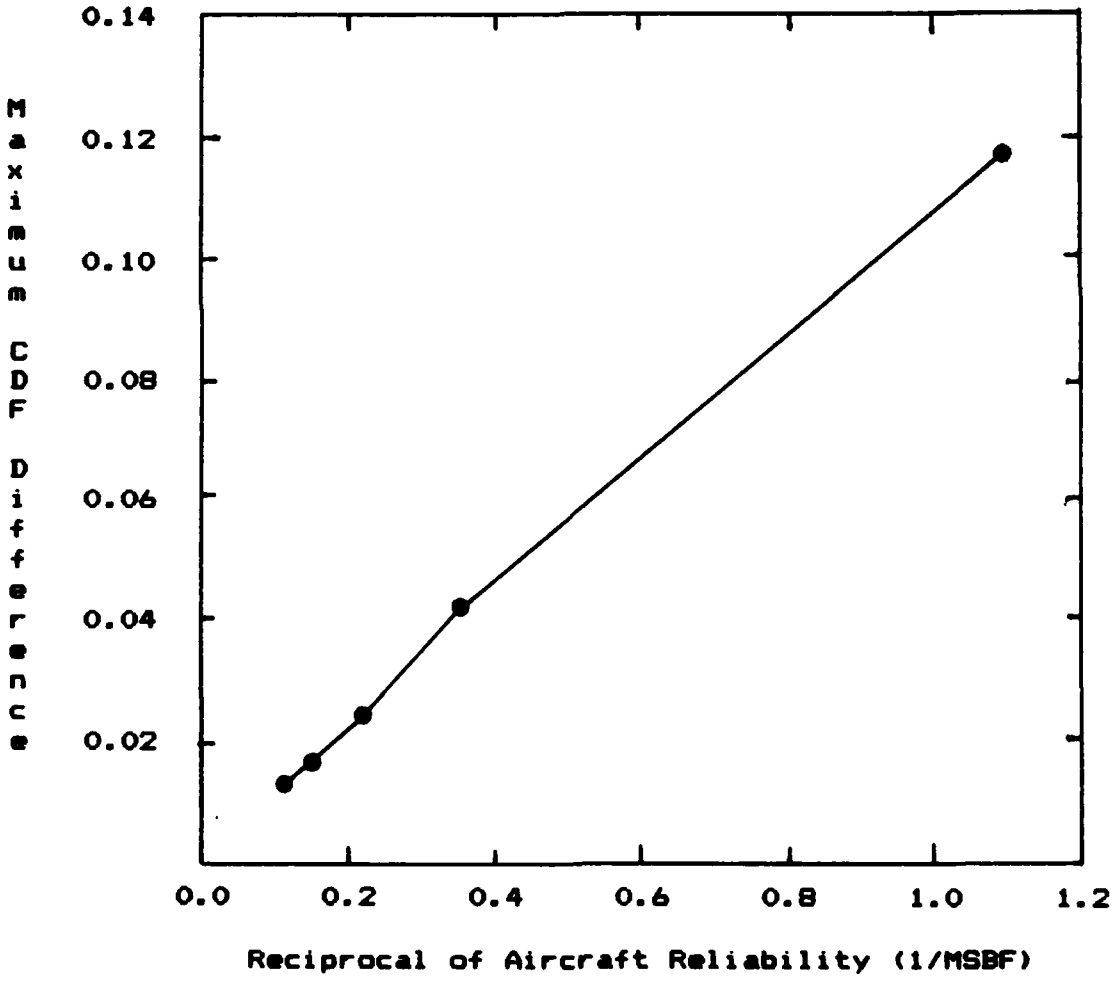

Figure 5.2. Maximum CDF Difference vs. 1/MSBF

While Eq (5.2) can be applied to determine the maximum amount the analytical CDF must be corrected by to represent the "actual" distribution, it is necessary to apply a correction at every point of interest on the CDF rather than just the point of maximum difference. Therefore, for an adjustment operation to be useful, it is neccessary to demonstrate a consistent relationship between the maximum difference and the difference at other points over the full range of repair times. The comparison portion of the Repair Time Distribution Model output provides the necessary information. For each run, values of the difference between analytical and simulation CDFs are listed over the range of repair times in increments of 0.05 on the simulation CDF.

Figure 5.3 shows various plots of the amount of CDF difference as a function of the value of the analytical CDF. The runs plotted represent a variety of factor levels and conditions examined in the sensitivity analysis. Note that the shape of the difference function is extremely consistent. The shapes are almost exactly identical for the runs at low reliability levels. At high reliability levels, the shapes are quite jagged because the maximum difference is small and magnifies the effect of random error. However, the general form is the same under all conditions; the difference function is strictly-concave and reaches its maximum just above the median of the analytical CDF. This difference function can be used to adjust any analytical CDF over its full range.

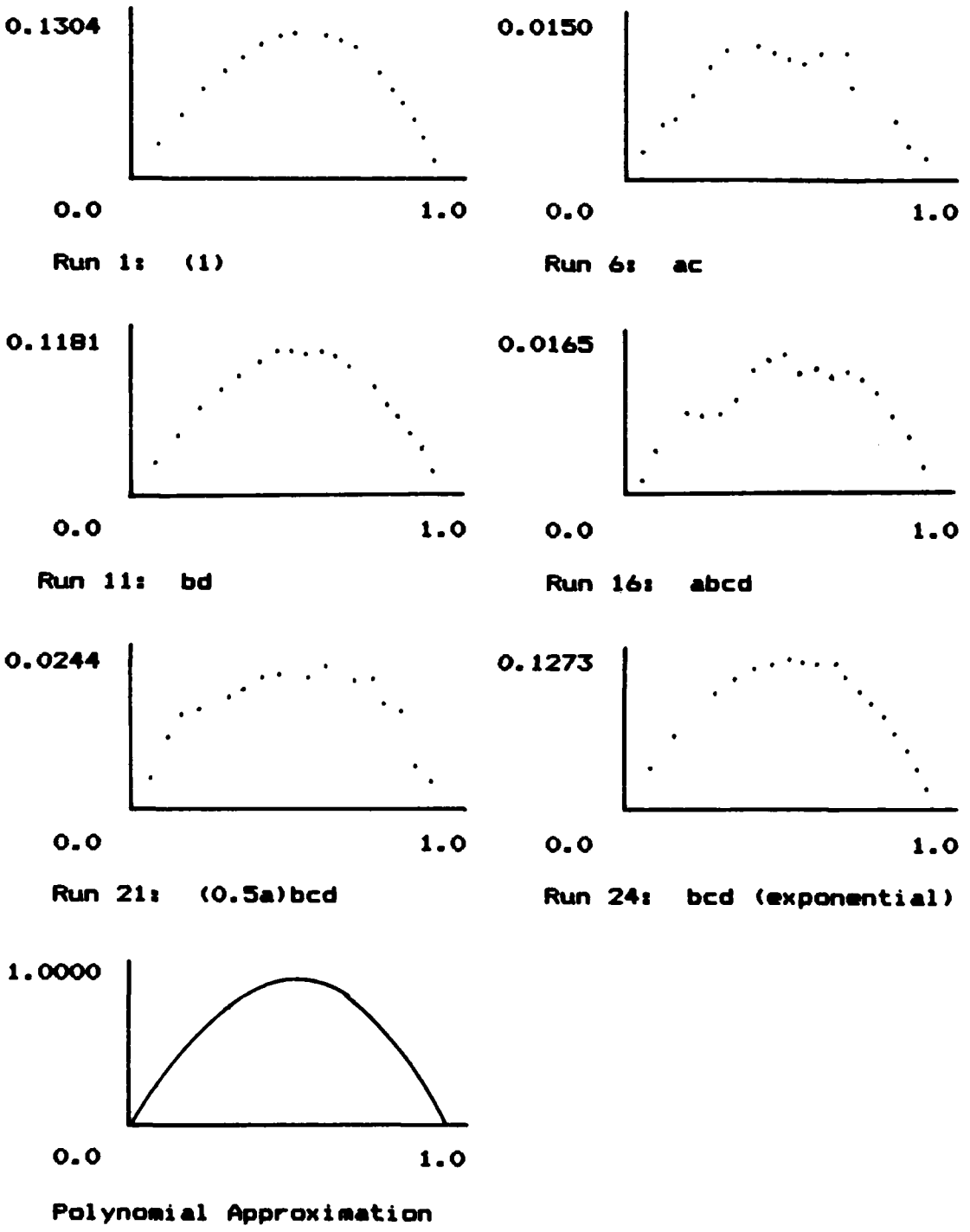

Figure 5.3. Plots of the Difference Function (CDF Difference vs. Analytial CDF)

To describe the difference function mathematically, CDF difference results of computer runs 3, 7, 11, and 15 are regressed using the BMDP polynomial regression program. The value of each CDF difference used is the regression is transformed to a proportion of the maximum CDF difference for its associated run. Only runs at low reliability levels are used since random error has minimal influence in these runs and we are most interested in performing a correction for less reliable systems. A polynomial regression equation with a very large number of terms could be generated, but substantial reduction in the coefficient of determination ceases beyond a third order equation (R^2=0.99831). The last plot in Figure 5.3 is generated using the resulting regression equation:

$$K = -0.00134 + 3.2372\ G - 1.8399\ G^2 - 1.3974\ G^3 \quad (5.3)$$

where K is the correction factor (proportion of maximum difference) and G is the value of the analytical CDF. Thus, to produce an adjusted CDF, the maximum CDF difference must be determined from the overall system MSBF using Eq (5.2). Then, for each point of interest on the CDF, Eq (5.3) must be applied to determine the correction factor. The value of the correction factor times the maximum CDF difference (K x M) must then be subtracted from the analytical CDF to produce an adjusted value of the CDF at that point.

Because of the consistent nature of the difference

function, the correction operation can be performed to make the single failure assumption apply to a system of any reliablity level over the range studied. It is important to point out that other assumptions are made in developing the analytical model (e.g. simultaneous subsystem repairs and exponentially distributed subsystem failures). Care should be taken to examine the applicability of these assumptions in applying the modified analytical method to less reliable systems, such as existing aircraft.

Computational Efficiency Comparison

Table 5.6 presents a summary of the amount of computer core processing time used by the analytical and simulation methods to form an aggregate repair time distribution. The time used by operations common to both methods, such as reading and transforming the input data, is excluded from the comparison. The times in Table 5.6 represent the average times for all runs made using the high and low subsystem reliability levels. While the simulation method uses considerably less computer time at low reliability than

Table 5.6

CPU Time Comparison (seconds)

	Low Reliability	High Reliability
Analytical Method	0.703	0.702
Simulation Method	186.360	1080.159

at high reliability levels, the analytical method uses much less time than the simulation method under any conditions. The analytical method could clearly be feasibly implemented on a microcomputer. Such implementation does not appear practical for simulation method, particularly for analysis of highly reliable aircraft such as the Advanced Tactical Fighter.

VI. Translation to Measures of Operational Effectiveness

Relevant Considerations

In order to apply the methodology of this project to reliability and maintainability allocation decisions, it is necessary to translate the aggregate aircraft repair time distribution into accepted measures of operational effectiveness. Such measures include aircraft availability and sortie generation capability. It is intuitively clear that decreasing the mean of an aircraft repair time distribution will improve the operational effectiveness realized by the aircraft if no other changes in the distribution occur. However, the impact of changes in other distribution characteristics (variance,skewness, etc.) is not intuitively discernable. Furthermore, the impact may vary with the particular concept of operations envisioned for the aircraft. It is therefore necessary to develop a model that will combine the aircraft repair time distribution and concept of operations to produce valid measures of operational effectiveness.

The aircraft concept of operations must consider several factors. An operational unit consisting of a fixed number of aircraft launches sorties according to a daily schedule. This schedule is constrained by many factors other than unscheduled maintenance, such as scheduled maintenance and mission planning constraints. Furthermore, whenever an aircraft returns from a sortie, it must undergo

routine "turn-around" operations, such as refueling and reloading of munitions, before it can begin another sortie. Another consideration particularly applicable to a fighter aircraft is the concept of a "sortie launch window." Tactical fighter operations typically consist of daylight missions, and the vast majority of sorties are therefore flown in a daily time "window" of daylight hours. The impact of this window concept is significant because it permits use of the non-window time to correct aircraft malfunctions without affecting the sortie generation rate.

General Approach

The factors discussed above complicate the problem of translating the analytical repair time distribution into measures of operational effectiveness. One approach to the problem would be the use of Monte Carlo simulation. A simulation model could be constructed using random variates to determine aircraft arrival times, failure rates, and repair times. However, use of simulation at this stage of the analysis would reintroduce the disadvantages avoided by the use of the analytical method for forming an aggregate repair time distribution. For example, the improvement in computational efficiency realized by using the analytical method would be partly lost.

A unique approach that can incorporate all of the necessary concepts without resorting to Monte Carlo

techniques is a "deterministic simulation" based on a model already developed by the ATF System Program Office (50). The central idea of the model is that the movement of aircraft from on status to another (e.g. flying a sortie to being repaired) can be modeled as a continuous flow. At discrete points in time, the quantities of aircraft in each status can be counted. These quantities can in turn be used to determine the aircraft availability and sortie generation rate at each discrete point in time. If the interval between the points of time is sufficiently small, the average values for these discrete availabilities and sortie generation rates will approximate the theoretical values for the entire time period examined. The effect of launch constraints not caused by unscheduled maintenance can be modeled by restricting the number of aircraft that can be launched during each time interval between time points. Also, the effect of a sortie launch window can be modeled by preventing launches in a time interval if that interval falls outside the launch window.

Description of Model

At any point in time, an aircraft will be in one of four states. It will either be flying a sortie, undergoing turn operations, undergoing repairs, or waiting for launch in a ready condition. In each interval between time points examined, aircraft may change from one state to another in accordance with the relationships illustrated in Figure 6.1.

Since we are interested in calculating average theoretical values, the movement between states need not be restricted to whole numbers of aircraft. Portions of aircraft can be moved from one state to another in accordance with the probability associated with that movement. For example, if an aircraft design produces a probability of failure of 0.30, three-tenths of a single aircraft returning from a sortie will enter the repair state and seven-tenths of the aircraft will immediately enter the turn state.

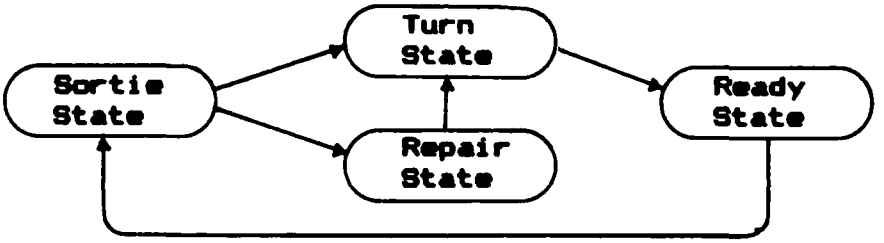

Figure 6.1. Relationship of Aircraft States

A key element of the model is the method used to move aircraft quantities from the repair state to the turn state. The analytical repair time CDF produced by the analytical method is presented in a numerical form. Values of the CDF are provided for various points of time in constant fixed intervals. If these interval widths are selected to coincide with the interval widths used in the operational effectiveness model, probability of movement from the repair to turn state in a single time interval can easily be obtained. The probability of movement in the interval

between repair time t_1 and repair time t_2 is simply the difference in cumulative probabilities associated with the two times $\{F(t_1)-F(t_2)\}$.

To implement the repair time interval probabilities on a computer, the probabilities can be stored in an array whose elements represent each time interval. The number of elements in the array can be established by determining the number of time intervals necessary to reach a total cumulative probability very near to 1.0. The probability associated with the last interval can then be set equal to 1.0 minus the cumulative probability associated with the upper bound of the previous interval. Table 6.1 presents a simplified example of computations for repair time interval probabilities using 0.5 hour time intervals.

In order to track the quantity of aircraft in any state at any point in time, state arrays must be established for the sortie, turn, and repair states. The number of elements in the repair state array will be equal to the number of elements in the repair time probability array, thus maintaining a one-to-one correspondence. If we assume that sortie and turn times are constant, the number of elements in the sortie and turn state arrays will be equal to the state duration divided by the time interval width. For example, using a 0.5 hour interval and a 2.0 hour constant sortie duration, the sortie state array will contain four elements. The example shown in Figure 6.2 illustrates the

configuration of the various state arrays; the rectangular symbols in the figure represent array elements.

Table 6.1

Example of Repair Time Interval Probabilities

Time (t)	F(t)	Interval	Probability
0.00	0.000		
		1	0.037 (0.037 - 0.000)
0.50	0.037		
		2	0.211 (0.248 - 0.037)
1.00	0.248		
		3	0.232 (0.480 - 0.248)
1.50	0.480		
		4	0.187 (0.667 - 0.480)
2.00	0.667		
		5	0.135 (0.802 - 0.667)
2.50	0.802		
		6	0.088 (0.890 - 0.802)
3.00	0.890		
		7	0.053 (0.943 - 0.890)
3.50	0.943		
		8	0.030 (0.973 - 0.943)
4.00	0.973		
		9	0.027 (1.000 - 0.973)
4.50	0.986		

In implementing the operational effectiveness model, time must be advanced in the specified time increment up to a specified maximum time. At each time increment, aircraft quantities must move through the state arrays or from one state to another. In the example in Figure 6.2, if 5.0 aircraft are launched at time t, they are placed in the fourth (last) element of the sortie state array. The 5.0

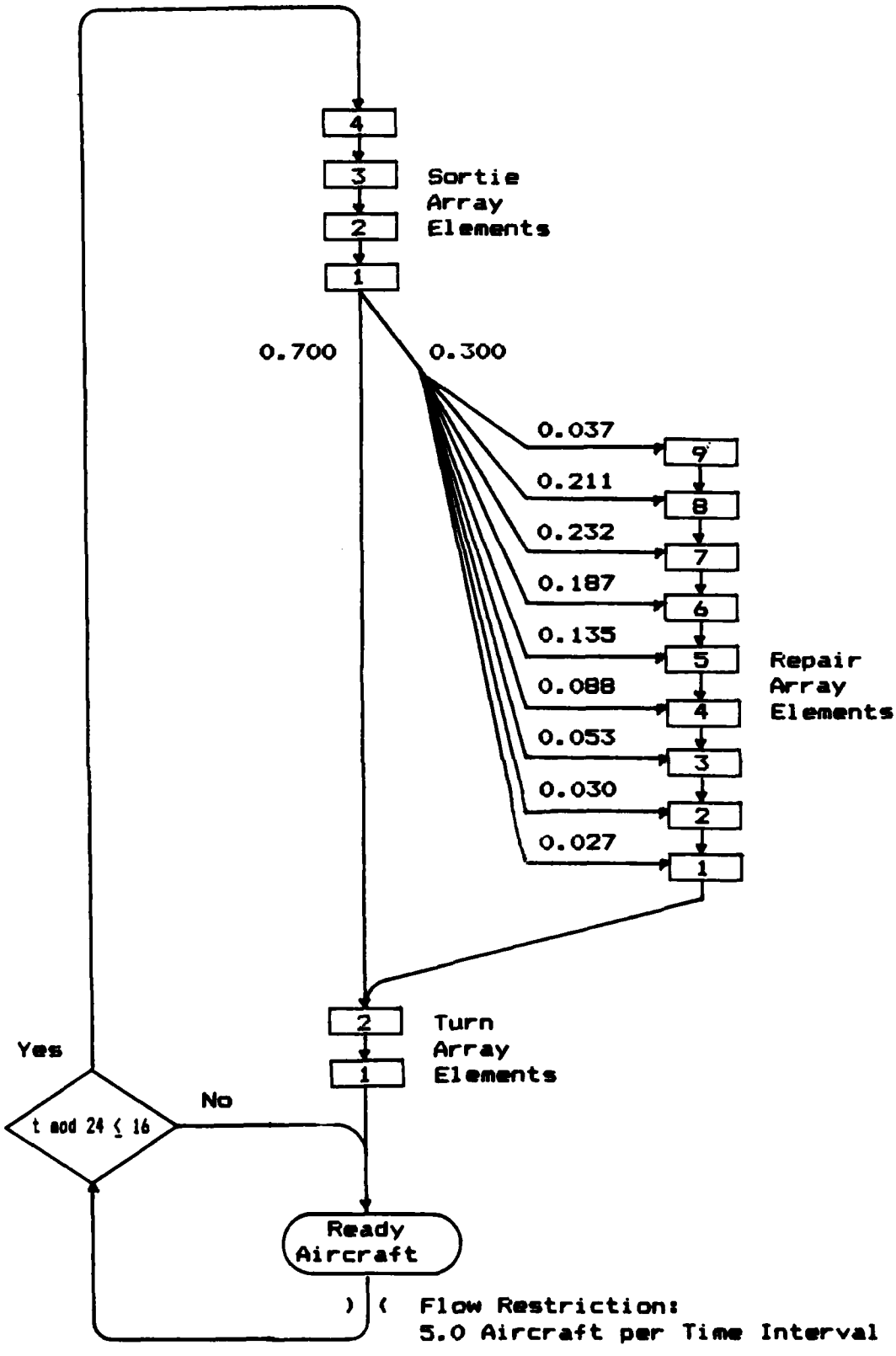

Figure 6.2. Movement of Aircraft Quantities Between States

aircraft move to the third element of the sortie state array at time t+0.5, to the second element of the array at t+1.0, and to the first element of the array at time t+1.5. At time t+2.0, the aircraft leave the sortie state array. If aircraft reliability is 0.70, 3.50 aircraft (5.0 x 0.70) enter the last element of the turn array and 1.50 aircraft enter the repair array. Each element of the repair array receives a quantity of aircraft equal to 1.50 times the repair time interval probability associated with the array element.

At any point in time examined, all aircraft leaving the repair array immediately enter the last element of the turn array. In the example in Figure 6.2, the aircraft turn time is 1.0 hours (two array elements). All aircraft leaving the turn array are added to an existing quantity of ready aircraft, some of which may immediately enter the last element of the sortie array in accordance with launch constraints. If the current time is not in the sortie launch window, no aircraft enter the sortie array. If the quantity of aircraft in the ready state is less than the maximum quantity of permitted launches per interval, all aircraft in the ready state enter the last element of the sortie array and the quantity of ready aircraft is reduced to zero. If the quantity of aircraft in the ready state is greater than the maximum permitted launch quantity, the maximum permitted launch quantity enters the last element of

the sortie array and the quantity of ready aircraft is reduced accordingly. In the example in Figure 6.2, the maximum permitted launch quantity is 5.0 aircraft and the sortie launch windown is open 16.0 hours a day.

For any point in time, an aircraft availability can be calculated as the sum of the quantities of aircraft in the sortie and ready states divided by the total number of aircraft in the operational unit. This computation requires a determination of the total quantities of aircraft in each array at each time increment. To determine the average availability for the entire period considered by the model, the availabilities at each time increment can be iteratively summed and then divided by the total number of time intervals examined. To determine the average daily sortie generation rate, the quantities of aircraft entering the sortie state during each time interval can be iteratively summed and then divided by the number of days in the period considered by the model.

Computer Implementation

The last portion of the Repair Time Distribution Model listed in Appendix B performs the operational effectiveness translation. Appendix A provides detailed documentation. The translation is performed twice in the program: once using the analytical single failure repair time distribution and once using the simulation multiple failure distribution. The analytical aircraft reliability includes the possibility

of multiple failures and is used in each case.

In addition to providing an average aircraft availability and sortie generation rate, the implemented program also lists the minimum availability encountered among all the time increments examined. To indicate how aircraft status and availability fluctuate over time, current availability, sortie generation rate, and quantities of aircraft in each state are presented at points in time which are separated by a user-specified time interval. Also, an average repair rate is computed, which is the sum of all aircraft quantities entering the repair state divided by the the total number of days in the period considered in the model.

Translation Model Results

Typical Output. The sample output in Appendix C presents operational effectiveness results using the ATF data in Table 1.1. The repair time CDF is computed for time increments of 0.2 hours up to a maximum repair time of 8.0 hours. A 2.4 hour sortie time is used to reflect 2.0 flying hours and an additional 0.4 hours for ground operations (engine start, ground checks, taxi-out, and taxi-back). The aircraft normal turn time for refueling and reloading is 0.4 hours. The concept of operations employs a 16.0 hour sortie launch window, with the flow of aircraft restricted to 2.0 launches per 0.2 hour increment (10.0 launches per hour).

Since the maximum possible repair time is no greater than the daily amount of time outside the sortie launch window, the average availability and sortie generation rate is identical for each day of operations. Thus, to verify that the model is operating properly, operational effectiveness calculations are performed for a 48.0 hour period. Operational effectiveness results are presented in 2.0 hour time increments.

The results in Appendix C indicate a negligible difference in measures of operational effectiveness for the single and multiple failure repair time distributions when ATF reliability and maintainability data are used. Average aircaft availability is 0.8661 for the analytical single failure CDF and 0.8655 for the simulation multiple failure CDF, a difference of only about 0.07 per cent. The sortie generation rate is 5.5070 for the single failure distributon and 5.5028 for the multiple failure distribution, representing a difference of only 0.08 per cent. The single failure assumption is therefore clearly appropriate for the purposes of supporting reliability and maintainability allocation decisions for the ATF under the hypothesized concept of operations.

Factor Analysis. The results from the experimental design presented in Chapter V can be used to examine the effect of various relevant factors on measures of operational effectiveness and on the applicability of

the single failure assumption. Each run of the design includes computation of an aircraft availability and sortie generation rate using the concept of operations described above (16.0 hour sortie launch window and maximum launch rate of 10.0 aircraft per hour). The following factors are included in the experimental design:

A) Overall aircraft reliability

B) Variability among subsystem reliabilities

C) Variances of subsystem repair time distributions

D) Means of subsystem repair time distributions

In order to test the factors for statistical significance using a single replicate of the design, it is necessary to assume the effect of certain higher order interactions to be negligible (46:274). By assuming third and fourth order effects are insignificant, they can be used to represent random error. The main effects and two-term interactions can then be tested for statistical significance.

Table 6.2 summarizes the effects of each factor on the aircraft availability and sortie generation rate produced from a multiple failure repair time distribution. Critical values of the F statistic for α=0.05 and α=0.01 are shown below the table. While several main effects and interactions appear statistically significant, it is apparent that the dominant effects are exerted by factor A (aircraft reliability) and factor D (subsystem mean repair times).

Table 6.2

Factor Effects on Measures of Operational Effectiveness

	Aircraft Availability		Sortie Generation Rate	
Factor	Effect	F Statistic	Effect	F Statistic
A	0.1186	36439.0724 **	1.0053	11707.2720 **
B	3.0625E-05	24.2610 **	0.0218	5.5044 *
AB	-2.2375	12.9504 *	-0.0159	2.9190
C	-6.6250E-04	1.1353	0.0490	27.8662 **
AC	3.1875E-03	26.2820 **	-8.5750E-03	0.8516
BC	1.2500E-05	4.0418E-04	1.0000E-04	1.1582E-04
D	-0.07594	14916.6035 **	-0.5770	3855.7915 **
AD	0.0519	6971.0988 **	0.3826	1695.4675 **
BD	1.5875E-3	6.5190 *	0.0106	1.3199
CD	3.1625E-04	25.8713 **	0.0468	25.3412 **

** F(0.01) = 21.20
* F(0.05) = 6.61

Figure 6.3 graphically depicts the effect of aircraft reliability and mean repair time on aircraft availability. The two sets of plots on the graph represent the two different levels of mean repair time. The solid plot in each set depicts the single failure case, and the dashed plot depicts the multiple failure case. The curvilinearity of the plots is established from additional runs of the analytical method using intermediate reliability levels.

An interesting result apparent from Figure 6.3 is that improvement in aircraft reliability yields a substantially decreasing marginal return in availability. If availability is used as a measure of operational effectiveness and the effect of queuing delays is not considered, improvement in

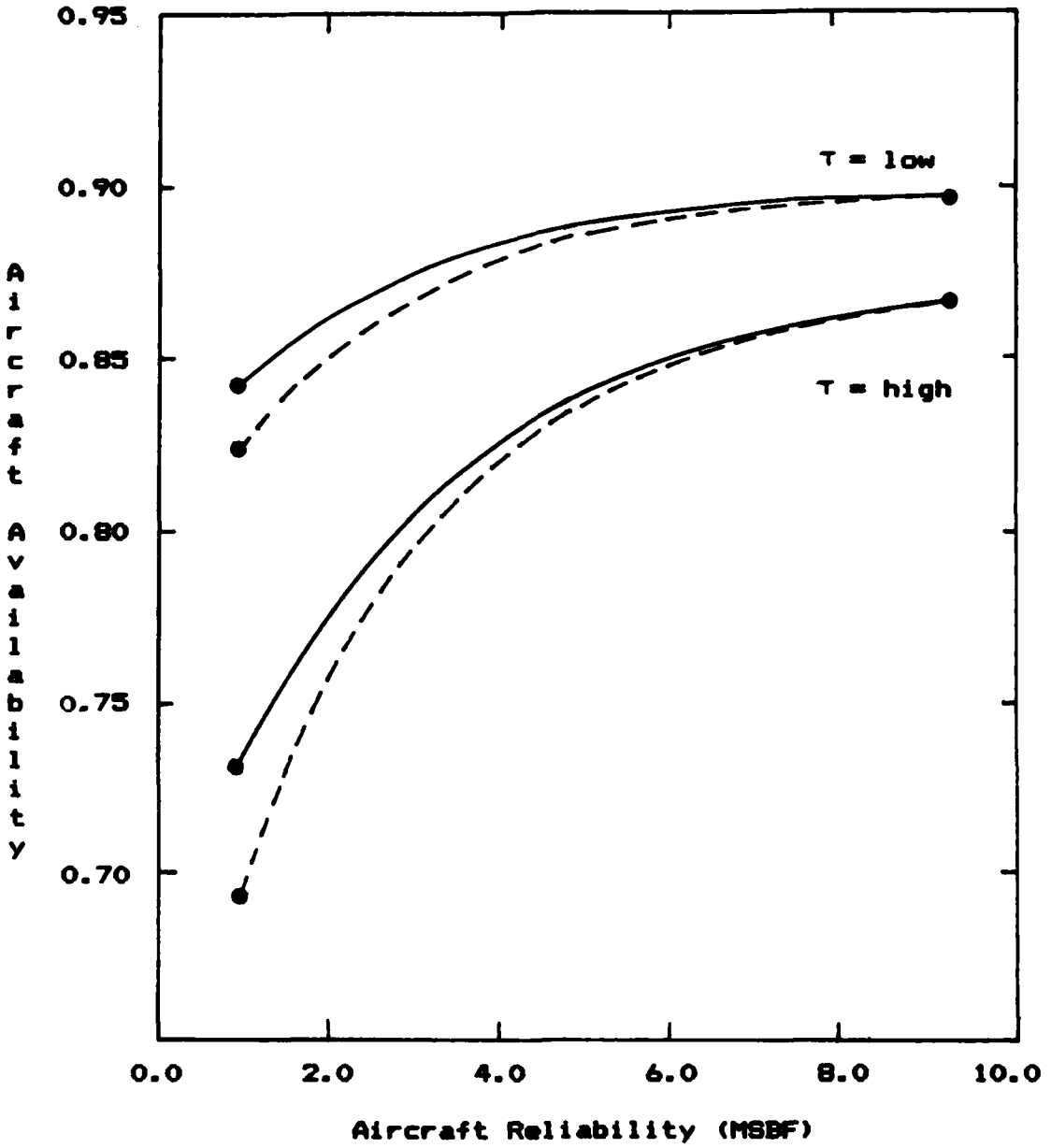

Figure 6.3. Aircraft Availability vs. Aircraft Reliability and Mean Repair Time

reliability beyond 5.0 MSBF does not appear justified for the hypothesized concept of operations. Reduction in mean repair time appears to offer considerable benefit, particularly at low reliability levels. In addition, Figure

6.3 indicates that the single failure assumption appears to have little influence on availability results for this concept of operations unless the aircraft reliability is low and the mean repair time is high.

Figure 6.4 presents similar results for the aircraft sortie generation rate. The lower group of plots depicts the hypothesized concept of operations. Significant interaction of the reliability and maintainability factors is again apparent. Reliability improvement again offers diminishing marginal returns and mean repair time exerts noticable influence.

The effects of reliability and maintainability characteristics on an aircraft sortie generation rate are greatly influenced by the concept of operations. For this reason, an additional group of plots is presented for a totally unrestricted operating scenario. In this scenario, the sortie launch window is open 24.0 hours a day and no restrictions are placed on the number of launches per time interval. The results shown represent the average sortie generation rate realized over a thirty day period.

The single failure plots for the new scenario reflect the results of additional runs of the analytical methodology. The multiple failure plots are produced using the correction factor technique described in Chapter V. The plots indicate that removal of launch constraints not related to unscheduled maintenance results in

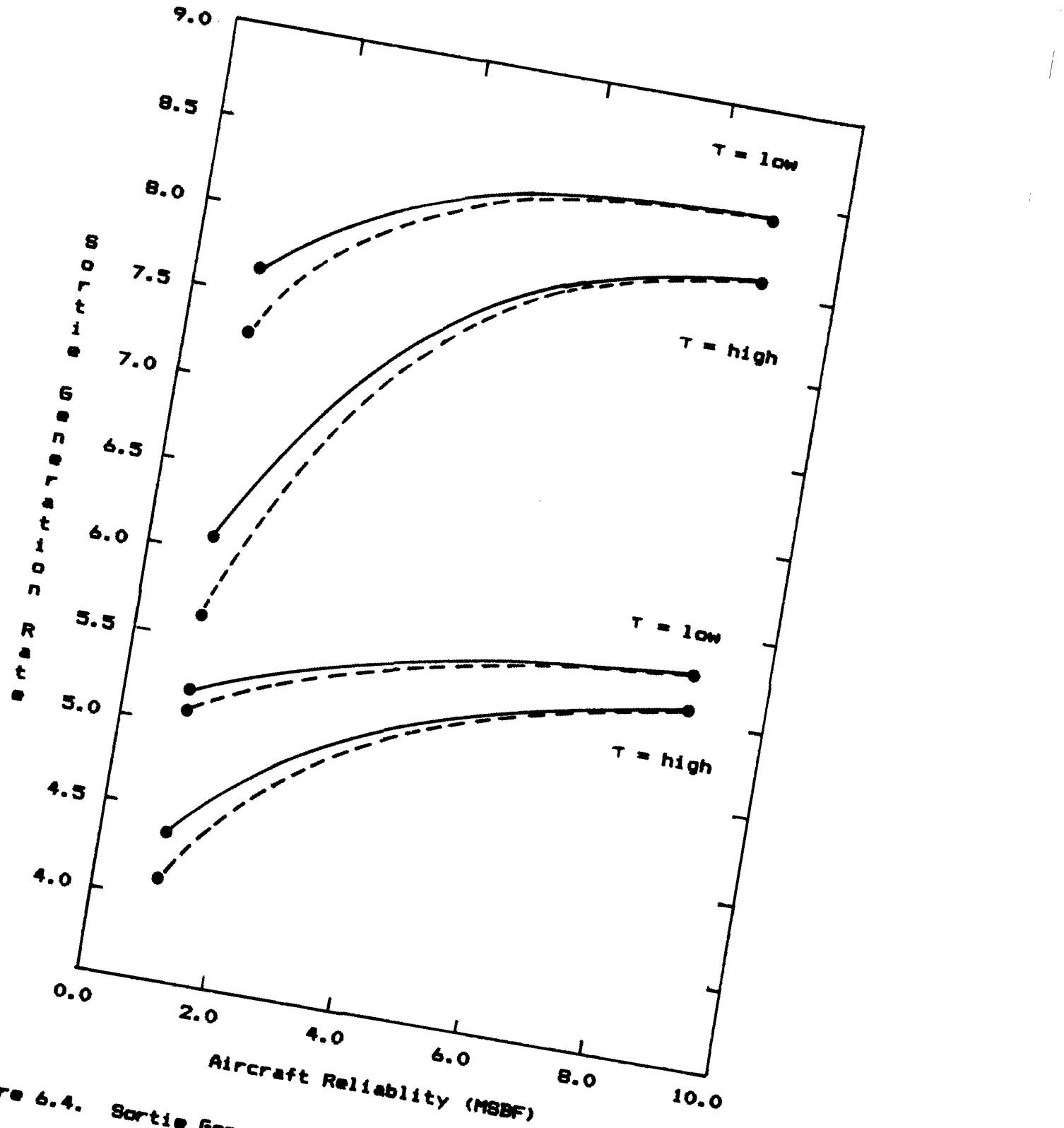

Figure 6.4. Sortie Generation Rate vs. Aircraft Reliability and Mean Repair Time

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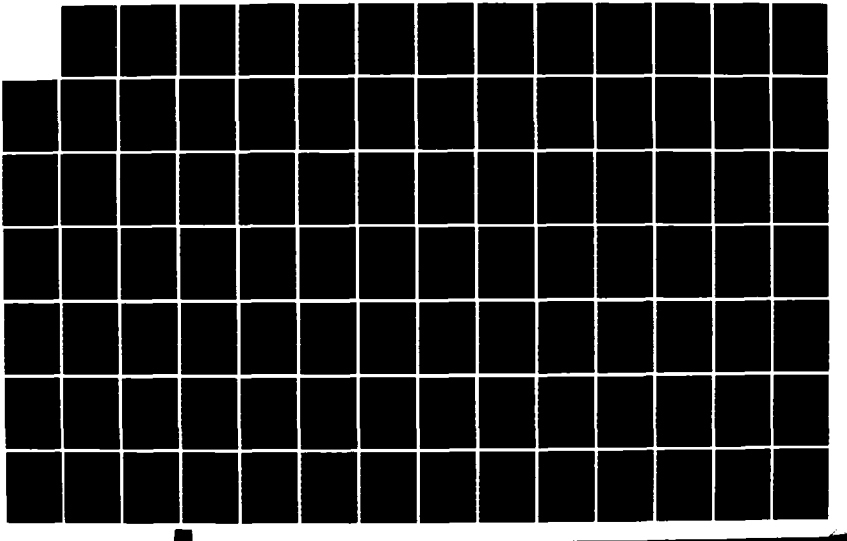

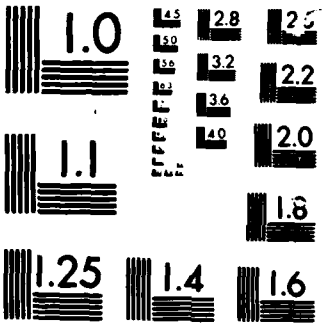

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amplification of the effect of R&M factors on sortie generation capability. Also, the plots indicate that the impact of the single failure assumption becomes particularly significant at low reliability levels under the unrestricted concept of operations.

Modified Repair Time Distribution Model

To facilitate application of the project methodology to ATF reliability and maintainability allocation decisions, the modified computer program listed in Appendix D is provided to permit rapid evaluation of the effect of subsystem R&M characteristics on measures of operational effectiveness. The program is a second version of the Repair Time Distribution Model developed for the project and is designed for implementation on a FORTRAN capable microcomputer such as the Zenith model Z-100 or Z-150. Appendix A describes the specific differences between the two versions of the program. Sample output is provided in Appendix E.

A major change incorporated in the the modified program is the elimination of the simulation and comparison routines. The program forms the aggregate repair time CDF using only the analytical methodology. In order to extend the reliability levels to which the methodology is applicable, the correction factor procedure discussed in Chapter V is employed to produce an adjusted repair time CDF. This adjusted CDF can then be used in the translation

to measures of operational effectiveness.

The modified version uses an extensive network of menus to facilitate user interaction. The user can interactively change subsystem data and the concept of operations. Changed data can be overwritten to the permanent data file or used for a single run of the program. This feature permits rapid assessment of alternative allocation strategies or measurement of the impact of proposed subsystem modifications.

VII. Extension of Methodology to Constrained Resources

Impact of Resource Constraints

The aggregate repair time distribution formed by the analytical methodology of this project does not incorporate delays caused by queuing for scarce resources required for the accomplishment of unscheduled maintenance. These resources can generally be classified under one of three categories: manpower, spare parts, or equipment. Because of relatively low reliability and high maintenance requirements of current aircraft, resource constraints often have a substantial impact on system operational effectiveness. Many simulation models currently used to estimate measures of operational effectiveness use resource requirements and availabilities as primary inputs (57:2).

If the reliability levels estimated for the Advanced Tactical Fighter are realized, resource requirements for the ATF will be much less than the requirements for current aircraft. In order to prevent severe underutilization of maintenance specialists, the concept of maintenance envisioned for the ATF involves substantial combining of Air Force Specialty Codes (AFSC). One concept considered by the ATF System Program Office assigns all subsystem work unit codes to only five types of specialists, with subsystem responsibilities assigned as shown in Table 7.1 (50). Table 7.1 also lists the minimum number of each type of specialist required to perform all tasks on every assigned subsystem.

Table 7.1

ATF Manpower Requirements for Unscheduled Maintenance

Specialist AFSC	Number Required	Assigned Subsystem Work Unit Codes
42770	2	11
43170	2	12,13,14,41,45,46,47
42670	2	23,24
32670	3	42,44,49,51,55,62,63,64,65,71,76,97
31670	3	74,75

The negligible effect of manpower constraints on ATF repair time is evidenced by the results of a Monte Carlo simulation developed by this project for preliminary investigation of the factors contributing to an aircraft repair time distribution. The simulation generated aircraft arrivals according to a Poisson process (time between arrivals exponentially distributed) reflecting a sortie generation rate of 6.0 sorties per aircraft per day. The maintainability characteristics of the aircraft subsystems were set to the values shown in Table 1.1. Multiple runs of the simulation were performed with subsystem reliabilities scaled to reflect different levels of overall aircraft reliability. For the constrained runs, manpower availability was set to the minimum requirements shown in Table 7.1. For the unconstrained runs, the availability of each type of specialist was set to a very high number (100). Figure 7.1 presents a plot of the change

in aircraft mean repair resulting from resource constraints vs. overall aircraft reliability.

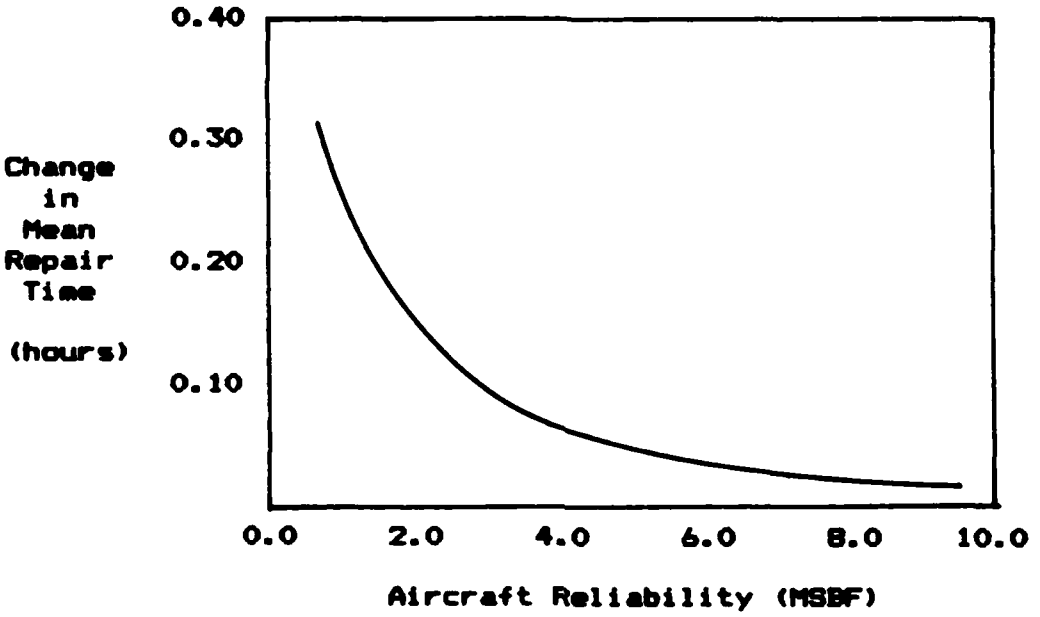


Figure 7.1. Impact of Manpower Constraints vs. Aircraft Reliability

Figure 7.1 indicates that even severe manpower constraints have virtually no impact on mean repair time for a highly reliable system such as the ATF. However, the manpower constraints begin to exert some influence at lower reliability levels where the analytical method for forming a repair time distribution may still be applicable. Extension of the project methodology to include handling of resource constraints is therefore desirable, since the methodology could then be used to iteratively determine the resource requirements associated with various R&M allocation strategies.

Complicating Factors

The task of incorporating the effect of queuing delays into the methodology of this project is complicated by the fact that the operating environment of an aircraft is generally a closed queuing network. The form of an aircraft repair time distribution influences the demand for maintenance resources, which in turn influences the form of the repair time distribution. Recent efforts have applied classical queuing theory to the specific problem of determining aircraft availability and the probability of stock-out for various spare parts (44:257; 59:253). However, such an approach requires the assumption that aircraft repair time is exponentially distributed. Furthermore, the methodology does not provide information relative to the effects of subtle changes in repair time distributions on measures of operational effectiveness.

In addition to the difficulty caused by the closed nature of the operating environment, more complexity arises from the fact that the magnitudes of queuing delays depend on the availability of numerous specific resources. The complexity of the problem suggests that queuing delays cannot be analytically incorporated into a single aggregate repair time distribution for an aircraft. However, the project methodology could be adapted to consider the ultimate impact of individual resource constraints on measures of operational effectiveness.

Adaptation of Model

The general approach to adapting the project methodology can best be described by considering the specific example of manpower resource constraints. Rather than forming a single repair time distribution for the entire aircraft, separate analytical repair time distributions could be formed for each of the five groups of subsystems delineated in Table 7.1. The cumulative distribution functions for the five repair time distributions could then be used to form five separate repair state arrays according to the methodology presented in Chapter VI. By applying the single failure assumption, the probability that any failed aircraft will enter a particular repair state array k can be calculated as

$$p_k = \sum_{i=1}^{K} (1-r_i) \; / \; \sum_{i=1}^{N} (1-r_i) \qquad (7.1)$$

where r_i is the sortie reliability of subsystem i, K is the total number of subsystems requiring resource k, and N is the total number of aircraft subsystems.

The movement of aircraft quantities between state arrays is illustrated by the example in Figure 7.1. Aircraft quantities leaving the sortie state are portioned into failed and non-failed quantities as determined by the overall aircraft reliability. The failed aircraft are then portioned into the five repair state arrays in accordance with probabilities calculated using Eq (7.1). Each array

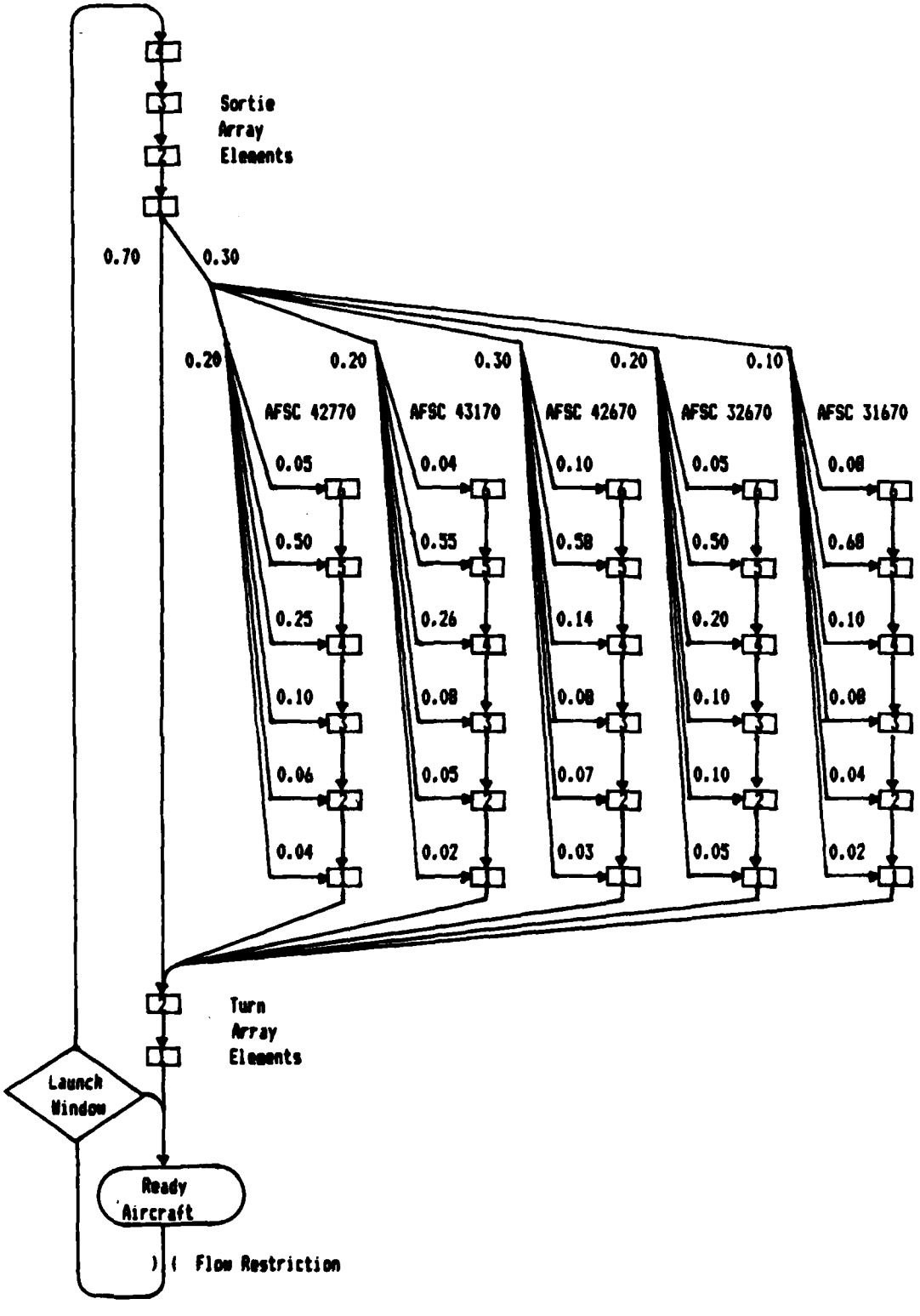


Figure 7.2. State Arrays with Manpower Constraints

element receives a quantity of aircraft determined by the corresponding cumulative distribution function.

To model the impact of resource constraints, movement from one array element to the next can be restricted to the maximum quantity of aircraft which available resources can service. For example, if manpower availability is sufficient to service only one aircraft, any aircraft quantity in excess of 1.0 remains in its current array element for the next time increment. Separate availabilities can be set for each type of resource.

Limitations

The general approach of generating multiple repair time distributions is particularly well suited to the manpower problem because the aircraft subsystems can be divided into groups that require only one type of maintanence specialist. However, if one or more subsystems routinely require more than one type of specialist for repair, the methodology breaks down because mutually exclusive repair arrays can not be constructed.

The requirement for mutually exclusive repair arrays becomes particularly limiting when it is necessary to simultaneously model constraints on different categories of resources, such as manpower and equipment. Separate repair time distributions and arrays must then be constructed for all groups of repairs requiring particular combinations of resources. Advancement of aircraft quantities through

each repair array is limited to the quantity of aircraft that can be serviced by the most constrained resource required for the repair. This approach would be workable as long as each equipment item is used by only one type of maintenance specialist. For multi-purpose equipment such as external power sources and light stands, the methodology breaks down. Such equipment is used by more than one type of specialist, and mutually exclusive repair arrays could not be constructed.

Actual computer implementation of an extended model for handling resource constraints is beyond the scope of this project. It should be pointed out that while the general approach uses sub-aggregate repair time distributions rather than a complete aggregate distribution, it is still necessary to assume that only one subsystem will fail before repair is initiated. However, since this assumption has been shown to be reasonable for advanced technology aircraft such as the ATF, further effort at extending the methodogy is justified.

VIII. Summary and Conclusions

Applicability of Method

Essential Conditions. The analytical methodology presented in this project can quickly and accurately form an aggregate repair time distribution for an advanced technology aircraft. However, the applicability of the method is contingent on the following conditions:

1) The probability of failure of any aircraft subsystem is not affected by other subsystem failures

2) The time between failures of each subsystem is exponentially distributed

3) Only one subsystem failure occurs before aircraft repair is initiated

These conditions permit formulation of an aggregate repair time distribution as a probabilistic mixture of known or estimated subsystem repair time distributions. The mean and variance of the aggregate distribution can then be obtained, along with a cumulative probability of aircraft repair within any specified period of time.

For an aircraft in the early stages of development, the condition of independence of major subsystem failures can be reasonably assumed. Only later in the developmental process, when empirical data on interactive subsystem performance is available, can correlations between major subsystem failures be identified. The exponentiality of subsystem failure distributions can be similarly justified. The failure intervals of current aircraft subsystems frequently exhibit

exponential behavior, and the applicability of other distributional forms is generally determined only after empirical data on subsystem reliability is available. Furthermore, the mathematical theory of reliability asserts that all subsystem failure time distributions approach exponential forms as subsystem reliability improves (38:278).

The existence of a reasonable approximation of the last essential condition (single subsystem failures) can be determined by comparing an analytical single failure repair time distribution with a distribution reflecting multiple subsystem failures. The multiple failure distribution can be produced using Monte Carlo simulation. Several factors could influence the amount of disparity between the single and multiple failure distributions, including overall aircraft reliability, variability among subsystem reliabilities, and variances of subsystem repair times. For the particular example of the Advanced Tactical Fighter, overall aircraft reliability emerges as the only critical factor even when all potentially relevant factors are varied over wide ranges. If application of the project methodology is contemplated for an aircraft with characteristics outside of the ranges explored in this project, the approach presented for identifying critical factors could be reaccomplished.

Reliability Requirements. The level of overall aircraft reliability neccesary for justification of the single

failure assumption is dependent on a number of factors. Statistical difference between single and multiple failure repair time distributions can be ensured for any reliability level by using a sufficiently large sample size in forming the multiple failure distribution. However, statistical difference does not necessarily imply a practical significance. The subsystem reliability estimates for the ATF reflect an overall aircraft reliability of 9.5324 Mean Sorties Between Failures. This overall reliability translates to a maximum difference between single and multiple cumulative distribution functions of about 0.016. The CDF difference increases to about 0.023 as reliability decreases to 5.0 MSBF, and then rises rapidly.

While the maximum CDF difference is a useful measure of disparity of single and multiple failure distributions, the ultimate issue is whether or not the assumption affects the operational effectiveness measures upon which reliability and maintainability allocation decisions are based. It is apparent that the subsystem reliability levels estimated for the Advanced Tactical Fighter are sufficient to warrant the single failure assumption, since the disparity between single and multiple failure distributions is negligible. At lower reliability levels, the impact of the assumption depends on the hypothesized concept of operations and the magnitudes of the subsystem repair times. However, within the ranges of reliability and maintainability

characteristics examined in this project, it appears that an overall aircraft reliability greater than 5.0 MSBF ensures a negligible impact of the single failure assumption on measures of operational effectiveness for any concept of operations.

Comparison with Simulation

When the analytical method can be reasonably applied to form an aggregate repair time distribution, it is far more efficient than Monte Carlo simulation. Using ATF reliability and maintainability estimates as input data, the amount of computer core processing time used by each method differs by several orders of magnitude. When implemented on a Digital Research VMS/VAX computer, the analytical method expends about 0.7 seconds of CPU time vs. 1080.2 seconds for the simulation method. Thus, the analytical method facilitates rapid iterative evaluation of the effect of changes in subsystem reliability and maintainability characteristics, whereas simulation requires substantial turn-around time.

Limitations

The analytical method appears to apply primarily to the early stages of the weapon system acquisition process, when many details about subsystem performance and the aircraft concept of maintenance are unknown. As more information is obtained, the value of the analytical method decreases

because it cannot incorporate intricate details. For example, the analytical method cannot accomodate the precise forms of subsystem failure distributions, which could eventually be obtained through developmental testing.

The applicability of the analytical method to individual aircraft components below the major subsystem level is also questionable. If overall system reliability is sufficent to warrant the single failure assumption, the probabilistic mixture concept can be extended to any component level as long as component failures are independent. However, complete independence of components below the major subsystem level does not appear likely.

The most significant limitation of the analytical method is its inability to incorporate queuing delays into the aggregate repair time distribution. Because of the closed nature of the aircraft operating environment and the need for complex matching of individual tasks to particular resources, consideration of resource limitations eludes an analytical approach. While the high reliability of advanced technology aircraft reduces the impact of resource limitations, these constraints should be included in R&M allocation decisions once sufficient information about the aircraft concept of maintenance is known.

The analytical methodology can be adapted to form sub-aggregate repair time distributions for groups of subsystems which require particular types of a specific category of

resource (e.g. manpower). Queuing effects due to constraints on this category of reource can then be included in measures of operation effectiveness. However, this approach can only handle one category of resources at a time. Furthermore, the resource requirements of the various groups of subsystems for which repair time distributions are formed must be mutually exclusive.

Recommendations

While the methodology presented in this project has been applied specifically to the Advanced Tactical Fighter, the approach could theoretically be applied to any weapon system which experiences failures during a "time-limited operational sequence." Many weapon systems to which the method could be applied may have reliability and maintainability characteristics which are not included in the ranges examined in this project. Determination of the effects of subsystem characteristics over wider ranges should be pursued. The effect of other variables, such as the number of major subsystems, should also be examined.

The quality of decisions on how reliability and maintainability characteristics should be allocated between subsystems ultimately depends on how well R&M characteristics can be translated into measures of operational effectiveness. While the analytical method for forming an aggregate repair time distribution has been

thoroughly defined, the "deterministic simulation" model employed to translate the aggregate distribution into measures of operational effectiveness has been presented primarily for demonstration purposes. While the basic methodology of the translation model is already in use at the ATF System Program Office, little has been done to validate the approach. An interesting topic for further research would be measurement of the model accuracy with respect to historical data or the results of a complex Monte Carlo simulation.

Many additional features could be incorporated into the translation model. For example, the sortie and turn state arrays could be designed to reflect non-constant sortie and turn times, as does the repair state array. The model could also be expanded to include additional factors affecting operational effectiveness, such as aircraft attrition and battle damage. More effort at adapting the translation model to incorporate queuing delays also appears justified. Attempts to consider different types of resource constraints may lead to a usable approach for handling multiple categories of resources. Such a breakthrough would substantially increase the value of the analytical method presented in this project.

Appendix A

Documentation for Repair Time Distribution Model

General Description

The FORTRAN program listed in Appendix B, Repair Time Distribution Model (Version 1.0), implements the project methodology. Since one objective of the program is to compare analytical and simulation methods for computational efficiency, the program is carefully structured for efficient use of processing time as well as readability. To eliminate redundant declaration and dimension statements in the various subroutines, implicit variable typing is used and variables are passed between subroutines through the use of labeled COMMON statements. A description of each variable name included in COMMON statements is documented at the beginning of the main program. Local variable definitions are documented in the individual subroutines. The flowchart in Figure A.1 graphically illustrates the relationship between the main program and all FORTRAN subroutines and functions.

Component Descriptions

Main Program. The main program first lists all of the labeled COMMON statements. Statement INIT contains variables which receive their values from input data or transformed input data. Statement CALC contains variables which pertain to the analytical calculations. Statement SIM1 contains the variables used in implementing the simulation model. SIM2 contains the variables necessary to form and analyze a simulation single or multiple failure

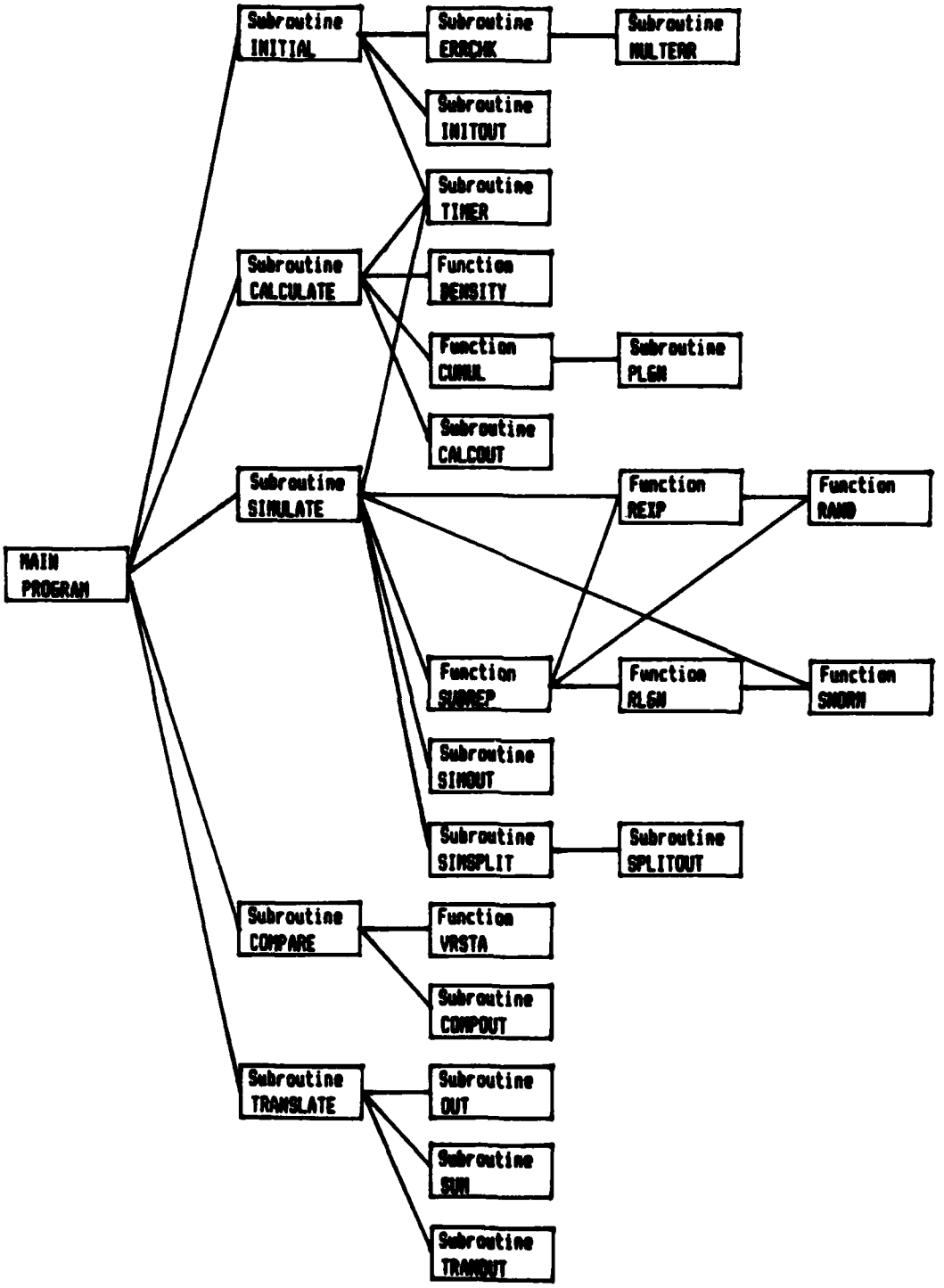


Figure A.1. Relationship Between Program Components

repair time distribution, depending on which array of observations (single or multiple failure) is passed to the subroutines which share SIM2. Statement COMP contains variables pertaining to the comparison of analytical and simulation CDFs. Finally, statement TRAN contains variables needed to determine the operational efficiency of an aircraft based on each repair time CDF.

The main program opens and rewinds the data file "RTDM1.DAT," which contains all input data. It then opens the output file "RTDM1.OUT," which is used to store the program results. The main program calls subroutine INITIAL to read and transform the input data. It then calls subroutine CALCULATE to implement the analytical method.

Before implementing the simulation method, the main program sets the number of observations required (N failed aircraft). It also sets the random number seeds (NS1, NS2) and the level of confidence (CL) for which confidence intervals on output parameters are to be computed. The variable NSO is set to 2 if a single failure distribution is desired in addition to the multiple failure distribution. If a single failure distribution is not desired, NSO is set to 1. The main program calls subroutine SIMULATE to implement the simulation model.

After analytical and simulation methods are implemented, the main program calls Subroutine COMPARE to compare the resulting analytical and simulation cumulative distribution

functions. Then, for each of the two CDFs, subroutine TRANSLATE is called on to determine associated measures of operational effectiveness. The input and output files are then closed and the main program prints a termination message.

Subroutine INITIAL. Subroutine INITIAL first reads in a time increment (TI), for which a probability density and cumulative probability are calculated, stored, and plotted for the system repair time distribution. The next variable read is TM, which is the maximum repair time for which the calculations are performed. Thus, probability densities and cumulative probabilities are recorded and displayed for TM/TI repair times. INITIAL then reads a scaling factor (SCALE), which is a multiplier between 0.0 and 1.0 used to reduce subsystem reliabilities.

After reading the total number of subsystems (NSUB), INITIAL reads the subsystem work unit code (NWUC), mean sorties between failures (SMSBF), and repair time data (NDIS,SQM,SMRT,SVRT) for each subsystem. The integer NDIS represents the repair time distibutional form for each maintenance action on each subsystem. NDIS values of 1 or 2 correspond to lognormal or exponential distributional forms respectively. An NDIS value of 0 represents a maintenance action that has no probability of occurring. The repair time data also includes a conditional probability (SQM), mean repair time (SMRT), and repair time variance (SVRT) for

each subsystem.

Subroutine INITIAL next multiplies all subsystem reliabilities (SMSBF) by SCALE. Since values of μ(SMU), σ^2 (SSSSQ), and σ(SSS) for lognormal subsystem distributions are used several times throughout the program, they are calculated once in subroutine INITIAL using Eqs (3.14) and (3.15) and are made available to the rest of the program through the COMMON/INIT statement. The variances of exponential distributions are calculated from the mean, since the exponential distribution is defined by a single parameter.

Subroutine INITIAL next reads several parameters which pertain to the calculation of availability and sortie generation capability. These parameters include the aircraft force size (NAF), sortie time (ST), turn time (TT), sortie launch window (SW), maximum launches per time interval (STIM), operational effectiveness output increment (TIA), and maximum time for operational effectiveness output (TMA). All input data is checked for errors using subroutine ERRCHK and is printed to the output file using subroutine INITOUT. Subroutine TIMER is then called on to determine the amount of CPU time used processing inital data since this data is used by both the analytical and simulation methods.

Subroutine ERRCHK. Subroutine ERRCHK first calls on subroutine MULTERR to ensure that the maximum repair time to

be recorded (TM) is an even multiple of the repair time increment (TI). ERRCHK also ensures that all distributional form codes are 0, 1, or 2 and ensures that no probability is associated with a code of 0. ERRCHK then confirms that the maintenance action probabilities sum to 1.0 for each subsystem. The availability/sortie generation data are checked for errors using MULTERR. The sortie time (ST), turn time (TT), and sortie window (SW) must all be multiples of the repair time increment (TI). Also, the operational effectiveness time increment (TIO) and maximum operational effectiveness output time (TMO) must be multiples of TI. If any input data errors are encountered, an appropriate error message is printed, including the total number of errors detected (NERR). The program is then terminated with a FORTRAN STOP command.

Subroutine MULTERR. Subroutine MULTERR receives two variables as arguments, and stores them as XM and XI. Also received are two character strings (CXM and CXI), which are descriptors of XM and XI. MULTERR checks to confirm that XM is an even multiple of XI. If XM is not a multiple of XI, an appropiate message is printed and the error counter (NERR) is increased by one.

Subroutine INITOUT. Subroutine INITOUT writes the input data to an output file in a readable format with appropriate labels. The distributional form codes (NDIS) are converted to three-letter alphabetic identifiers (CNDIS).

Subroutine Timer. Subroutine time calls a library subroutine which returns an integer (ICT) representing the current total CPU time used by the program in one-hundredths of a second. This integer is converted to a real number representing CPU time used in seconds (CT). The array CPU is used to store the CPU time used by each phase of the program (current time minus time of previous phase). CPUT(1) is the CPU time used to read and transform the input data, CPUT(2) is the time used by the analytical method, and CPUT(3) is the time used by the simulation method.

Subroutine CALCULATE. Subroutine CALCULATE computes an analytical aircraft reliability, repair time, repair time variance, repair time pdf, and repair time CDF. It begins by initializing several values to be computed. Since the overall system reliability (ARA) is computed by iteratively multiplying subsystem reliabilities, it is initialized to 1.0. To compute conditional probabilities of subsystem failure given system failure based on the single-failure assumption (SPM), a sum of subsystem failure probabilities must be computed as shown in Eq (3.2). This sum is initialized to 0.0 in subroutine CALCULATE as the local variable APF. The aircraft mean repair time (AMRTA) and variance of repair time (AVRTA) are also initialized to 0.0.

After initialization, CALCULATE determines the system reliability by multiplying subsystem reliabilities. It then sums subsystem failure probabilities to determine APF. An

overall system MSBF is computed using the inverse of Eq (3.1). For each maintenance action on each subsystem, a single probability SPM is computed which represents p_{ij} in Eq (3.8).

CALCULATE computes the system mean repair time (AMRTA) by summing the subsystem mean repair times weighted by p_{ij} as shown in Eq (3.9). To compute the variance, CALCULATE computes the second moment by summing the weighted second moments of the subsystem distributions and storing it as the variable AVRTA. The subsytem second moments are calculated using Eq (3.13) or Eq (3.18) for lognormal or exponential distributional forms respectively. AVRTA is converted to the true system repair time variance by subtracting the square of the mean repair time as shown in Eq (3.10).

Subroutine CALCULATE next computes the probability density and cumulative probability for system repair time from 0.0 to a maximum time TM in intervals of TI. The functions DENSITY and CUMUL return the probability density and cumulative probability values for repair time T, which is passed as an argument. These values are stored in the arrays DEN and CUMA where each element of the arrays represent each time increment. Subroutine CALCULATE then calls on subroutine CALCOUT to write the analytical results to the output file and calls on TIMER to record the CPU time used by the analytical method.

Function DENSITY. Function DENSITY computes the system repair time probability density at time T as a weighted sum of subsystem probability densities as shown in Eq (3.8). Subsystem probability densities are computed as according to Eq (2.2) if the subsystem distribution is lognormal or Eq (2.1) if the subsystem distribution is exponential.

Function CUMUL. Function CUMUL computes the cumulative probability of the system repair time at time T as a weighted sum of subsystem probabilities as shown in Eq (3.19). If the subsystem repair time distribution is exponential, its cumulative probability is computed as shown in Eq (3.20). If the subsystem distribution is lognormal, it is computed using the standard normal transformation shown in Eq (3.22). CUMUL calls on the function PLGN to return the cumulative probability associated with the transformed repair time. The subsystem array subscript I, maintenance action array subscript J, and repair time T are passed as arguments.

Function PLGN. Function PLGN first transforms the time T, which is passed as an argument, to a transformed time X. It then calculates the standard normal cumulative probability associated with X using the Ibbetson algorithm.

Subroutine CALCOUT. Subroutine CALCOUT first writes the system reliability (ARA), mean sorties between failures (AMSBF), mean repair time (AMRTA), and repair time variance (AVRTA) to the output file with appropriate labels. CALCOUT

then produces a plot of probability density and cumulative probability vs. time (see sample output in Appendix C). The plot is produced through the use of a string of 100 alphanumeric characters (LINE), which is initialized to include only blank characters. For each time increment, the associated probability density and cumulative probability are printed in the plot margin. The element of LINE corresponding with the probabiltiy density rounded to the nearest 0.01 is replaced with the letter "P". Likewise, the element of LINE corresponding with the cumulative probability rounded to the nearest 0.01 is replaced with the letter "C". The letter "P" takes precedence in the event "P" and "C" correspond to the same element of LINE for a particular time increment.

Subroutine SIMULATE. Subroutine SIMULATE begins by initializing the array NFA, which counts the number of simulated aircraft arriving with different numbers of failed subsystems. The total number of aircraft arriving with failures (NFAT) is also initialized to zero. The simulation continues to run until NFAT is equal to the required number of observations (N). For each arriving aircraft, the number of failed subsystems and the single and multiple failure repair times are initialized to zero. The aircraft failure time in sorties (AFT) is used in forming the single failure distribution and is initialized to 1.0 since the smallest subsystem repair time less than 1.0 will be used.

For each subsystem of each arriving aircraft, the simulation generates a subsystem failure time to determine if the the subsystem has failed during the sortie. This is accomplished through random sampling from an exponential distribution using function REXP. If the subsystem has failed, function SUBREP is called on to return the subsystem repair time and the subsystem failure counter NFSUB is increased by one. If the subsystem failure time in sorties is less than any previous subsystem failure time, the temporary single failure repair time observation (TASFRT) is replaced by the subsystem repair time (SRT). If the subsystem repair time is greater than any previous subsystem repair time, the temporary multiple failure repair time observation (TAMFRT) is replaced by the subsystem repair time (SRT). Next, the number of failed aircraft (NAFT) and failed aircraft counter array (NAF) are updated. The NAF array keeps track of the number of aircraft arriving with 0, 1, 2, 3, 4, 5, or 6 or more failures. The final temporary single and multiple failure repair times are stored as elements in the arrays ASFRT and AMFRT, which are used by later subroutines to form the repair time distributions.

Once the required number of repair time observations are obtained and stored, the total number of arriving aircraft and single and multiple failure reliabilities (ASFR and AMFR) are computed using NAF and NAFT. Subroutine SIMOUT is called to write this information to the output

file. Before forming repair time distributions, SIMULATE employs subroutine SNORM to calculate the appropriate percentage point of the normal distribution (z-value) needed to form confidence intervals on distribution parameters. SIMULATE then calls subroutine SIMSPLIT to form a multiple failure repair time distribution and single failure distribution if desired. The total number of observations (N), confidence level (CL), z-value (ZA), and array of observations (ASFRT or AMFRT) are passed as arguments. Finally, subroutine TIMER is called on to store the CPU time used by the simulation model.

Function REXP. Function REXP returns a random variate from an exponential distribution with mean SMRT, which is passed as an argument. First, REXP calls on function RAND to obtain a random number. It then produces an exponential random variate using the inverse-transform transform relationship of Eq (4.9).

Function RAND. Function RAND is a multiplicative random number generator that produces a random number distributed uniformly from 0 to 1.0 using an integer seed NS. NS is passed as an argument and is changed for use in generating a new random number when RAND is next called on.

Function SUBREP. Function SUBREP generates a repair time for a failed subsystem. First, a random number is generated to determine which maintenance action is required according to Table 4.1. Given this action J and the subsystem

number I, which is passed as an argument, SUBREP generates a subsystem repair time by the appropriate random variate generator for action J on subsystem I. If the repair time distribution for action J on subsystem I is exponential, SUBREP employs function REXP, which is described above. If the distribution is lognormal, SUBREP employs function RLGN.

Function RLGN. Function RLGN generates a lognormal random variate with parameters SMU and SSG, which are passed as arguments. A random number is generated using RAND and is transformed to a lognormal variate according to Eq (4.10). The standard normal random variate required by Eq (4.10) is obtained using function SNORM.

Function SNORM. Function SNORM transforms a number R, which is passed as an argument, into the percentage point of the normal distribution corresponding to cumulative probability R. SNORM is modularized as a separate subroutine of RLGN because it is also used to provide the z-value needed to determine confidence intervals on parameters of the simulation repair time distributions. SNORM determines the standard normal percentage point using the Beasley-Springer numerical method.

Subroutine SIMOUT. Subroutine SIMOUT writes the failed aircraft array (NFA), total number of failed aircraft NFAT, and single and multiple failure reliabilities to the output file using a readable labeled format.

Subroutine SIMSPLIT. Subroutine SIMSPLIT produces a

mean (AMRT), variance (AVRT), and empirical probability distribution based on an array of observations that is passed to it. SIMSPLIT is always called on to produce a multiple failure distribution and is called on to produce a single failure distribution if NSO=2. The array of observations passed to SIMSPLIT is stored in the local array ART. The array CUMS is used to store cumulative probabilities at TM/TI repair time intervals and is shared with the main program through the COMMON/SIM1 statement. The COMMON/SIM2 statement includes variables shared by SIMSPLIT and its output subroutine SPLITOUT.

Subroutine SIMSPLIT first computes the mean and variance of the repair time distribution. The mean is stored in the first element of the three-element array AMRT; the second and third element are lower and upper confidence limits respectively. The variance and its confidence limits are similarly stored in the three-element array AVRT. SIMSPLIT first initializes AMRT(1) and AVRT(1). AMRT(1) is temporarily used to store the iterative sum of all repair time observations and is converted to the sample mean by dividing by the total number of observations (N). AVRT(1) is temporarily used to store the iterative sum of the squares of the repair time observations and is converted to the sample variance $\hat{\gamma}^2$ according to computational formula

$$\hat{\gamma}^2 = \left(\sum_{i=1}^{n} T_i - n\bar{T}_i\right) / (n - 1) \qquad \text{(A.1)}$$

where T_i is the repair time for observation i, $\bar{T}_i$ is the sample mean, and n is the sample size (54:48). Upper and lower confidence limits on the mean and variance are computed according to Eqs (4.1) and (4.2). The Chi-squared percentage point required by Eq (4.2) is computed according to Eq (4.3) using the previously computed standard normal z-value (ZA).

Subroutine SIMSPLIT next sums the number of repair time observations that fall in each time interval of width TI up to maximum repair time TM. The number of observations in any interval K is stored as FRQ(K) and is converted to a relative frequency by dividing by the total number of observations (N). For each interval, a cumulative frequency CUMS(K) is computed as the sum of FRQ(K) and the frequency of all previous intervals. SIMSPLIT then calls SPLITOUT to print the distribution parameters and a graphical depiction of the distribution.

Subroutine SPLITOUT. Subroutine SPLITOUT first writes the repair time distribution mean and variance (with confidence limits) to the output file in an appropriate format. SPLITOUT then prints a plot the repair time distribution in a manner similar to CALCOUT in the analytical method. The relative frequency for each time interval is printed in place of a probability density and is graphically indicated by a line of asterisk (*) symbols. The cumulative frequency, which represents the simulation

cumulative probability for each time interval, is indicated by the character "C."

Subroutine COMPARE. Subroutine COMPARE determines the average and maximum difference between the single failure analytical repair time CDF and the multiple failure simulation CDF. COMPARE begins with several initialization statements. The square of the z-value associated with the confidence limits for all results is used several times in the subroutine and is calculated and stored as ZASQ. Portions of Eqs (4.5) and (4.6) which are used more than once in the subroutine are calculated and stored as the temporary variables T1, T2, T3, and T4. The average difference between CDFs (PDA) and the maximum difference between CDFs (PDM) are initialized to zero. The term KI establishes the number of observations in each of twenty equal increments for which CDF difference information is stored and displayed. The terms K and NN are counters used to accomplish the storing operation.

To form the simulation CDF, each observation must be sorted in increasing order of repair time. This is accomplished by an IMSL library routine (VSRTA), which is based on a sorting algorithm recommended by the Association for Computing Machinery (8:Sec 347,1). For each element of the sorted array, the value of the simulation CDF (PS(I)) is equal to the sequence number of the element (I) divided by the total number of obvservations (N). Confidence limits

for PS(1) are computed using Eqs (4.5) and (4.6) and are stored as PS(2) and PS(3).

For each value of PS(1), an analytical value for the CDF is computed using function CUMUL. The repair time used in calling CUMUL is the average of the range of repair times for which PS(1) maintains its value, as shown in Figure A.2. The difference between the analytical and simulation CDFs for each observation is stored as PD. The value PDA is temporarily used to store the iterative sum the CDF differences, and is eventually converted to the average difference by dividing by the total number of observations (N).

For every observation, if the difference between CDFs is greater then any previous difference, it becomes the new maximum difference (PDM) and the repair time where it occurs is stored as PDMT. Note that this difference is not the true Kolomgornov-Smirnov statistic, which is shown on Figure A.2. However, for a sample size of 40,000, the error is on the order of 0.000125 (1/2n), so the maximum CDF difference computed by the program is a reasonable approximation of the true KS statistic.

The next portion of subroutine COMPARE stores difference information at intervals of 0.05 of the simulation CDF for any sample size. This information provides an indication of how the difference between CDFs varies over the full range of repair times. For each

interval, values of repair time (RT), analytical CDF (PAK), simulation CDF (PSK) and difference between CDFs (PDK) are stored. PSK and PDK are arrays having three elements to accomodate an estimator and upper and lower confidence limits. The subroutine ends by calling subroutine COMPOUT, which prints the results of the comparison.

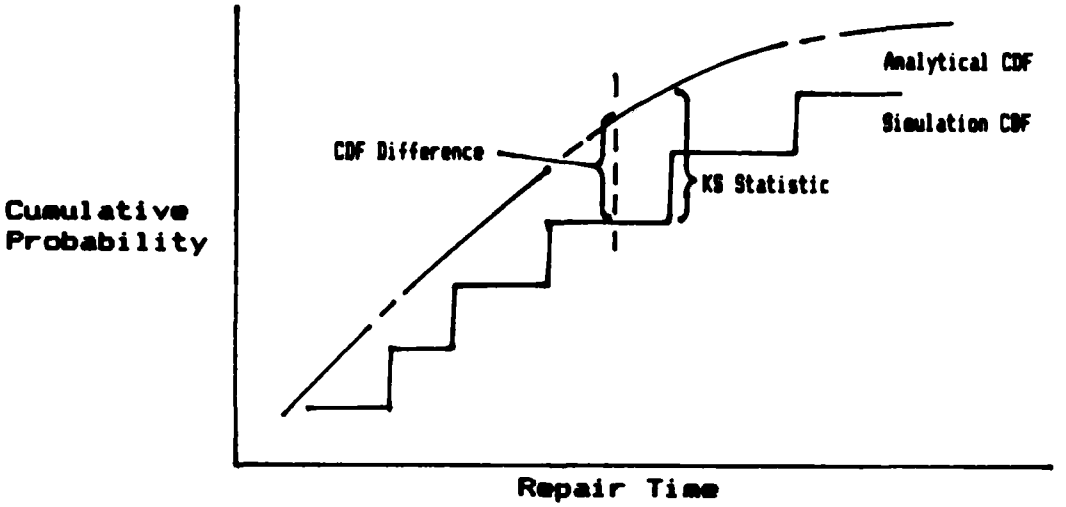


Figure A.2. Computed CDF Difference and the True KS Statistic

Subroutine COMPOUT. Subroutine COMPOUT prints the results of the CDF comparison to the output file in an appropriate format. It also prints the amount of computer core processing time used by the analytical method and by the simulation method. This information provides a comparison of the relative computational efficiency of the two methods.

Subroutine TRANSLATE. Subroutine TRANSLATE converts

an aircraft repair time distribution and analytical reliability into measures of operational effectiveness for a user specified concept of operations. To permit the use of subroutine TRANSLATE for both analytical and simulation repair time distributions, the analytical reliability (ARA) and repair time CDF array (CUM) are passed as arguments. The variables specifying the concept of operations are read from the input data file and are made available to TRANSLATE through the COMMON/INIT statement.

Subroutine TRANSLATE begins by determining the number of elements in the sortie and turn state arrays (NS and NT) by dividing the duration of each activity by the time increment TI. The number of elements in the repair state array (NR) is obtained by dividing the maximum repair time for CDF computations (TM) by TI. All elements of the sortie, turn, and repair state arrays (SSTE, TSTE, RSTE) are then initialized to zero.

TRANSLATE next developes an array consisting of repair time interval probabilities (RTIP). The number of elements in RTIP corresponds to the number of elements in the RSTE array and the number of time increments for which repair time CDF values are calculated. The value of each element in the RTIP array is calculated as the difference between CDF values at each end of the repair time interval the element represents as shown in the example in Table 6.1.

Before TRANSLATE begins examining individual time

increments, the average aircraft availability (AVLA), minimum aircraft ability (AVLM), total quantities of sorties generated (TSOR), and total quantity of aircraft repaired (TREP) are initialized to zero. The quantity of ready aircraft is initialized to the aircraft force size (NAF). Next, an output interval width (KI) is calculated which indicates the number of time intervals examined between each interval for which results are stored for output. A counter of output intervals (K) and a counter of intervals currently examined within the current output interval (NTI) are initialized to zero.

TRANSLATE next begins stepping through time intervals to make availability and sortie generation calculations. For each time interval, subroutine OUT is called on to return the quantities of aircraft leaving each state during the interval (SOUT, TOUT, ROUT). The quantity of aircraft entering the repair state (RIN) is calculated as the quantity leaving the sortie state (SOUT) times the probability of aircraft failure (1-ARA). The quantity of aircraft entering the turn state is calculated as the quantity of non-failed aircraft leaving the sortie state (SOUT x ARA) plus the quantity of aircraft leaving the repair state. The quantity of ready aircraft (RA) is increased by the quantity of aircraft leaving the turn state (TOUT).

TRANSLATE next determines if the current time is in

the sortie launch window by calculating the time of day (WT). If WT is not in the sortie launch window, the quantity of aircraft entering the sortie array (SIN) is set equal to zero. If WT is in the sortie launch window, TRANSLATE compares the quantity of ready aircraft with the maximum number of launches permitted per time interval and sets SIN equal to the smaller of the two quantities, adjusting RA accordingly.

Once the quantities of aircraft entering each state are determined, TRANSLATE loads these quantities into the appropriate state array elements. The quantity of aircraft entering the sortie state array (SIN) is loaded into the last element of the sortie array (SSTE) and the quantity entering the turn state is loaded into the last element of the turn array (TSTE). Then the quantity of aircraft entering the repair array is portioned according to the repair time increment probabilities in RTIP and added to the corresponding elements of the repair state array (RSTE).

To calculate an aircraft availability for each time interval, TRANSLATE next calls subroutine SUM to determine the quantities of aircraft in each state. Aircraft availability (AVL) is calculated as the total quantity of aircraft flying sorties (QS) or in a ready state (RA) over the aircraft force size (NAF). AVL is then added to AVLA, which is temporatily used to store the sum of time interval availabilities for conversion to an overall average

availability for the time period considered. If AVL is less than the current minimum availability, the minimum availability AVLM is replaced by AVL. Then the total quantity of sorties generated (TSOR) is increased by SIN and the total quantity of repairs performed is increased by RIN.

Subroutine TRANSLATE next determines if the current time interval is one of the K intervals for which results are to be stored for output. The results stored include the current time (TK), quantities of aircraft in each state (QSK, QTK, QRK, RAK), and aircraft availability (AVLK). An average sortie generation rate up to the current time (SRATEK) is also stored.

When TRANSLATE completes calculation of results for each time interval, the sum of interval availabilities stored in AVLA is converted to an average aircraft availability by dividing by the number of time intervals examined (TI/TMO). A daily average sortie generation rate (SRATE) and repair rate (RRATE) are also calculated. Subroutine TRANOUT is then called on to print the operational effectiveness results.

Subroutine OUT. Subroutine OUT manipulates the NX elements of an array XSTE, which is passed as an argument. The aircraft quantity in the first element of XSTE is returned as XOUT and all other elements of the array are moved up one element. The quantity of aircraft in the last element of the array is set equal to zero.

Subroutine SUM. Subroutine SUM adds the aircraft quantities in the XT elements of the array XSTE and returns the sum as QX.

Subroutine TRANOUT. Subroutine TRANOUT prints the operational effectiveness results calculated in TRANSLATE in an appropriate labeled format.

Microcomputer Version

Appendix D lists the FORTRAN code for Version 2.0 of the Repair Time Distribution Model, designed for use on a FORTRAN capable microcomputer such as a Zenith model Z-100 or Z-150. This version eliminates the simulation and comparison portions of the original model, calculating only an analytical CDF and corresponding measures of operational effectiveness. A nested system of menus permits a high level of user interaction in manipulating the input data and obtaining corresponding results.

The subroutines adapted to version 2.0 of the model contain some modifications. To facilitate repeated use of the transformation operations in subroutine INITIAL, the read statements in INITIAL are transferred to a new subroutine READIN, which is called on by the main program immediately after the input data file is opened. Subroutine CALCULATE contains an additional operation for predicting a maximum CDF adjustment (PDM). PDM is computed according to Eq (5.2) and is used to adjust the analytical repair time CDF to reflect the possibility of multiple subsystem

failures. CALCULATE also calls on a new subroutine ACUMUL, which employs Eq (5.3) to compute an adjusted CDF value for every time increment of the analytical repair time distribution. Subroutine CALCOUT is modified to include the adjusted CDF values. The adjusted CDF is represented by the symbol "A" on the graphical plot of the repair time distribution.

The main program of Version 2.0 prints a menu allowing the user four selection options. Selection 1 prints a listing of the current input data by calling subroutine INITIAL. Selection 3 runs the entire program by calling subroutines INITIAL, CALCULATE, and TRANSLATE. The user is given the option of directing the program output to a file "RTDM.OUT," or directly to a printer. Before TRANSLATE is called on, the user is given the option of which repair time CDF (adjusted or unadjusted) to use in determining measures of operational effectiveness. Menu selection 4 terminates the session. Selection 2 from the main menu allows the user to interactively change the input data by calling a new subroutine CHNGDAT.

Subroutine CHNGDAT. Subroutine CHGNDAT presents a data change menu with six selection options. Selections 1 and 2 allow the user to change the repair time distribution time increment and maximum time. Selection 3 allows the user to change input data for an existing subsystem by calling a new subroutine SUBCHNG. Selection 4 allows the user to change

the concept of operations data by calling a new subroutine CONCHNG. Selection 5 calls the new subroutine RECORD to overwrite all data changes for the session permanently to the input data file. Selection 6 returns the user to the main menu.

Subroutine SUBCHNG. Subroutine SUBCHNG first prompts the user to enter the work unit code of the subsystem to be changed. SUBCHNG then presents a menu including the current values of all data elements for the subsystem. Selection of a data element to be changed results in an appropriate prompt. The user may change as many data elements as desired before exiting the subroutine.

Subroutine CONCHNG. Subroutine CONCHNG presents a menu including the current values of all data elements for the concept of operations. Selection of a data element to be changed results in an appropriate prompt. The user may change as many data elements as desired before exiting the subroutine.

Subroutine RECORD. Subroutine rewinds the input data file and writes the current values of all input data elements to the input file for permanent storage. At any time during an interactive session, the user can run the model portion of the program using changed data without employing RECORD to permanently overwrite the changes to the basic data set. This permits evaluation of many design alternatives while preserving a basic data set.

Appendix B

Program Listing of Repair Time Distribution Model (Version 1.0)

```
C*************************************************************************C
C                                                                         C
C     REPAIR TIME DISTRIBUTION MODEL (VERSION 1.0)                        C
C                                                                         C
C     THIS PROGRAM COMBINES SUBSYSTEM RELIABILITY AND                     C
C     MAINTAINABILITY ESTIMATES TO FORM A REPAIR TIME DISTRIBUTION        C
C     FOR THE ADVANCED TACTICAL FIGHTER BY USING SIMULATION AND           C
C     ANALYTICAL METHODS.  THE ANALYTICAL METHOD ASSUMES THAT ONLY        C
C     ONE SUBSYSTEM WILL FAIL BEFORE REPAIR IS INITIATED.  THE            C
C     SIMULATION METHOD FORMS A REPAIR TIME DISTRIBUTION ASSUMING         C
C     SINGLE FAILURE AND ALSO A DISTRIBUTION ALLOWING MULTIPLE            C
C     FAILURES.  THE MULTIPLE FAILURE DISTRIBUTION REFLECTS THE           C
C     MAXIMUM REPAIR TIME OF ALL FAILED SUBSYSTEMS.  THE PROGRAM          C
C     ALSO COMPARES THE ANALYTICAL AND MULTIPLE FAILURE SIMULATION        C
C     RESULTS FOR ACCURACY AND COMPUTIONAL EFFICIENCY.  IT THEN           C
C     DETERMINES A REPRESENTATIVE EFFECT OF THE ACCURACY DIFFERENCE       C
C     ON AIRCRAFT AVAILABILITY AND SORTIE GENERATION CAPABILITY           C
C     UNDER A USER-SPECIFIED CONCEPT OF OPERATIONS.                       C
C                                                                         C
C     GLOBAL VARIABLE DEFINITIONS                                         C
C                                                                         C
C       **** INITIAL DATA VARIABLES                                       C
C                                                                         C
C         TI          = TIME INCREMENT FOR REPAIR TIME PDF/CDF          C
C                       COMPUTATIONS                                      C
C         TM          = MAXIMUM REPAIR TIME FOR PDF/CDF COMPUTATIONS    C
C         SCALE       = RELIABILITY SCALING FACTOR                      C
C                                                                         C
C         NSUB        = TOTAL NUMBER OF SUBSYSTEMS                      C
C                                                                         C
C         NWUC(I)     = WORK UNIT CODE OF SUBSYSTEM I                   C
C         SMSBF(I)    = MEAN NUMBER OF SORTIES BETWEEN FAILURES OF      C
C                       SUBSYSTEM I                                       C
C         SREL(I)     = SORTIE RELIABILITY OF SUBSYSTEM I               C
C                                                                         C
C         NDIS(I,J)   = TYPE OF DISTRIBUTION OF MAINTENANCE ACTION      C
C                       J ON SUBSYSTEM I                                  C
C                       (0=NONE, 1=LOGNORMAL, 2=EXPONENTIAL)              C
C         SQM(I,J)    = PROBABILITY THAT MAINTENANCE ACTION J IS        C
C                       REQUIRED GIVEN SUBSYSTEM I HAS FAILED             C
C         SMRT(I,J)   = MEAN REPAIR TIME FOR ACTION J ON SUBSYSTEM I    C
C         SVRT(I,J)   = VARIANCE OF REPAIR TIME FOR ACTION J ON         C
C                       SUBSYSTEM I                                       C
C         SMU(I,J)    = LOGNORMAL MU FOR ACTION J ON SUBSYSTEM I        C
C         SSGSQ(I,J)  = LOGORMAL SIGMA SQUARED FOR ACTION J ON          C
C                       SUBSYSTEM I                                       C
C         SSG(I,J)    = LOGNORMAL SIGMA FOR ACTION J ON SUBSYSTEM I     C
C                                                                         C
C                       MAINTENANCE        J=1:  REMOVE AND REPLACE     C
C                       ACTION CODES       J=2:  REPAIR IN PLACE        C
C                                          J=3:  CAN NOT DUPLICATE      C
```

```
C         NAF          = AIRCRAFT FORCE SIZE                                  C
C         ST           = AIRCRAFT SORTIE TIME                                 C
C         TT           = AIRCRAFT TURN TIME                                   C
C         SW           = SORTIE LAUNCH TIME WINDOW                            C
C         STIM         = MAXIMUM AIRCRAFT LAUNCHES PER TIME INTERVAL TI       C
C         TIO          = OPERATIONAL EFFECTIVENSS OUTPUT TIME INCREMENT       C
C         TMO          = MAXIMUM TIME FOR OPERATIONAL EFFECTIVENESS           C
C                        OUTPUT                                               C
C                                                                             C
C       **** ANALYTICAL VARIABLES                                             C
C                                                                             C
C         ARA          = AIRCRAFT RELIABILITY                                 C
C         AMSBF        = AIRCRAFT MEAN NUMBER OF SORTIES BETWEEN              C
C                        FAILURES                                             C
C         SPM(I,J)     = PROBABILITY THAT MAINT ACTION J ON SUBSYSTEM         C
C                        I IS REQUIRED GIVEN AIRCRAFT HAS FAILED              C
C         AMRTA        = AIRCRAFT MEAN REPAIR TIME                            C
C         AVRTA        = AIRCRAFT VARIANCE OF REPAIR TIME                     C
C         DEN(K)       = REPAIR TIME PROBABILITY DENSITY AT TIME              C
C                        INCREMENT K                                          C
C         CUMA(K)      = REPAIR TIME CUMULATIVE PROBABILITY AT TIME           C
C                        INCREMENT K                                          C
C                                                                             C
C       **** SIMULATION VARIABLES                                             C
C                                                                             C
C         N            = NUMBER OF FAILED AIRCRAFT (SAMPLE SIZE)              C
C         NS1          = RANDOM NUMBER SEED FOR SUBSYSTEM FAILURES            C
C         NS2          = RANDOM NUMBER SEED FOR REPAIR TIMES                  C
C         CL           = OUTPUT CONFIDENCE LEVEL                              C
C         ZA           = OUTPUT Z-VALUE                                       C
C         NSO          = NUMBER OF SIMULATION OUTPUTS                         C
C                        (NSO=1:   MULTIPLE FAILURE ONLY)                     C
C                        (NSO=2:   SINGLE AND MULTIPLE FAILURE)               C
C                                                                             C
C         NFA(K)       = NUMBER OF AIRCRAFT ARRIVING WITH K FAILED            C
C                        SUBSYSTEMS                                           C
C         NFAT         = TOTAL NUMBER OF AIRCRAFT ARRIVING WITH               C
C                        FAILED SUBSYSTEMS                                    C
C         NAT          = TOTAL NUMBER OF AIRCRAFT                             C
C                                                                             C
C         ASFRT(I)     = SINGLE FAIULRE REPAIR TIME FOR AIRCRAFT I            C
C         AMFRT(I)     = MULTIPLE FAILURE REPAIR TIME FOR AIRCRAFT I          C
C         ASFR         = AIRCRAFT SINGLE FAILURE RELIABILITY                  C
C         AMFR         = AIRCRAFT MULTIPLE FAILURE RELIABILITY                C
C                                                                             C
C         AMRT(1)      = AIRCRAFT MEAN REPAIR TIME                            C
C                        (AMRT(2),AMRT(3)) = CONFIDENCE INTERVAL              C
C         AVRT(1)      = AIRCRAFT VARIANCE OF REPAIR TIME                     C
C                        (AMRT(2),AVRT(3)) = CONFIDENCE INTERVAL              C
C         FRQ(K)       = REPAIR TIME FREQUENCY FOR TIME INTERVAL K            C
C         CUMS(K)      = REPAIR TIME CUMULATIVE FREQUENCY AT TIME             C
C                        INCREMENT K                                          C
```

```
C                                                                       C
C       **** COMPARISON VARIABLES                                       C
C                                                                       C
C         RTK(K)      = REPAIR TIME AT SIMULATION CDF INCREMENT K        C
C         PAK(K)      = ANALYTICAL PROPORTION AT INCREMENT K             C
C         PSK(1,K)    = SIMULATION PROPORTION AT INCREMENT K             C
C                       (PSK(2),PSK(3)) = CONFIDENCE INTERVAL            C
C         PDK(1,K)    = DIFFERENCE BETWEEN PROPORTIONS AT INCREMENT K    C
C                       (PDK(2,K),PDK(3,K)) = CONFIDENCE INTERVAL        C
C         PDA         = AVERAGE DIFFERENCE BETWEEN PROPORTIONS           C
C         PDM         = MAXIMUM DIFFERENCE BETWEEN PROPORTIONS           C
C         PDMT        = TIME AT MAX DIFFERENCE BETWEEN PROPORTIONS       C
C                                                                       C
C       **** OPERATIONAL EFFECTIVENESS TRANSLATION VARIABLES            C
C                                                                       C
C         TK(K)       = TIME AT TIME INCREMENT K                         C
C         QSK(K)      = QUANTITY OF AIRCRAFT FLYING SORTIES AT TK(K)     C
C         QTK(K)      = QUANTITY OF AIRCRAFT BEING TURNED AT TK(K)       C
C         QRK(K)      = QUANTITY OF AIRCRAFT BEING REPAIRED AT TK(K)     C
C         RAKK)       = QUANTITY OF READY AIRCRAFT AT TK(K)              C
C         AVLK(K)     = AIRCRAFT AVAILABILITY AT TK(K)                   C
C         SRATEK(K)   = SORTIE GENERATION RATE UP TO TK(K)               C
C         AVLA        = AVERAGE AIRCRAFT AVAILABILITY                    C
C         AVLM        = MINIMUM AIRCRAFT AVAILABILITY                    C
C         TSOR        = TOTAL QUANTITY OF SORTIES FLOWN                  C
C         SRATE       = SORTIE GENERATION RATE                           C
C         TREP        = TOTAL QUANTITY OF REPAIRS PERFORMED              C
C         RRATE       = REPAIR RATE                                      C
C                                                                       C
C       **** TIMING VARIABLES                                           C
C                                                                       C
C         CPUT(1)     = CPU TIME REQUIRED FOR DATA INPUT AND             C
C                       TRANSFORMATION                                   C
C         CPUT(2)     = CPU TIME USED BY ANALYTICAL METHOD               C
C         CPUT(3)     = CPU TIME USED BY SIMULATION METHOD               C
C                                                                       C
C***********************************************************************C
C
```

```
      PROGRAM RTDM1
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
C
      COMMON/SIM1/N,NS1,NS2,CL,ZA,NSO,NFA(0:6),NFAT,NAT,ASFRT(100000)
     &           ,ASFR,AMFRT(100000),AMFR,CUMS(100)
C
      COMMON/SIM2/AMRT(3),AVRT(3),FRQ(100)
C
      COMMON/COMP/PDA,PDM,PDMT,RTK(20),PAK(20),PSK(3,20),PDK(3,20)
C
      COMMON/TRAN/TK(500),QSK(500),QTK(500),QRK(500),RAK(500),AVLK(500)
     &           ,SRATEK(500),AVLA,AVLM,TSOR,SRATE,TREP,RRATE
C
      COMMON/CPU/CPUT(3)
C
      OPEN (UNIT=11,FILE='RTDM1.DAT',STATUS='OLD')
      REWIND(11)
      OPEN (UNIT=12,FILE='RTDM2.OUT',STATUS='NEW')
C
      CALL INITIAL
C
      CALL CALCULATE
C
      N=40000
      READ (11,*) NS1
      READ (11,*) NS2
      CL=0.95
      NSO=1
      CALL SIMULATE
C
      CALL COMPARE
C
      WRITE (12,10)
10    FORMAT ('1','*** ANALYTICAL AVAILABILITY AND ',
     &        'SORTIE GENERATION RESULTS ***'//)
      CALL TRANSLATE(ARA,CUMA)
      WRITE (12,20)
20    FORMAT ('1','*** SIMULATION AVAILABILITY AND ',
     &        'SORTIE GENERATION RESULTS ***'//)
      CALL TRANSLATE(ARA,CUMS)
C
      WRITE (12,30)
30    FORMAT ('1','*** NORMAL PROGRAM TERMINATION ***')
      CLOSE(11)
      CLOSE(12)
      END
```

```
C
C*************************************************************************
C
      SUBROUTINE INITIAL
C
C     *** SUBROUTINE INITIAL READS THE INPUT DATA AND PERFORMS
C         TRANSFORMATIONS ON THE DATA TO PRODUCE ADDITIONAL VARIABLES
C         USED REPEATEDLY THROUGHOUT THE PROGRAM.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO
C
      COMMON/CPU/CPUT(3)
C
      READ (11,*) TI,TM,SCALE,NSUB
C
      DO 20 I=1,NSUB
          READ (11,*) NWUC(I),SMSBF(I),
     &                (NDIS(I,J),SQM(I,J),SMRT(I,J),SVRT(I,J),J=1,3)
          SMSBF(I)=SMSBF(I)*SCALE
          SREL(I)=EXP(-1.0/SMSBF(I))
          DO 10 J=1,3
              SMRTSQ=SMRT(I,J)*SMRT(I,J)
              IF (NDIS(I,J).EQ.1) THEN
                  SMU(I,J)=ALOG(SMRTSQ/SQRT(SVRT(I,J)+SMRTSQ))
                  SSGSQ(I,J)=ALOG((SVRT(I,J)+SMRTSQ)/SMRTSQ)
                  SSG(I,J)=SQRT(SSGSQ(I,J))
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  SVRT(I,J)=1.0/SMRTSQ
                ENDIF
10          CONTINUE
20      CONTINUE
C
      READ (11,*) NAF,ST,TT,SW,STIM,TIO,TMO
C
      CALL ERRCHK
      CALL INITOUT
      CALL TIMER(1)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE ERRCHK
C
C     *** SUBROUTINE ERRCHK CHECKS THE INPUT DATA FOR ILLEGAL VALUES
C         AND RELATIONAL INCONSISTENCIES.  IF ILLEGAL VALUES OR
C         INCONSISTENCIES ARE FOUND, AN ERROR MESSAGE IS DISPLAYED AND
C         THE PROGRAM IS TERMINATED.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO
C
C     *** LOCAL VARIABLE DEFINITIONS
C         NERR = NUMBER OF ERRORS IDENTIFIED
C
      NERR=0
C
      CALL MULTERR(TM,TI,'CDF MAX TIME','CDF TIME INCR',NERR)
C
      DO 60 I=1,NSUB
          DO 40 J=1,3
              IF ((NDIS(I,J).NE.0).AND.(NDIS(I,J).NE.1)
     &            .AND.(NDIS(I,J).NE.2)) THEN
                  WRITE (12,20) J,NWUC(I)
20                FORMAT (1X,'INPUT ERROR -- NDIS FOR ACTION ',I1,
     &                    ' ON SUBSYSTEM ',I2,' NOT 0, 1, OR 2'/)
                  NERR=NERR+1
              ENDIF
              IF ((NDIS(I,J).EQ.0).AND.(SQM(I,J).NE.0.0)) THEN
                  WRITE (12,30) J,NWUC(I)
30                FORMAT (1X,'INPUT ERROR -- SQM FOR ACTION ',I1,
     &                    ' ON SUBSYSTEM ',I2,' MUST BE 0.0'/)
                  NERR=NERR+1
              ENDIF
40        CONTINUE
          IF (ABS(SQM(I,1)+SQM(I,2)+SQM(I,3)-1.0).GT.0.001) THEN
              WRITE (12,50) NWUC(I)
50            FORMAT (1X,'INPUT ERROR -- SUM OF SQM FOR SUBSYSTEM ',
     &                I2,' NOT EQUAL TO 1.0'/)
              NERR=NERR+1
          ENDIF
60    CONTINUE
C
      CALL MULTERR(ST,TI,'SORTIE TIME    ','CDF TIME INCR  ',NERR)
      CALL MULTERR(TT,TI,'TURN TIME      ','CDF TIME INCR  ',NERR)
      CALL MULTERR(SW,TI,'SORTIE WINDOW  ','CDF TIME INCR  ',NERR)
      CALL MULTERR(TIO,TI,'AVAIL TIME INCR','CDF TIME INCR  ',NERR)
      CALL MULTERR(TMO,TIO,'AVAIL MAX TIME ','AVAIL TIME INCR ',NERR)
C
```

```
      IF (NERR.GT.0) THEN
          WRITE (12,70) NERR
70        FORMAT (1X,I2,' INPUT ERRORS DETECTED:  PROGRAM TERMINATED')
          STOP
        ENDIF
C
      RETURN
      END
C
C*******************************************************************************
C
      SUBROUTINE MULTERR(XM,XI,CXM,CXI,NERR)
C
C     *** SUBROUTINE MULTERR VERIFIES THAT XI IS AN EVEN MULTIPLE OF XM.
C         IF XI IS NOT A MULTIPLE OF XM, AN ERROR MESSAGE IS PRINTED AND
C         THE ERROR COUNTER IS INCREASED BY ONE.
C
C     *** LOCAL VARIABLE DEFINITIONS
C         CXM, CXI = IDENTIFIERS OF OFFENDING VARIABLES
C
      CHARACTER*15 CXM,CXI
C
      IF (ABS(AMOD(XM+0.0001,XI)).GT.0.001) THEN
          WRITE (12,10) CXM,CXI
10        FORMAT (1X,'INPUT ERROR -- ',A15,' NOT A MULTIPLE OF ',A15/)
          NERR=NERR+1
        ENDIF
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE INITOUT
C
C     *** SUBROUTINE INITOUT PRINTS THE INPUT DATA TO THE OUTPUT FILE IN
C         A LABELED FORMAT.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO
C
C     *** LOCAL VARIABLE DEFINITIONS
C         CNDIS(I,J) = ALPHANUMERIC IDENTIFIER FOR DISTRIBUTIONAL FORM
C                      OF MAINTENANCE ACTION J ON SUBSYSTEM I
C                      'N/A' = NOT APPLICABLE
C                      'LGN' = LOGNORMAL
C                      'EXP' = EXPONENTIAL
C
      CHARACTER*3 CNDIS(30,3)
C
      DO 20 I=1,NSUB
          DO 10 J=1,3
              IF (NDIS(I,J).EQ.0) THEN
                  CNDIS(I,J)='N/A'
                ELSEIF (NDIS(I,J).EQ.1) THEN
                  CNDIS(I,J)='LGN'
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  CNDIS(I,J)='EXP'
                ENDIF
10            CONTINUE
20        CONTINUE
C
      WRITE (12,30)
30    FORMAT (1X,'*** INITIAL DATA ***'//)
C
      WRITE (12,40) TI
40    FORMAT (1X,'PDF/CDF REPAIR TIME INCREMENT:  ',F5.2)
      WRITE (12,50) TM
50    FORMAT (1X,'PDF/CDF MAXIMUM REPAIR TIME:    ',F5.2/)
      WRITE (12,60) SCALE
60    FORMAT (1X,'RELIABILITY SCALING FACTOR:     ',F5.2/)
C
      WRITE (12,70) NSUB
70    FORMAT (1X,'TOTAL NUMBER OF SUBSYSTEMS:     ',I5/)
C
```

```
      WRITE (12,80)
 80   FORMAT (1X,T31,'REMOVE AND REPLACE',T65,'REPAIR IN PLACE',T99,
     &       'CAN NOT DUPLICATE'/)
      WRITE (12,90)
 90   FORMAT (1X,'SUBSYS',2X,'  SUBSYS',2X,'SUBSYS',
     &       3(4X,'  DIST',2X,'  COND',2X,'  MEAN',2X,'  VAR-'))
      WRITE (12,100)
100   FORMAT (1X,'  CODE',2X,'    MSBF',2X,'   REL',
     &       3(4X,'  TYPE',2X,'  PROB',2X,'  TIME',2X,' IANCE')/)
C
      DO 120 I=1,NSUB
          WRITE (12,110) NWUC(I),SMSBF(I),SREL(I),
     &           (CNDIS(I,J),SQM(I,J),SMRT(I,J),SVRT(I,J),J=1,3)
110        FORMAT (1X,I6,1X,F9.3,2X,F6.3,3(7X,A3,3(2X,F6.3)))
120      CONTINUE
C
      WRITE (12,130)
130   FORMAT (//1X,'AVAILABILITY/SORTIE GENERATION PARAMETERS'/)
      WRITE (12,140) NAF
140   FORMAT (1X,'AIRCRAFT FORCE SIZE:              ',I6)
      WRITE (12,150) ST
150   FORMAT (1X,'AIRCRAFT SORTIE TIME:             ',F6.2)
      WRITE (12,160) TT
160   FORMAT (1X,'AIRCRAFT TURN TIME:               ',F6.2)
      WRITE (12,170) SW
170   FORMAT (1X,'SORTIE LAUNCH WINDOW:             ',F6.2)
      WRITE (12,180) STIM
180   FORMAT (1X,'MAXIMUM LAUNCHES PER PERIOD TI:   ',F6.2/)
      WRITE (12,190) TIO
190   FORMAT (1X,'AVAIL/SORT GEN TIME INCREMENT:    ',F6.2)
      WRITE (12,200) TMO
200   FORMAT (1X,'AVAIL/SORT GEN MAXIMUM TIME:      ',F6.2)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE TIMER(NT)
C
C     *** SUBROUTINE TIMER DETERMINES THE AMOUNT OF CORE PROCESSING
C         TIME USED BY AN OPERATION.
C
      COMMON/CPU/CPUT(3)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         ICT = CURRENT CPU TIME USED BY PROGRAM IN HUNDRETHS OF A
C               SECOND
C         CT  = CURRENT CPU TIME USED BY PROGRAM IN SECONDS
C
      INCLUDE '($JPIDEF)'
      CALL LIB$GETJPI(JPI$_CPUTIM,,,ICT)
      CT=FLOAT(ICT)/100.0
C
      IF (NT.EQ.1) THEN
         CPUT(NT)=CT
        ELSE
         CPUT(NT)=CT-CPUT(NT-1)
        ENDIF
C
      RETURN
      END
C
```

```
C*******************************************************************************
C
      SUBROUTINE CALCULATE
C
C     *** SUBROUTINE CALCULATE COMPUTES AN ANALYTICAL MEAN AND VARIANCE
C         FOR THE AIRCRAFT REPAIR TIME DISTRIBUTION.  IT ALSO COMPUTES
C         THE VALUE OF THE PROBABILITY DENSITY FUNCTION AND CUMULATIVE
C         DISTRIBUTION FUNCTION AT EACH TIME INCREMENT TI UP TO A
C         MAXIMUM REPAIR TIME TM.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
C
      COMMON/CPU/CPUT(3)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         APF = PROBABILITY OF AIRCRAFT FAILURE ASSUMING ONLY ONE
C               SUBSYSTEM FAILS
C
      ARA=1.0
      APF=0.0
      AMRTA=0.0
      AVRTA=0.0
C
      DO 10 I=1,NSUB
          ARA=ARA*SREL(I)
          APF=APF+(1.0-SREL(I))
10      CONTINUE
      AMSBF=-1.0/ALOG(ARA)
C
      DO 30 I=1,NSUB
          DO 20 J=1,3
              SPM(I,J)=((1.0-SREL(I))/APF)*SQM(I,J)
              AMRTA=AMRTA+SPM(I,J)*SMRT(I,J)
              IF (NDIS(I,J).EQ.1) THEN
                  AVRTA=AVRTA
     &                 +SPM(I,J)*EXP(2*SMU(I,J)+2*SSGSQ(I,J))
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  AVRTA=AVRTA+SPM(I,J)*2*SMRT(I,J)*SMRT(I,J)
                ENDIF
20          CONTINUE
30      CONTINUE
C
```

```
      AVRTA=AVRTA-AMRTA**2
      DO 40 T=TI,TM,TI
          K=NINT(T/TI)
          DEN(K)=DENSITY(T)
          CUMA(K)=CUMUL(T)
40      CONTINUE
C
      CALL CALCOUT
      CALL TIMER(2)
C
      RETURN
      END
C
```

```
C*****************************************************************************
C
      FUNCTION DENSITY(T)
C
C     *** FUNCTION DENSITY RETURNS THE VALUE OF THE AIRCRAFT REPAIR TIME
C         PROBABILITY DENSITY FUNCTION ASSOCIATED WITH REPAIR TIME T.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NMUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         TDENSITY = TEMPORARY VARIABLE FORM STORING ITERATIVE WEIGHTED
C                    SUM OF SUBSYSTEM DENSITIES
C
      TDENSITY=0.0
C
      DO 20 I=1,NSUB
          DO 10 J=1,3
              IF (NDIS(I,J).EQ.1) THEN
                  TDENSITY=TDENSITY+SPM(I,J)*
     &                     EXP(-((ALOG(T)-SMU(I,J))**2)/(2*SSGSQ(I,J)))
     &                     /(T*2.5066283*SSG(I,J))
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  TDENSITY=TDENSITY+SPM(I,J)*
     &                     EXP(-T/SMRT(I,J))/SMRT(I,J)
                ENDIF
10            CONTINUE
20        CONTINUE
C
      DENSITY=TDENSITY
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION CUMUL(T)
C
C     *** FUNCTION CUMUL RETURNS THE VALUE OF THE AIRCRFT REPAIR TIME
C         CUMULATIVE DISTRIBUTION FUNCTION ASSOCIATED WITH REPAIR TIME
C         T.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,MMUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         TCUMUL = TEMPORARY VARIABLE FOR STORING ITERATIVE WEIGHTED
C                  SUM OF SUBSYSTEM CDF VALUES
C
      TCUMUL=0.0
C
      DO 20 I=1,NSUB
          DO 10 J=1,3
              IF (NDIS(I,J).EQ.1) THEN
                  TCUMUL=TCUMUL+SPM(I,J)*PLGN(I,J,T)
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  TCUMUL=TCUMUL+SPM(I,J)*(1.0-EXP(-T/SMRT(I,J)))
                ENDIF
10            CONTINUE
20        CONTINUE
C
      CUMUL=TCUMUL
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION PLGN(I,J,T)
C
C     *** FUNCTION PLGN RETURNS THE CUMULATIVE PROBABILITY ASSOCIATED
C         WITH REPAIR TIME T FOR A LOGNORMAL SUBSYSTEM REPAIR TIME
C         DISTRIBUTION FOR MAINTENANCE ACTION J ON SUBSYSTEM I.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NMUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO
C
      DATA A0/0.797884560593/,A1/-0.531923007300/
      DATA A2/0.319152932694/,A3/-0.151968751364/
      DATA A4/0.059054035642/,A5/-0.019198292004/
      DATA A6/0.005198775019/,A7/-0.001075204047/
      DATA A8/0.000124818987/
      DATA B0/0.999936657524/,B1/0.000535310849/
      DATA B2/-0.002141268741/,B3/0.005353579108/
      DATA B4/-0.009279453341/,B5/0.011630447319/
      DATA B6/-0.010557625006/,B7/0.006549791214/
      DATA B8/-0.002034254874/,B9/-0.000794620820/
      DATA B10/0.001390604284/,B11/-0.0006760904986/
      DATA B12/-0.000019538132/,B13/0.000152529290/
      DATA B14/-0.000045255659/
C
      X=(ALOG(T)-SMU(I,J))/SQRT(SSGSQ(I,J))
      V=ABS(X)/2.0
C
      IF (V.GE.3.0) THEN
          Z=1.0
        ELSEIF (V.LT.1.0) THEN
          W=V*V
          Z=(((((((A8*W+A7)*W+A6)*W+A5)*W+A4)*W+A3)*W+A2)*W+A1)*W+A0)
     &      *V*2
        ELSEIF (V.GE.1.0) THEN
          V=V-2.0
          Z=((((((((((((B14*V+B13)*V+B12)*V+B11)*V+B10)*V+B9)*V+B8)
     &      *V+B7)*V+B6)*V+B5)*V+B4)*V+B3)*V+B2)*V+B1)*V+B0
        ENDIF
C
      IF (X.GT.0.0) THEN
          PLGN=(Z+1.0)/2.0
        ELSE
          PLGN=(1.0-Z)/2.0
        ENDIF
C
      RETURN
      END
C
```

```
C*******************************************************************************
C
      SUBROUTINE CALCOUT
C
C     *** SUBROUTINE CALCOUT WRITES THE RESULTS OF THE ANALYTICAL
C         COMPUTATIONS TO THE OUTPUT FILE IN A LABELED FORMAT.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TID,TMO
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         LINE = CHARACTER STRING FOR GRAPHICAL PLOT OF REPAIR TIME
C                DISTRIBUTION
C
      CHARACTER*100 LINE
C
      WRITE (12,10)
10    FORMAT ('1','*** ANALTYICAL RESULTS ***'//)
C
      WRITE (12,20) ARA
20    FORMAT (1X,'AIRCRAFT RELIABILITY:                    ',F7.4)
      WRITE (12,30) AMSBF
30    FORMAT (1X,'AIRCRAFT MEAN SORTIES BETWEEN FAILURES:  ',F7.4/)
      WRITE (12,40) AMRTA
40    FORMAT (1X,'SINGLE FAILURE MEAN REPAIR TIME:         ',F7.4)
      WRITE (12,50) AVRTA
50    FORMAT (1X,'SINGLE FAILURE VARIANCE OF REPAIR TIME:  ',F7.4//)
C
      WRITE (12,60)
60    FORMAT (1X,'PDF(T)',2X,'CDF(T)',1X,'  TIME')
      WRITE (12,70)
70    FORMAT (1X,T25,20('+',4X),'+')
C
      DO 100 T=TI,TM,TI
         K=NINT(T/TI)
         DO 80 L=1,100
            LINE(L:L)=' '
            IF (L.EQ.NINT(100.0*DEN(K))) THEN
               LINE(L:L)='P'
             ELSEIF (L.EQ.NINT(100.0*CUMA(K))) THEN
               LINE(L:L)='C'
             ELSEIF (L.EQ.100) THEN
               LINE(L:L)='+'
             ENDIF
80         CONTINUE
         WRITE (12,90) DEN(K),CUMA(K),T,LINE
90       FORMAT (1X,2(F6.4,2X),F5.2,T25,'+',A100)
100   CONTINUE
```

```
C
      WRITE (12,70)
      WRITE (12,110)
110   FORMAT (1X,T24,'0.0',7X,'0.1',7X,'0.2',7X,'0.3',7X,'0.4',7X,
     &        '0.5',7X,'0.6',7X,'0.7',7X,'0.8',7X,'0.9',7X,'1.0'//)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE SIMULATE
C
C     *** SUBROUTINE SIMULATE EMPLOYS MONTE CARLO SIMULATION TO PRODUCE
C         A REPAIR TIME DISTRIBUTION WHICH INCLUDES REPAIR TIMES OF
C         AIRCRAFT WITH MULTIPLE SUBSYSTEM FAILURES.  A SINGLE FAILURE
C         DISTRIBUTION IS ALSO PRODUCED IF REQUESTED BY THE USER.
C         AIRCRAFT RELIABILITY, MEAN REPAIR TIME (WITH CONFIDENCE
C         LIMITS) AND REPAIR TIME VARIANCE (WITH CONFIDENCE LIMITS) ARE
C         ALSO COMPUTED.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SS6(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO
C
      COMMON/SIM1/N,NS1,NS2,CL,ZA,NSO,NFA(0:6),NFAT,NAT,ASFRT(100000)
     &           ,ASFR,AMFRT(100000),AMFR,CUMS(100)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         NFSUB  = NUMBER OF FAILED SUBSYSTEMS
C         AFT    = AIRCRAFT FAILURE TIME IN SORTIES
C         TASFRT = TEMPORARY AIRCRAFT SINGLE FAILURE REPAIR TIME
C         TAMFRT = TEMPORARY AIRCRAFT MULTIPLE FAILURE REPAIR TIME
C         SFT    = SUBSYSTEM FAILURE TIME IN SORTIES
C         SRT    = SUBSYSTEM REPAIR TIME
C
      DO 10 I=0,6
         NFA(I)=0
10      CONTINUE
      NFAT=0
C
20    IF (NFAT.LT.N) THEN
         NFSUB=0
         AFT=1.0
         TASFRT=0.0
         TAMFRT=0.0
         DO 30 I=1,NSUB
            SFT=REXP(SMSBF(I),NS1)
            IF (SFT.LE.1.0) THEN
               SRT=SUBREP(I,NS2)
               NFSUB=NFSUB+1
               IF (SFT.LT.AFT) THEN
                  AFT=SFT
                  TASFRT=SRT
               ENDIF
               TAMFRT=AMAX1(TAMFRT,SRT)
            ENDIF
30       CONTINUE
```

```
          IF (NFSUB.EQ.0) THEN
             NFA(0)=NFA(0)+1
             ELSE
               NFAT=NFAT+1
               ASFRT(NFAT)=TASFRT
               AMFRT(NFAT)=TAMFRT
               IF (NFSUB.EQ.1) THEN
                   NFA(1)=NFA(1)+1
                 ELSEIF (NFSUB.GT.1) THEN
                   DO 40 K=2,5
                        IF (NFSUB.EQ.K) NFA(K)=NFA(K)+1
40                   CONTINUE
                   IF (NFSUB.GT.5) NFA(6)=NFA(6)+1
                 ENDIF
             ENDIF
           GOTO 20
         ENDIF
C
      NAT=NFA(0)+NFAT
      ASFR=1.0-FLOAT(NFA(1))/NAT
      AMFR=FLOAT(NFA(0))/NAT
      CALL SIMOUT
C
      ZA=SNORM(1.0-(1.0-CL)/2.0)
C
      IF (NSO.EQ.2) THEN
          WRITE (12,50)
50        FORMAT ('1','SINGLE FAILURE REPAIR TIME RESULTS'//)
          CALL SIMSPLIT(N,CL,ZA,ASFRT,CUMS)
        ENDIF
C
      WRITE (12,60)
60    FORMAT ('1','MULTIPLE FAILURE REPAIR TIME RESULTS'//)
      CALL SIMSPLIT(N,CL,ZA,AMFRT,CUMS)
      CALL TIMER(3)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION REXP(SMRT,NS)
C
C     *** FUNCTION REXP RETURNS A RANDOM VARIATE FROM AN EXPONENTIAL
C         DISTRIBUTION WITH MEAN SMRT USING RANDOM NUMBER SEED NS.
C
      R=RAND(NS)
      REXP=-SMRT*ALOG(R)
C
      RETURN
      END
C
C*************************************************************************
C
      FUNCTION RAND(NS)
C
C     *** FUNCTION RAND RETURNS A RANDOM VARIABLE DISTRIBUTED UNIFORMLY
C         ON THE INTERVAL FROM 0 TO 1 USING RANDOM NUMBER SEED NS.
C
      INTEGER A,D,B15,B16,XHI,XALO,LEFTLO,FHI,K
C
      DATA A/16807/,B15/32768/,B16/65536/,D/2147483647/
C
      XHI=NS/B16
      XALO=(NS-XHI*B16)*A
      LEFTLO=XALO/B16
      FHI=XHI*A+LEFTLO
      K=FHI/B15
      NS=(((XALO-LEFTLO*B16)-D)+(FHI-K*B15)*B16)+K
      IF (NS.LT.0) NS=NS+D
      RAND=FLOAT(NS)*4.656612875E-10
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION SUBREP(I,NS)
C
C     *** FUNCTION SUBREP RETURNS A REPAIR TIME FOR A FAILED SUBSYSTEM
C         I USING RANDOM NUMBER SEED NS.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO
C
C     *** LOCAL VARIABLE DEFINITIONS
C         TYPEM = VARIABLE FOR DETERMINING THE TYPE OF MAINTENANCE
C                 REQUIRED FOR A SUBSYSTEM
C
      TYPEM=RAND(NS)
C
      IF (TYPEM.LE.SQM(I,1)) THEN
          IF (NDIS(I,1).EQ.1) THEN
              SUBREP=RLGN(SMU(I,1),SSG(I,1),NS)
            ELSEIF (NDIS(I,1).EQ.2) THEN
              SUBREP=REXP(SMRT(I,1),NS)
            ENDIF
        ELSEIF (TYPEM.LE.(SQM(I,1)+SQM(I,2))) THEN
          IF (NDIS(I,2).EQ.1) THEN
              SUBREP=RLGN(SMU(I,2),SSG(I,2),NS)
            ELSEIF (NDIS(I,2).EQ.2) THEN
              SUBREP=REXP(SMRT(I,2),NS)
            ENDIF
        ELSEIF (TYPEM.GT.(SQM(I,1)+SQM(I,2))) THEN
          IF (NDIS(I,3).EQ.1) THEN
              SUBREP=RLGN(SMU(I,3),SSG(I,3),NS)
            ELSEIF (NDIS(I,3).EQ.2) THEN
              SUBREP=REXP(SMRT(I,3),NS)
            ENDIF
        ENDIF
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION RLGN(SMU,SSG,NS)
C
C     *** FUNCTION RLGN RETURNS A RANDOM VARIATE FROM A LOGNORMAL
C         DISTRIBUTION WITH PARAMETERS SMU AND SSG USING RANDOM NUMBER
C         SEED NS.
C
      R=RAND(NS)
      RLGN=EXP(SMU+SSG*SNORM(R))
C
      RETURN
      END
C
C*************************************************************************
C
      FUNCTION SNORM(R)
C
C     *** FUNCTION SNORM RETURNS A PERCENTAGE POINT OF A STANDARD NORMAL
C         DISTRIBUTION ASSOCIATED WITH CUMULATIVE PROBABILITY R.
C
      DATA A0/2.50662823884/,A1/-18.61500062529/
      DATA A2/41.39119773534/,A3/-25.44106049637/
      DATA B1/-8.4735109309/,B2/23.08336743743/
      DATA B3/-21.06224101826/,B4/3.13082909833/
      DATA C0/-2.78718931138/,C1/-2.20796479134/
      DATA C2/4.8501412713/,C3/2.32121276858/
      DATA D1/3.54388924762/,D2/1.63706781897/
C
      Q=R-0.5
C
      IF (ABS(Q).LE.0.42) THEN
          QSQ=Q*Q
          X=Q*(((A3*QSQ+A2)*QSQ+A1)*QSQ+A0)/
     &       ((((B4*QSQ+B3)*QSQ+B2)*QSQ+B1)*QSQ+1.0)
        ELSE
          IF (Q.GT.0.0) R=1.0-R
          R=SQRT(-ALOG(R))
          X=(((C3*R+C2)*R+C1)*R+C0)/((D2*R+D1)*R+1.0)
          IF (Q.LT.0.0) X=-X
        ENDIF
C
      SNORM=X
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE SIMOUT
C
C     *** SUBROUTINE SIMOUT WRITES THE SIMULATION AIRCRAFT RELIABILITY
C         RESULTS TO THE OUTPUT FILE IN A LABELED FORMAT.
C
      COMMON/SIM1/N,NS1,NS2,CL,ZA,NSO,NFA(0:6),NFAT,NAT,ASFRT(100000)
     &           ,ASFR,AMFRT(100000),AMFR,CUMS(100)
C
      WRITE (12,10)
10    FORMAT ('1','*** SIMULATION RESULTS ***'//)
C
      WRITE (12,20)
20    FORMAT (1X,'SUBSYSTEM FAILURES'/)
      WRITE (12,30)
30    FORMAT (1X,'NUMBER FAILURES    NUMBER AIRCRAFT'/)
      DO 50 I=0,5
          WRITE (12,40) I,NFA(I)
40        FORMAT (1X,7X,I1,15X,I6)
50      CONTINUE
      WRITE (12,60) NFA(6)
60    FORMAT (1X,7X,'6+',14X,I6/)
      WRITE (12,70) NFAT
70    FORMAT (1X,'TOTAL NUMBER OF AIRCRAFT ARRIVING WITH FAILURES:  ',
     &        I7)
      WRITE (12,80) NAT
80    FORMAT (1X,'TOTAL NUMBER OF AIRCRAFT:                        ',
     &        I7//)
C
      WRITE (12,90) ASFR
90    FORMAT (1X,'AIRCRAFT SINGLE FAILURE RELIABILITY:    ',F6.4)
      WRITE (12,100) AMFR
100   FORMAT (1X,'AIRCRAFT MULTIPLE FAILURE RELIABILITY:  ',F6.4)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE SIMSPLIT(N,CL,ZA,ART,CUMS)
C
C     *** SUBROUTINE SIMSPLIT PRODUCES AN AIRCRAFT REPAIR TIME
C         DISTRIBUTION FROM AN ARRAY OF REPAIR TIME OBSERVATIONS ART.
C         A MEAN AND VARIANCE OF THE DISTRIBUTION ARE COMPUTED WITH
C         CONFIDENCE LIMITS FOR A CONFIDENCE LEVEL OF CL (CORRESPONDING
C         TO THE PERCENTAGE POINT OF THE STANDARD NORMAL DISTRIBUION ZA).
C         CUMULATIVE PROBABILITIES FOR A SET OF INCREMENTAL REPAIR TIMES
C         ARE STORED IN THE ARRAY CUMS.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIQ,TMO
C
      COMMON/SIM2/AMRT(3),AVRT(3),FRQ(100)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         FRQC(K) = FREQUENCY COUNTER FOR NUMBER OF REPAIR TIME
C                   OBSERVATIONS IN TIME INTERVAL K
C
      DIMENSION ART(100000),FRQC(100),CUMS(100)
C
      AMRT(1)=0.0
      AVRT(1)=0.0
      DO 10 I=1,N
          AMRT(1)=AMRT(1)+ART(I)
          AVRT(1)=AVRT(1)+ART(I)*ART(I)
10      CONTINUE
C
      AMRT(1)=AMRT(1)/N
      AVRT(1)=(AVRT(1)-N*AMRT(1)*AMRT(1))/(N-1)
C
      T1=ZA*SQRT(AVRT(1)/N)
      AMRT(2)=AMRT(1)-T1
      AMRT(3)=AMRT(1)+T1
C
      T2=2.0*FLOAT(N-1)*AVRT(1)
      T3=SQRT(FLOAT(2*N-1))
      AVRT(2)=T2/((T3+ZA)*(T3+ZA))
      AVRT(3)=T2/((T3-ZA)*(T3-ZA))
C
```

```
      DO 30 T=TI,TM,TI
          K=NINT(T/TI)
          FRQC(K)=0.0
          CUMS(K)=0.0
          DO 20 I=1,N
              IF ((ART(I).GT.(T-TI)).AND.(ART(I).LE.T)) THEN
                  FRQC(K)=FRQC(K)+1.0
                ENDIF
20          CONTINUE
C
          FRQ(K)=FRQC(K)/N
C
          IF (K.EQ.1) THEN
              CUMS(K)=FRQ(K)
            ELSE
              CUMS(K)=CUMS(K-1)+FRQ(K)
            ENDIF
30        CONTINUE
C
      CALL SPLITOUT(CL,CUMS)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE SPLITOUT(CL,CUMS)
C
C     *** SUBROUTINE SPLITOUT WRITES AN AIRCRAFT REPAIR TIME
C         DISTRIBUTION TO THE OUTPUT FILE IN A LABELED FORMAT.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO
C
      COMMON/SIM2/AMRT(3),AVRT(3),FRQ(100)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         LINE = CHARACTER STRING FOR GRAPHICAL PLOT OF THE
C                SIMULATION REPAIR TIME DISTRIBUTION
C
      CHARACTER*100 LINE
      DIMENSION CUMS(100)
C
      WRITE (12,10) AMRT(1)
10    FORMAT (1X,'AIRCRAFT MEAN REPAIR TIME:          ',F7.4)
      WRITE (12,20) CL,AMRT(2),AMRT(3)
20    FORMAT ('+',50X,F4.2,' CONFIDENCE INTERVAL:  (',F7.4,','F7.4,')')
      WRITE (12,30) AVRT(1)
30    FORMAT (1X,'AIRCRAFT VARIANCE OF REPAIR TIME:  ',F7.4)
      WRITE (12,20) CL,AVRT(2),AVRT(3)
C
      WRITE (12,40)
40    FORMAT (//1X,'FRQ(T)',2X,'CUM(T)',2X,'  TIME')
      WRITE (12,50)
50    FORMAT (1X,T25,20('+',4X),'+')
C
      DO 80 T=TI,TM,TI
          K=NINT(T/TI)
          DO 60 L=1,100
              LINE(L:L)=' '
              IF (L.LE.NINT(100.0*FRQ(K))) THEN
                  LINE(L:L)='*'
                ELSEIF (L.EQ.NINT(100.0*CUMS(K))) THEN
                  LINE(L:L)='C'
                ELSEIF (L.EQ.100) THEN
                  LINE(L:L)='+'
                ENDIF
60            CONTINUE
          WRITE (12,70) FRQ(K),CUMS(K),T,LINE
70        FORMAT (1X,2(F6.4,2X),F5.2,T25,'+',A100)
80      CONTINUE
C
```

```
      WRITE (12,50)
      WRITE(12,90)
90    FORMAT (1X,T24,'0.0',7X,'0.1',7X,'0.2',7X,'0.3',7X,'0.4',7X,
     &        '0.5',7X,'0.6',7X,'0.7',7X,'0.8',7X,'0.9',7X,'1.0'//)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE COMPARE
C
C     *** SUBROUTINE COMPARE COMPARES THE ANALYTICAL SINGLE FAILURE
C         REPAIR TIME CDF WITH THE SIMULATION MULTIPLE FAILURE
C         CDF FOR DISPARITY OF RESULTS.
C
      COMMON/SIM1/N,NS1,NS2,CL,ZA,NSO,NFA(0:6),NFAT,NAT,ASFRT(100000)
     &            ,ASFR,AMFRT(100000),AMFR,CUMS(100)
C
      COMMON/COMP/PDA,PDM,PDMT,RTK(20),PAK(20),PSK(3,20),PDK(3,20)
C
C     *** LOCAL VARIABLE DEFINITIONS
C         PA    = ANALYTICAL VALUE OF REPAIR TIME CDF CORRESPONDING TO
C                 A SORTED ARRAY ELEMENT
C         PS(1) = SIMULATION VALUE OF REPAIR TIME CDF CORRESPONDING TO
C                 A SORTED ARRAY ELEMENT
C                 (PS(2),PS(3)) = CONFIDENCE INTERVAL
C         PD    =  DIFFERENCE BETWEEN ANALYTICAL AND SIMULATION REPAIR
C                 TIME CDFS
C
      DIMENSION PS(3)
C
      CALL VSRTA(AMFRT,N)
C
      ZASQ=ZA*ZA
      T1=1.0/N
      T2=2.0*(N+ZASQ)
C
      PDA=0.0
      PDM=0.0
C
      KI=N/20
      K=0
      NN=0
C
      DO 20 I=1,N-1
C
          PS(1)=FLOAT(I)/N
          T3=1.0-PS(1)
          T4=2.0*N*PS(1)+ZASQ
          PS(2)=((T4-1.0)
     &          -ZA*SQRT(ZASQ-(2.0+T1)+4.0*PS(1)*(N*T3+1.0)))/T2
          PS(3)=((T4+1.0)
     &          +ZA*SQRT(ZASQ+(2.0-T1)+4.0*PS(1)*(N*T3-1.0)))/T2
C
```

```
            PA=CUMUL((AMFRT(I)+AMFRT(I+1))/2.0)
            PD=ABS(PA-PS(1))
            PDA=PDA+PD
            IF (PD.GT.PDM) THEN
                PDM=PD
                PDMT=AMFRT(I)
              ENDIF
C
            NN=NN+1
            IF (NN.EQ.KI) THEN
                NN=0
                K=K+1
                RTK(K)=AMFRT(I)
                PAK(K)=PA
                DO 10 J=1,3
                    PSK(J,K)=PS(J)
10                CONTINUE
                PDK(1,K)=PD
                IF ((PA.GE.PS(2)).AND.(PA.LE.PS(3))) THEN
                    PDK(2,K)=0.0
                  ELSE
                    PDK(2,K)=AMIN1(ABS(PS(2)-PA),ABS(PS(3)-PA))
                  ENDIF
                PDK(3,K)=AMAX1(ABS(PS(2)-PA),ABS(PS(3)-PA))
              ENDIF
C
20        CONTINUE
C
        PDA=PDA/N
C
        CALL COMPOUT
C
        RETURN
        END
C
```

```
C*************************************************************************
C
      SUBROUTINE COMPOUT
C
C     *** SUBROUTINE COMPOUT WRITES THE RESULTS OF THE CDF COMPARISON
C         TO THE OUTPUT FILE IN A LABELED FORMAT.  THE AMOUNT OF CPU
C         TIME USED BY THE ANALYTICAL AND SIMULATION METHODS IS ALSO
C         WRITTEN TO COMPARE THE METHODS FOR COMPUTATIONAL EFFICIENCY.
C
      COMMON/SIM1/N,NS1,NS2,CL,ZA,NSO,NFA(0:6),NFAT,NAT,ASFRT(100000)
     &            ,ASFR,AMFRT(100000),AMFR,CUMS(100)
C
      COMMON/COMP/PDA,PDM,PDMT,RTK(20),PAK(20),PSK(3,20),PDK(3,20)
C
      COMMON/CPU/CPUT(3)
C
      WRITE (12,10)
10    FORMAT ('1','*** COMPARISON -- SINGLE FAILURE ANALYTICAL ',
     &        'VS MULTIPLE FAILURE SIMULATION ***'//)
C
      WRITE (12,20)
20    FORMAT (1X,'PROPORTION (CDF) COMPARISON'/)
      WRITE (12,30)
30    FORMAT (1X,'REPAIR',2X,'  ANAL',2X,'SIMULATION PROPORTION',
     &        4X,'DIFFERENCE')
      WRITE (12,40) CL,CL
40    FORMAT (1X,'  TIME',2X,'  PROP',2X,
     &        2('(',F4.2,' CONF LIMITS)',7X)/)
C
      DO 60 K=1,19
         WRITE (12,50) RTK(K),PAK(K),PSK(1,K),PSK(2,K),
     &                 PSK(3,K),PDK(1,K),PDK(2,K),PDK(3,K)
50       FORMAT (1X,2(F6.4,2X),2(F6.4,'  (',F6.4,',',F6.4,')',2X))
60    CONTINUE
C
      WRITE (12,70) PDA
70    FORMAT (//1X,'AVERAGE CDF DIFFERENCE:  ',F6.4/)
      WRITE (12,80) PDM,PDMT
80    FORMAT (1X,'MAXIMUM CDF DIFFERENCE:  ',F7.5,
     &        ' AT TIME ',F6.4//)
C
      WRITE (12,90)
90    FORMAT (1X,'TIME COMPARISON'/)
      WRITE (12,100) CPUT(2)
100   FORMAT (1X,'ANALYTICAL CPU TIME USED:  ',F9.3)
      WRITE (12,110) CPUT(3)
110   FORMAT (1X,'SIMULATION CPU TIME USED:  ',F9.3)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE TRANSLATE(ARA,CUM)
C
C     *** SUBROUTINE TRANSLATE DETERMINES THE AIRCRAFT AVAILABILITY AND
C         SORTIE GENERATION RATE ASSOCIATED WITH THE AIRCRAFT REPAIR
C         TIME DISTRIBUTION CUM AND AIRCRAFT RELIABLITY ARA.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO
C
      COMMON/TRAN/TK(500),QSK(500),QTK(500),QRK(500),RAK(500),AVLK(500)
     &            ,SRATEK(500),AVLA,AVLM,TSOR,SRATE,TREP,RRATE
C
C     *** LOCAL VARIABLE DEFINITIONS
C         SSTE(I) = QUANTITY OF AIRCRAFT COMPLETING A SORTIE IN I
C                   TIME INCREMENTS
C         TSTE(I) = QUANTITY OF AIRCRAFT COMPLETING TURN OPERATIONS IN
C                   I TIME INCREMENTS
C         RSTE(I) = QUANTITY OF AIRCRAFT COMPLETING REPAIR OPERATIONS
C                   IN I TIME INCREMENTS
C         RTIP(I) = PROBABILITY OF AIRCRAFT REPAIR IN TIME INCREMENT I
C         NS      = NUMBER OF TIME INCREMENTS IN A SORTIE
C         NT      = NUMBER OF TIME INCREMENTS IN A TURN OPERATION
C         NR      = NUMBER OF POSSIBLE TIME INCREMENTS IN A REPAIR
C                   OPERATION
C         RA      = QUANTITY OF READY AIRCRAFT
C         SOUT    = QUANTITY OF AIRCRAFT COMPLETING SORTIES
C         TOUT    = QUANTITY OF AIRCRAFT COMPLETING TURN OPERATIONS
C         ROUT    = QUANTITY OF AIRCRAFT COMPLETING REPAIRS
C         SIN     = QUANTITY OF AIRCRAFT BEGINNING SORTIES
C         TIN     = QUANTITY OF AIRCRAFT BEGINNING TURN OPERATIONS
C         RIN     = QUANTITY OF AIRCRAFT BEGINNING REPAIRS
C         WT      = TIME OF DAY (FOR COMPARISON WITH SORTIE WINDOW)
C         QS      = QUANTITY OF AIRCRAFT FLYING SORTIES
C         QT      = QUANTITY OF AIRCRAFT BEING TURNED
C         QR      = QUANTITY OF AIRCRAFT BEING REPAIRED
C
      DIMENSION CUM(100),SSTE(100),TSTE(100),RSTE(100),RTIP(100)
C
      NS=ST/TI
      NT=TT/TI
      NR=TM/TI
C
      DO 10 I=1,NS
         SSTE(I)=0.0
10      CONTINUE
      DO 20 I=1,NT
         TSTE(I)=0.0
20      CONTINUE
```

```
      DO 30 I=1,NR
          RSTE(I)=0.0
30      CONTINUE
C
      RTIP(1)=CUM(1)
      DO 40 I=2,NR-1
          RTIP(I)=CUM(I)-CUM(I-1)
40      CONTINUE
      RTIP(NR)=1.0-CUM(NR-1)
C
      AVLA=0.0
      AVLM=1.0
      TSOR=0.0
      TREP=0.0
      RA=NAF
      KI=NINT(TIO/TI)
      K=0
      NTI=0
C
      DO 60 T=TI,TMO,TI
C
          CALL OUT(NS,SSTE,SOUT)
          CALL OUT(NT,TSTE,TOUT)
          CALL OUT(NR,RSTE,ROUT)
C
          RIN=(1.0-ARA)*SOUT
          TIN=ARA*SOUT+ROUT
          RA=RA+TOUT
          WT=T-IFIX(T/24.0)*24.0-0.001
          IF ((WT.GT.0.0).AND.(WT.LE.SW)) THEN
              IF (RA.LT.STIM) THEN
                  SIN=RA
                  RA=0.0
                ELSE
                  SIN=STIM
                  RA=RA-STIM
                ENDIF
            ELSE
              SIN=0.0
            ENDIF
C
          SSTE(NS)=SIN
          TSTE(NT)=TIN
          DO 50 I=1,NR
              RSTE(I)=RSTE(I)+RIN*RTIP(I)
50          CONTINUE
C
          CALL SUM(NS,SSTE,QS)
          CALL SUM(NT,TSTE,QT)
          CALL SUM(NR,RSTE,QR)
C
```

```
            AVL=(QS+RA)/(QS+QT+QR+RA)
            AVLA=AVLA+AVL
            AVLM=AMIN1(AVLM,AVL)
            TSOR=TSOR+SIN
            TREP=TREP+RIN
C
            NTI=NTI+1
            IF (NTI.EQ.KI) THEN
                NTI=0
                K=K+1
                TK(K)=T
                QSK(K)=QS
                QTK(K)=QT
                QRK(K)=QR
                RAK(K)=RA
                AVLK(K)=AVL
                SRATEK(K)=24.0*TSOR/(T*NAF)
              ENDIF
C
60      CONTINUE
C
      AVLA=AVLA*TI/TMO
      SRATE=24.0*TSOR/(TMO*NAF)
      RRATE=24.0*TREP/(TMO*NAF)
C
      CALL TRANSOUT
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE OUT(NX,XSTE,XOUT)
C
C     *** SUBROUTINE OUT RETURNS THE VALUE IN THE FIRST INCREMENT OF THE
C         ARRAY XOUT AND ADVANCES ALL OTHER INCREMENTS BY ONE POSITION.
C
C     *** LOCAL VARIABLE DEFINITIONS
C         XSTE(I) = QUANTITY OF AIRCRAFT COMPLETING ACTIVITY X IN I TIME
C                   INCREMENTS
C         NX      = NUMBER OF TIME INCREMENTS IN XSTE
C         XOUT    = QUANTITY OF AIRCRAFT COMPLETING ACTIVITY X AFTER ONE
C                   TIME INCREMENT
C
      DIMENSION XSTE(NX)
C
      XOUT=XSTE(1)
      DO 10 I=1,NX-1
          XSTE(I)=XSTE(I+1)
10      CONTINUE
      XSTE(NX)=0.0
C
      RETURN
      END
C
C*************************************************************************
C
      SUBROUTINE SUM(NX,XSTE,QX)
C
C     *** SUBROUTINE SUM DETERMINES THE TOTAL QUANTITY OF AIRCRAFT
C         ENGAGED IN ACTIVITY X.
C
C     *** LOCAL VARIABLE DEFINITIONS
C         XSTE(I) = QUANTITY OF AIRCRAFT COMPLETING ACTIVITY X IN I TIME
C                   INCREMENTS
C         NX      = NUMBER OF TIME INCREMENTS IN XSTE
C         QX      = TOTAL QUANTITY OF AIRCRAFT ENGAGED IN ACTIVITY X
C
      DIMENSION XSTE(NX)
C
      QX=0.0
      DO 10 I=1,NX
          QX=QX+XSTE(I)
10      CONTINUE
C
      RETURN
      END
C
```

```
C*******************************************************************************
C
      SUBROUTINE TRANSOUT
C
C     *** SUBROUTINE TRANSOUT WRITES THE AVAILABILITY AND SORTIE
C         GENERATION RESULTS TO THE OUTPUT FILE IN A LABELED FORMAT.
C
      COMMON/INIT/TI,TM,SCALE,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO
C
      COMMON/TRAN/TK(500),QSK(500),QTK(500),QRK(500),RAK(500),AVLK(500)
     &           ,SRATEK(500),AVLA,AVLM,TSOR,SRATE,TREP,RRATE
C
      WRITE (12,10)
10    FORMAT (1X,2X,'  TIME',2X,'!---  AIRCRAFT QUANTITIES ---!',2X,
     &        ' AVAIL',2X,'SOR GEN')
      WRITE (12,20)
20    FORMAT (1X,10X,'SORTIE',2X,'  TURN',2X,'REPAIR',2X,' READY',10X,
     &        '  RATE'/)
      DO 40 K=1,NINT(TMO/TIO)
         WRITE (12,30) TK(K),QSK(K),QTK(K),QRK(K),RAK(K),AVLK(K),
     &                 SRATEK(K)
30       FORMAT (1X,7F8.3)
40    CONTINUE
C
      WRITE (12,50) AVLA
50    FORMAT (//1X,'AVERAGE AVAILABILITY:      ',F9.4)
      WRITE (12,60) AVLM
60    FORMAT (1X,'MINIMUM AVAILABILITY:      ',F9.4/)
C
      WRITE (12,70) TSOR
70    FORMAT (1X,'TOTAL SORTIES LAUNCHED:    ',F9.4)
      WRITE (12,80) SRATE
80    FORMAT (1X,'SORTIE GENERATION RATE:    ',F9.4/)
C
      WRITE (12,90) TREP
90    FORMAT (1X,'TOTAL MAINTENANCE EVENTS:  ',F9.4)
      WRITE (12,100) RRATE
100   FORMAT (1X,'MAINTENANCE RATE:          ',F9.4)
C
      RETURN
      END
C
C*******************************************************************************
```

Appendix C

Sample Output for Repair Time Distribution Model (Version 1.0)

INITIAL DATA

PDF/CDF REPAIR TIME INCREMENT: 0.20
PDF/CDF MAXIMUM REPAIR TIME: 8.00

RELIABILITY SCALING FACTOR: 1.00

TOTAL NUMBER OF SUBSYSTEMS: 24

			REMOVE AND REPLACE				REPAIR IN PLACE				CAN NOT DUPLICATE			
SUBSYS CODE	SUBSYS MSBF	SUBSYS REL	DIST TYPE	COND PROB	MEAN TIME	VAR-IANCE	DIST TYPE	COND PROB	MEAN TIME	VAR-IANCE	DIST TYPE	COND PROB	MEAN TIME	VAR-IANCE
11	133.000	0.993	LGN	0.030	1.270	0.370	LGN	0.966	2.220	0.640	LGN	0.004	3.130	0.910
12	241.000	0.996	LGN	0.278	2.720	0.790	LGN	0.662	1.700	0.490	LGN	0.060	0.700	0.200
13	149.000	0.993	LGN	0.544	2.080	0.600	LGN	0.386	2.050	0.590	LGN	0.070	2.180	0.630
14	141.000	0.993	LGN	0.456	2.330	0.680	LGN	0.299	2.430	0.700	LGN	0.245	1.530	0.440
23	165.000	0.994	LGN	0.428	3.120	0.900	LGN	0.494	1.480	0.430	LGN	0.078	2.110	0.610
24	207.000	0.995	LGN	0.490	2.830	0.820	LGN	0.436	2.260	0.660	LGN	0.074	2.220	0.640
41	417.000	0.998	LGN	0.442	3.310	0.960	LGN	0.199	1.720	0.500	LGN	0.359	2.350	0.680
42	265.000	0.996	LGN	0.803	1.320	0.380	LGN	0.173	2.970	0.860	LGN	0.024	2.900	0.840
44	700.000	0.999	LGN	0.618	1.200	0.350	LGN	0.333	1.520	0.440	LGN	0.049	2.570	0.750
45	450.000	0.998	LGN	0.327	3.110	0.900	LGN	0.587	2.200	0.640	LGN	0.086	1.450	0.420
46	168.000	0.994	LGN	0.428	3.080	0.890	LGN	0.421	2.780	0.810	LGN	0.151	1.780	0.520
47	1000.000	0.999	LGN	0.523	1.800	0.520	LGN	0.315	1.710	0.500	LGN	0.162	1.480	0.430
49	3300.000	1.000	LGN	0.857	3.230	0.940	N/A	0.000	0.000	0.000	LGN	0.143	1.000	0.290
51	480.000	0.998	LGN	0.583	1.510	0.440	LGN	0.183	1.040	0.300	LGN	0.234	1.020	0.300
55	7200.000	1.000	LGN	0.389	1.120	0.320	LGN	0.222	1.130	0.330	LGN	0.389	0.370	0.110
62	2000.000	1.000	LGN	0.298	1.030	0.300	LGN	0.386	1.270	0.370	LGN	0.316	0.950	0.280
63	475.000	0.998	LGN	0.329	1.190	0.350	LGN	0.309	0.950	0.280	LGN	0.362	1.180	0.340
64	975.000	0.999	LGN	0.220	1.700	0.490	LGN	0.381	1.310	0.380	LGN	0.399	0.890	0.260
65	1600.000	0.999	LGN	0.685	1.290	0.370	LGN	0.137	0.920	0.270	LGN	0.178	0.840	0.240
71	622.000	0.998	LGN	0.497	1.260	0.370	LGN	0.222	0.970	0.280	LGN	0.281	1.120	0.320
74	36.500	0.973	LGN	0.359	1.350	0.390	LGN	0.094	1.260	0.370	LGN	0.547	1.040	0.300
75	80.000	0.988	LGN	0.274	1.630	0.470	LGN	0.089	1.680	0.490	LGN	0.637	1.010	0.290
76	295.000	0.997	LGN	0.635	2.280	0.660	LGN	0.184	1.710	0.500	LGN	0.181	1.480	0.430
97	11000.000	1.000	LGN	0.867	2.570	0.750	LGN	0.133	2.100	0.620	N/A	0.000	0.000	0.000

AVAILABILITY/SORTIE GENERATION PARAMETERS

AIRCRAFT FORCE SIZE: 24
AIRCRAFT SORTIE TIME: 2.40
AIRCRAFT TURN TIME: 0.40
SORTIE LAUNCH WINDOW: 16.00
MAXIMUM LAUNCHES PER PERIOD TI: 2.00

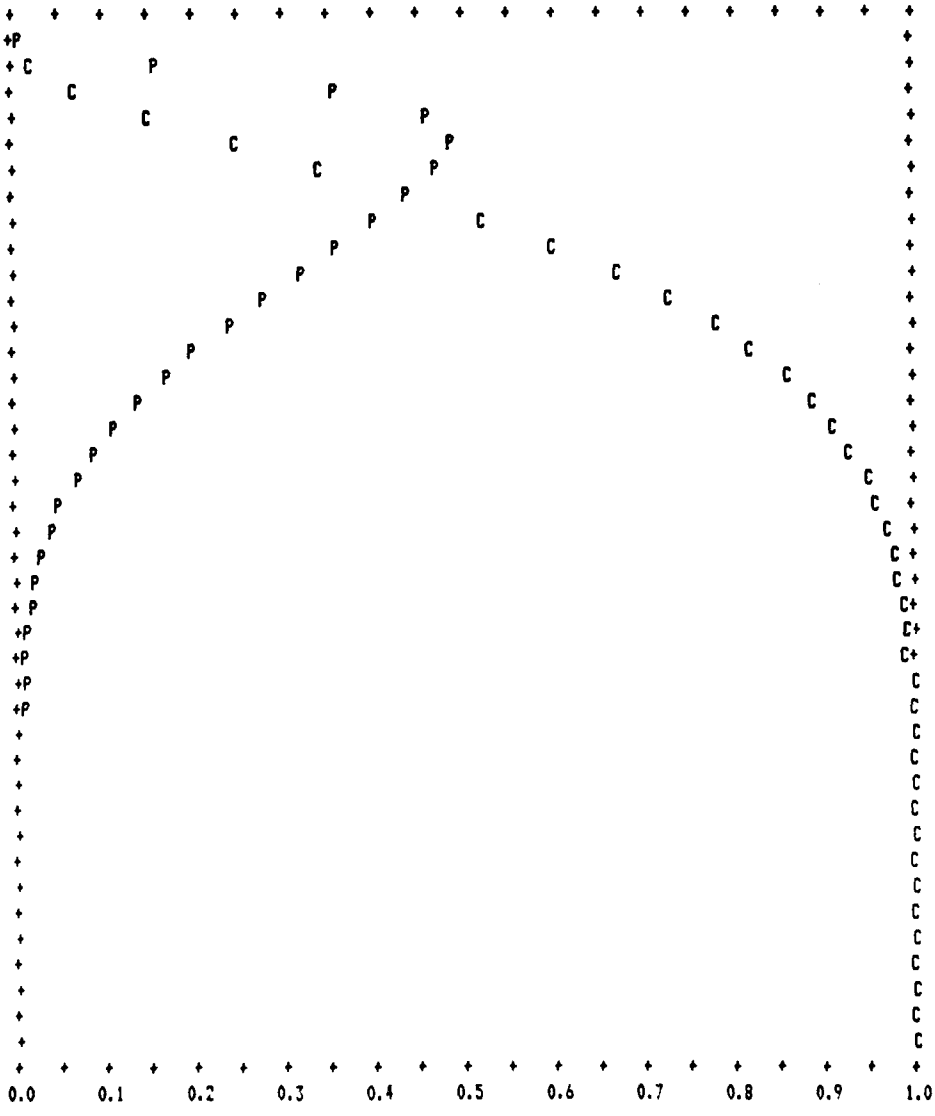
AVAIL/SORT GEN TIME INCREMENT: 2.00
AVAIL/SORT GEN MAXIMUM TIME: 48.00

ANALYTICAL RESULTS

AIRCRAFT RELIABILITY: 0.9004
AIRCRAFT MEAN SORTIES BETWEEN FAILURES: 9.5324

SINGLE FAILURE MEAN REPAIR TIME: 1.7439
SINGLE FAILURE VARIANCE OF REPAIR TIME: 0.9492

PDF(T)	CDF(T)	TIME
0.0139	0.0006	0.20
0.1616	0.0155	0.40
0.3556	0.0681	0.60
0.4633	0.1517	0.80
0.4900	0.2480	1.00
0.4745	0.3449	1.20
0.4424	0.4367	1.40
0.4041	0.5215	1.60
0.3634	0.5982	1.80
0.3218	0.6668	2.00
0.2803	0.7270	2.20
0.2400	0.7790	2.40
0.2021	0.8231	2.60
0.1674	0.8600	2.80
0.1365	0.8903	3.00
0.1097	0.9149	3.20
0.0871	0.9345	3.40
0.0683	0.9500	3.60
0.0530	0.9620	3.80
0.0407	0.9714	4.00
0.0311	0.9785	4.20
0.0235	0.9839	4.40
0.0177	0.9880	4.60
0.0133	0.9911	4.80
0.0099	0.9934	5.00
0.0074	0.9951	5.20
0.0055	0.9964	5.40
0.0040	0.9973	5.60
0.0030	0.9980	5.80
0.0022	0.9985	6.00
0.0016	0.9989	6.20
0.0012	0.9992	6.40
0.0009	0.9994	6.60
0.0007	0.9996	6.80
0.0005	0.9997	7.00
0.0004	0.9998	7.20
0.0003	0.9998	7.40
0.0002	0.9999	7.60
0.0001	0.9999	7.80
0.0001	0.9999	8.00



SIMULATION RESULTS

SUBSYSTEM FAILURES

NUMBER FAILURES	NUMBER AIRCRAFT
0	360252
1	38156
2	1800
3	42
4	2
5	0
6+	0

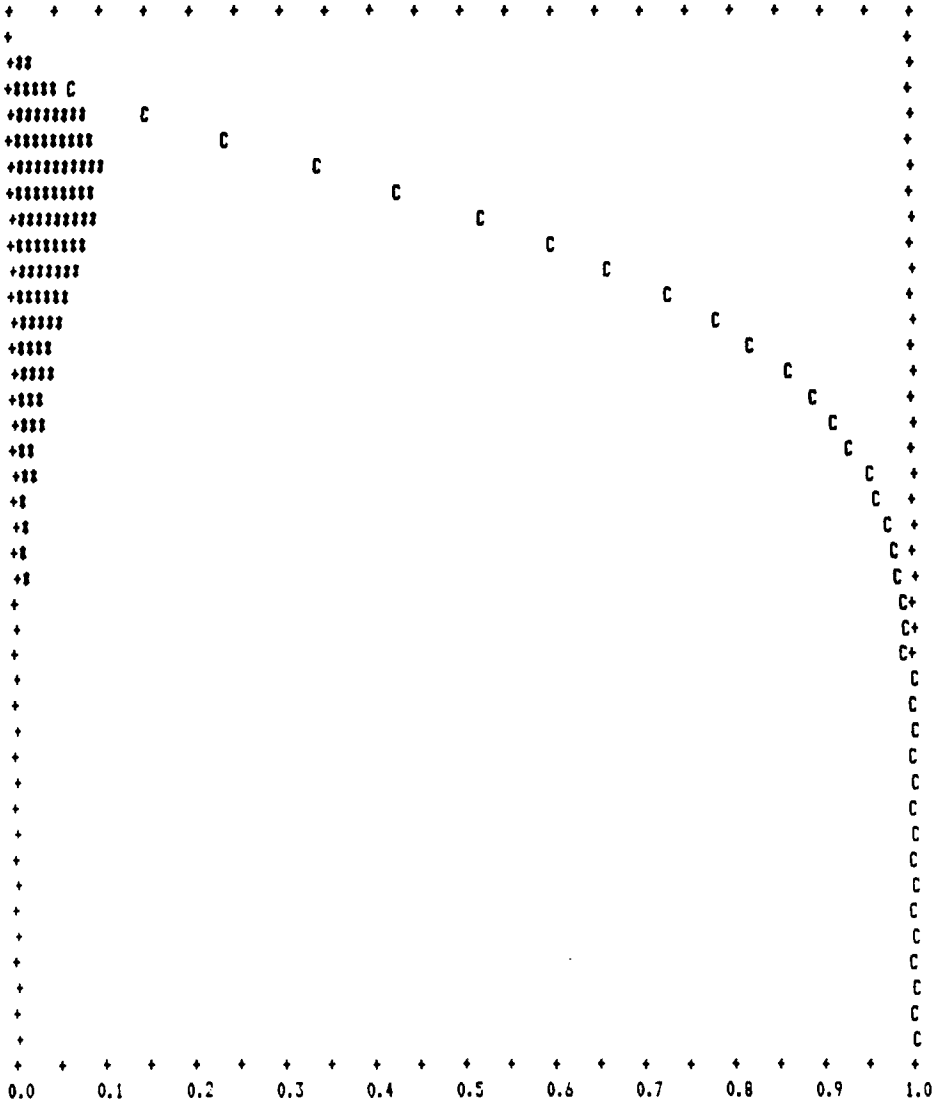
TOTAL NUMBER OF AIRCRAFT ARRIVING WITH FAILURES: 40000
TOTAL NUMBER OF AIRCRAFT: 400252

AIRCRAFT SINGLE FAILURE RELIABILITY: 0.9047
AIRCRAFT MULTIPLE FAILURE RELIABILITY: 0.9001

SINGLE FAILURE REPAIR TIME RESULTS

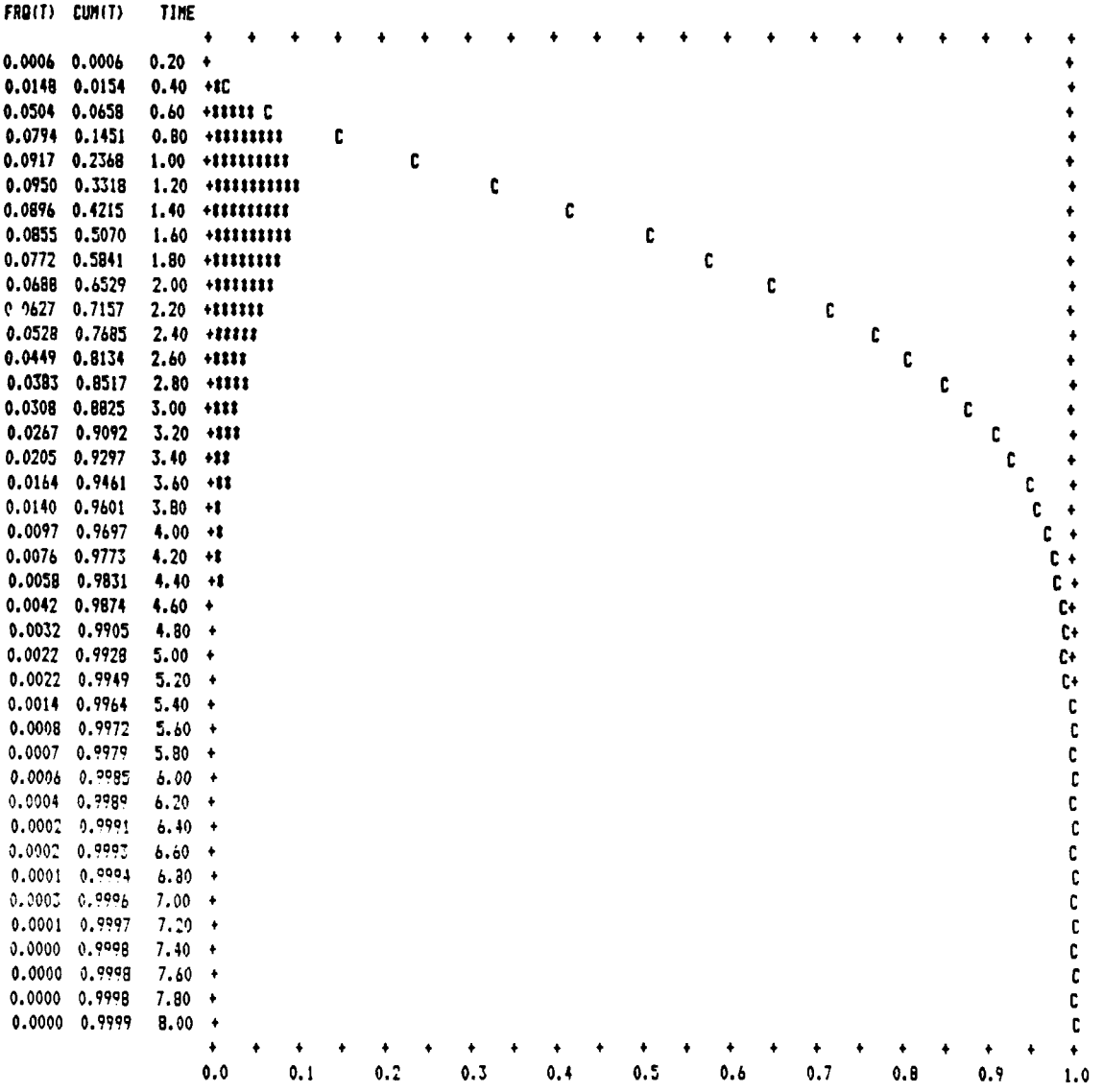
AIRCRAFT MEAN REPAIR TIME: 1.7515 0.95 CONFIDENCE INTERVAL: (1.7418, 1.7611)
AIRCRAFT VARIANCE OF REPAIR TIME: 0.9569 0.95 CONFIDENCE INTERVAL: (0.9437, 0.9704)

FRQ(T)	CUM(T)	TIME
0.0006	0.0006	0.20
0.0153	0.0159	0.40
0.0523	0.0683	0.60
0.0819	0.1501	0.80
0.0942	0.2444	1.00
0.0973	0.3417	1.20
0.0909	0.4326	1.40
0.0865	0.5192	1.60
0.0767	0.5958	1.80
0.0679	0.6637	2.00
0.0616	0.7254	2.20
0.0515	0.7768	2.40
0.0435	0.8204	2.60
0.0371	0.8575	2.80
0.0295	0.8870	3.00
0.0258	0.9129	3.20
0.0198	0.9327	3.40
0.0158	0.9484	3.60
0.0135	0.9620	3.80
0.0092	0.9711	4.00
0.0074	0.9785	4.20
0.0055	0.9841	4.40
0.0039	0.9880	4.60
0.0030	0.9910	4.80
0.0021	0.9932	5.00
0.0021	0.9952	5.20
0.0013	0.9965	5.40
0.0008	0.9974	5.60
0.0006	0.9980	5.80
0.0005	0.9985	6.00
0.0004	0.9989	6.20
0.0002	0.9991	6.40
0.0002	0.9993	6.60
0.0001	0.9994	6.80
0.0003	0.9996	7.00
0.0001	0.9997	7.20
0.0000	0.9998	7.40
0.0000	0.9998	7.60
0.0000	0.9998	7.80
0.0000	0.9999	8.00



MULTIPLE FAILURE REPAIR TIME RESULTS

AIRCRAFT MEAN REPAIR TIME: 1.7761 0.95 CONFIDENCE INTERVAL: (1.7664, 1.7858)
AIRCRAFT VARIANCE OF REPAIR TIME: 0.9720 0.95 CONFIDENCE INTERVAL: (0.9586, 0.9857)



COMPARISON -- SINGLE FAILURE ANALYTICAL VS MULTIPLE FAILURE SIMULATION

PROPORTION (CDF) COMPARISON

REPAIR TIME	ANAL PROP	SIMULATION PROPORTION (0.95 CONF LIMITS)		DIFFERENCE (0.95 CONF LIMITS)	
0.5521	0.0521	0.0500	(0.0479,0.0522)	0.0021	(0.0000,0.0042)
0.6950	0.1051	0.1000	(0.0971,0.1030)	0.0051	(0.0021,0.0081)
0.8107	0.1567	0.1500	(0.1465,0.1536)	0.0067	(0.0031,0.0102)
0.9222	0.2100	0.2000	(0.1961,0.2040)	0.0100	(0.0060,0.0139)
1.0241	0.2598	0.2500	(0.2457,0.2543)	0.0098	(0.0055,0.0141)
1.1304	0.3116	0.3000	(0.2955,0.3046)	0.0116	(0.0070,0.0161)
1.2365	0.3622	0.3500	(0.3453,0.3547)	0.0122	(0.0074,0.0169)
1.3505	0.4147	0.4000	(0.3952,0.4049)	0.0147	(0.0098,0.0195)
1.4652	0.4652	0.4500	(0.4451,0.4549)	0.0152	(0.0103,0.0201)
1.5825	0.5144	0.5000	(0.4951,0.5049)	0.0144	(0.0094,0.0193)
1.7088	0.5642	0.5500	(0.5451,0.5549)	0.0142	(0.0093,0.0192)
1.8426	0.6135	0.6000	(0.5951,0.6048)	0.0135	(0.0087,0.0184)
1.9907	0.6638	0.6500	(0.6453,0.6547)	0.0138	(0.0091,0.0185)
2.1501	0.7127	0.7000	(0.6954,0.7045)	0.0127	(0.0082,0.0173)
2.3239	0.7601	0.7500	(0.7457,0.7543)	0.0101	(0.0058,0.0144)
2.5381	0.8103	0.8000	(0.7960,0.8039)	0.0103	(0.0063,0.0143)
2.7896	0.8583	0.8500	(0.8464,0.8535)	0.0083	(0.0048,0.0118)
3.1224	0.9060	0.9000	(0.8970,0.9029)	0.0060	(0.0031,0.0090)
3.6504	0.9534	0.9500	(0.9478,0.9521)	0.0034	(0.0012,0.0056)

AVERAGE CDF DIFFERENCE: 0.0098

MAXIMUM CDF DIFFERENCE: 0.01611 AT TIME 1.5359

TIME COMPARISON

ANALYTICAL CPU TIME USED: 0.700
SIMULATION CPU TIME USED: 1074.420

ANALYTICAL AVAILABILITY AND SORTIE GENERATION RESULTS

TIME	AIRCRAFT QUANTITIES				AVAIL	SOR GEN
	SORTIE	TURN	REPAIR	READY		RATE
2.000	20.000	0.000	0.000	4.000	1.000	10.000
4.000	18.901	3.757	1.341	0.000	0.788	8.725
6.000	19.037	3.562	1.402	0.000	0.793	8.376
8.000	22.024	0.632	1.345	0.000	0.918	8.588
10.000	18.713	3.704	1.583	0.000	0.780	8.359
12.000	19.035	3.500	1.465	0.000	0.793	8.250
14.000	19.084	3.529	1.387	0.000	0.795	8.186
16.000	18.718	3.679	1.603	0.000	0.780	8.261
18.000	3.606	3.489	1.507	15.398	0.792	7.343
20.000	0.000	0.207	0.428	23.365	0.974	6.608
22.000	0.000	0.026	0.035	23.939	0.997	6.008
24.000	0.000	0.001	0.002	23.997	1.000	5.507
26.000	20.000	0.000	0.000	4.000	1.000	5.853
28.000	18.901	3.757	1.341	0.000	0.788	5.967
30.000	19.037	3.562	1.402	0.000	0.793	6.081
32.000	22.024	0.632	1.345	0.000	0.918	6.277
34.000	18.713	3.704	1.583	0.000	0.780	6.346
36.000	19.035	3.500	1.465	0.000	0.793	6.421
38.000	19.084	3.529	1.387	0.000	0.795	6.494
40.000	18.718	3.679	1.603	0.000	0.780	6.608
42.000	3.606	3.489	1.507	15.398	0.792	6.294
44.000	0.000	0.207	0.428	23.365	0.974	6.008
46.000	0.000	0.026	0.035	23.939	0.997	5.746
48.000	0.000	0.001	0.002	23.997	1.000	5.507

AVERAGE AVAILABILITY: 0.8661
MINIMUM AVAILABILITY: 0.7701

TOTAL SORTIES LAUNCHED: 264.3368
SORTIE GENERATION RATE: 5.5070

TOTAL MAINTENANCE EVENTS: 26.3253
MAINTENANCE RATE: 0.5484

SIMULATION AVAILABILITY AND SORTIE GENERATION RESULTS

TIME	AIRCRAFT QUANTITIES				AVAIL	SOR GEN
	SORTIE	TURN	REPAIR	READY		RATE
2.000	20.000	0.000	0.000	4.000	1.000	10.000
4.000	18.897	3.752	1.351	0.000	0.787	8.724
6.000	19.010	3.562	1.428	0.000	0.792	8.372
8.000	22.003	0.627	1.370	0.000	0.917	8.583
10.000	18.695	3.698	1.607	0.000	0.779	8.354
12.000	19.011	3.500	1.489	0.000	0.792	8.244
14.000	19.063	3.524	1.412	0.000	0.794	8.179
16.000	18.701	3.672	1.627	0.000	0.779	8.254
18.000	3.600	3.484	1.531	15.385	0.791	7.337
20.000	0.000	0.211	0.446	23.342	0.973	6.603
22.000	0.000	0.028	0.037	23.935	0.997	6.003
24.000	0.000	0.002	0.002	23.997	1.000	5.502
26.000	20.000	0.000	0.000	4.000	1.000	5.848
28.000	18.897	3.752	1.351	0.000	0.787	5.963
30.000	19.010	3.562	1.428	0.000	0.792	6.076
32.000	22.003	0.627	1.370	0.000	0.917	6.272
34.000	18.695	3.698	1.607	0.000	0.779	6.341
36.000	19.011	3.500	1.489	0.000	0.792	6.416
38.000	19.063	3.524	1.412	0.000	0.794	6.489
40.000	18.701	3.672	1.627	0.000	0.779	6.603
42.000	3.600	3.484	1.531	15.385	0.791	6.288
44.000	0.000	0.211	0.446	23.342	0.973	6.003
46.000	0.000	0.028	0.037	23.935	0.997	5.742
48.000	0.000	0.002	0.002	23.997	1.000	5.502

AVERAGE AVAILABILITY: 0.8655
MINIMUM AVAILABILITY: 0.7695

TOTAL SORTIES LAUNCHED: 264.1163
SORTIE GENERATION RATE: 5.5024

TOTAL MAINTENANCE EVENTS: 26.3033
MAINTENANCE RATE: 0.5480

NORMAL PROGRAM TERMINATION

Appendix D

Program Listing of Repair Time Distribution Model (Version 2.0)

```
C*************************************************************************C
C                                                                         C
C     REPAIR TIME DISTRIBUTION MODEL (VERSION 2.0)                        C
C                                                                         C
C     THIS PROGRAM COMBINES SUBSYSTEM RELIABILITY AND                     C
C     MAINTAINABILITY ESTIMATES TO FORM A REPAIR TIME DISTRIBUTION        C
C     FOR THE ADVANCED TACTICAL FIGHTER.  THE MEAN, VARIANCE,             C
C     PROBABILITY DENSITY FUNCTION, AND CUMULATIVE DISTRIBUTION           C
C     FUNCTION OF THE REPAIR TIME DISTRIBUTION ARE DETERMINED             C
C     ANALYTICALLY BASED ON THE ASSUMPTION THAT ONLY ONE SUBSYSTEM        C
C     WILL FAIL BEFORE REPAIR EFFORTS ARE BEGUN ON THE ENTIRE             C
C     SYSTEM.  AN ADJUSTED CUMULATIVE DISTRIBUTION IS COMPUTED TO         C
C     REFLECT THE EFFECT OF POSSIBLE MULTIPLE SUBSYSTEM FAILURES.         C
C     THE USER MAY THEN EMPLOY THE ADJUSTED OR UNADJUSTED REPAIR          C
C     TIME DISTRIBUTION TO DETERMINE THE AVAILABILITY AND SORTIE          C
C     GENERATION CAPABILITY OF THE AIRCRAFT UNDER A SPECIFIED             C
C     CONCEPT OF OPERATIONS.                                              C
C                                                                         C
C     GLOBAL VARIABLE DEFINITIONS                                         C
C                                                                         C
C       ****  INITIAL DATA VARIABLES                                      C
C                                                                         C
C         TI          = TIME INCREMENT FOR REPAIR TIME PDF/CDF          C
C                       COMPUTATIONS                                      C
C         TM          = MAXIMUM REPAIR TIME FOR PDF/CDF COMPUTATIONS    C
C                                                                         C
C         NSUB        = TOTAL NUMBER OF SUBSYSTEMS                      C
C                                                                         C
C         NWUC(I)     = WORK UNIT CODE OF SUBSYSTEM I                   C
C         SMSBF(I)    = MEAN NUMBER OF SORTIES BETWEEN FAILURES OF      C
C                       SUBSYSTEM I                                       C
C         SREL(I)     = SORTIE RELIABILITY OF SUBSYSTEM I               C
C                                                                         C
C         NDIS(I,J)   = TYPE OF DISTRIBUTION OF MAINTENANCE ACTION      C
C                       J ON SUBSYSTEM I                                  C
C                       (0 = NONE, 1 = LOGNORMAL, 2 = EXPONENTIAL)        C
C         SQM(I,J)    = PROBABILITY THAT MAINTENANCE ACTION J IS        C
C                       REQUIRED GIVEN SUBSYSTEM I HAS FAILED             C
C         SMRT(I,J)   = MEAN REPAIR TIME FOR ACTION J ON SUBSYSTEM I    C
C         SVRT(I,J)   = VARIANCE OF REPAIR TIME FOR ACTION J ON         C
C                       SUBSYSTEM I                                       C
C         SMU(I,J)    = LOGNORMAL MU FOR ACTION J ON SUBSYSTEM I        C
C         SSGSQ(I,J)  = LOGORMAL SIGMA SQUARED FOR ACTION J ON          C
C                       SUBSYSTEM I                                       C
C         SSG(I,J)    = LOGNORMAL SIGMA FOR ACTION J ON SUBSYSTEM I     C
C                                                                         C
C                         MAINTENANCE       J=1:  REMOVE AND REPLACE    C
C                         ACTION CODES      J=2:  REPAIR IN PLACE       C
C                                           J=3:  CAN NOT DUPLICATE     C
C                                                                         C
```

```
C         NAF          = AIRCRAFT FORCE SIZE                                C
C         ST           = AIRCRAFT SORTIE TIME                               C
C         TT           = AIRCRAFT TURN TIME                                 C
C         SW           = SORTIE LAUNCH TIME WINDOW                          C
C         STIM         = MAXIMUM AIRCRAFT LAUNCHES PER TIME PERIOD TI       C
C         TIO          = OPERATIONAL EFFECTIVENESS OUTPUT TIME              C
C                        INCREMENT                                          C
C         TMO          = MAXIMUM TIME FOR OPERATIONAL EFFECTIVENESS         C
C                        OUTPUT                                             C
C                                                                           C
C         NERR         = NUMBER OF INPUT DATA ERRORS IDENTIFIED             C
C                                                                           C
C       **** ANALYTICAL VARIABLES                                           C
C                                                                           C
C         ARA          = AIRCRAFT RELIABILITY                               C
C         AMSBF        = AIRCRAFT MEAN NUMBER OF SORTIES BETWEEN            C
C                        FAILURES                                           C
C         SPM(I,J)     = PROBABILITY THAT MAINT ACTION J ON SUBSYSTEM       C
C                        I IS REQUIRED GIVEN AIRCRAFT HAS FAILED            C
C         AMRTA        = AIRCRAFT MEAN REPAIR TIME                          C
C         AVRTA        = AIRCRAFT REPAIR TIME VARIANCE                      C
C         DEN(K)       = REPAIR TIME PROBABILITY DENSITY AT TIME            C
C                        INCREMENT K                                        C
C         CUMA(K)      = REPAIR TIME CUMULATIVE PROBABILITY AT TIME         C
C                        INCREMENT K (SINGLE FAILURE)                       C
C         CUMAA(K)     = ADJUSTED REPAIR TIME CUMULATIVE PROBABILITY        C
C                        AT TIME INCREMENT K (MULTIPLE FAILURE)             C
C         PDM          = ESTIMATED MAXIMUM DIFFERENCE BETWEEN SINGLE        C
C                        AND MULTIPLE FAILURE CDFS                          C
C                                                                           C
C       **** OPERATIONAL EFFECTIVENESS TRANSLATION VARIABLES                C
C                                                                           C
C         TK(K)        = TIME AT TIME INCREMENT K                           C
C         QSK(K)       = QUANTITY OF AIRCRAFT IN FLYING SORTIES AT          C
C                        TK(K)                                              C
C         QTK(K)       = QUANTITY OF AIRCRAFT BEING TURNED AT TK(K)         C
C         QRK(K)       = QUANTITY OF AIRCRAFT BEING REPAIRED AT TK(K)       C
C         RA(K)        = QUANTITY OF READY AIRCRAFT AT TK(K)                C
C         AVLK(K)      = AIRCRAFT AVAILABILITY AT TK(K)                     C
C         SRATEK(K)    = SORTIE GENERATION RATE UP TO TK(K)                 C
C         AVLA         = AVERAGE AIRCRAFT AVAILABILITY                      C
C         AVLM         = MIMIMIM AIRCRAFT AVAILABILITY                      C
C         TSOR         = TOTAL QUANTITY OF SORTIES FLOWN                    C
C         SRATE        = SORTIE GENERATION RATE                             C
C         TREP         = TOTAL QUANTITY OF REPAIRS PERFORMED                C
C         RRATE        = REPAIR RATE                                        C
C                                                                           C
C***************************************************************************C
C
```

```
      PROGRAM RTDM2
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
     &           ,CUMAA(100),PDM
C
      COMMON/TRAN/TK(500),QSK(500),QTK(500),QRK(500),RAK(500),AVLK(500)
     &           ,SRATEK(500),AVLA,AVLM,TSOR,SRATE,TREP,RRATE
C
C     *** LOCAL VARIABLE DEFINITIONS
C         MSEL = MENU SELECTION NUMBER
C         NOUT = INDICATOR FOR OUTPUT DESTINTION
C         NCDF = INDICATOR FOR USE OF ADJUSTED CDF IN AVAIL/SORTIE GEN
C                COMPUTATIONS
C
      OPEN (UNIT=11,FILE='RTDM2.DAT',STATUS='OLD')
      REWIND(11)
      CALL READIN
C
20    WRITE (*,30)
30    FORMAT ('1'/
     &        '1','**********************************************************'/
     &           ' *                                                        *'/
     &           ' *  REPAIR TIME DISTRIBUTION MODEL (VERSION 2.0)          *'/
     &           ' *                                                        *'/
     &           ' **********************************************************'/
     &        ///' ****  MAIN MENU  ****'//
     &           ' 1.  PRINT CURRENT DATA'/
     &           ' 2.  CHANGE DATA'/
     &           ' 3.  RUN PROGRAM'/
     &           ' 4.  EXIT TO OPERATING SYSTEM'//
     &           ' ENTER SELECTION NUMBER:')
C
      READ (*,*) MSEL
C
      IF (MSEL.EQ.1) THEN
          CALL INITIAL
        ELSEIF (MSEL.EQ.2) THEN
          CALL CHNGDAT
```

```
        ELSEIF (MSEL.EQ.3) THEN
          WRITE (*,35)
35        FORMAT (/' SELECT OUTPUT DESTINATION:  ',
     &            '1=FILE "RTDM2.OUT", 0=PRINTER)')
          READ NOUT
          IF (NOUT.EQ.1) THEN
              OPEN (UNIT=12,FILE='RTDM2.OUT',STATUS='NEW')
            ELSE
              OPEN (UNIT=12,FILE='PRN')
            ENDIF
          CALL INITIAL
          IF (NERR.GT.0) GOTO 20
          CALL CALCULATE
          WRITE (*,40)
40        FORMAT (/' USE ADJUSTED CDF FOR AVAILABILITY/SORTIE GEN ',
     &            'COMPUTATIONS?  (1=YES, 0=NO)')
          READ (*,*) NCDF
          IF (NCDF.EQ.1) THEN
              CALL TRANSLATE(ARA,CUMAA)
            ELSE
              CALL TRANSLATE(ARA,CUMA)
            ENDIF
        ELSEIF (MSEL.EQ.4) THEN
          GOTO 50
        ENDIF
C
      GOTO 20
C
50    CLOSE(11)
      CLOSE(12)
      END
C
```

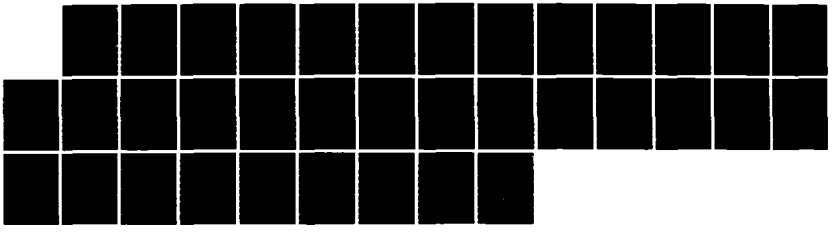
```
C*************************************************************************
C
      SUBROUTINE READIN
C
C     *** SUBROUTINE READIN READS THE INPUT DATA FROM THE INPUT DATA
C         FILE.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO,NERR
C
      READ (11,*) TI,TM,NSUB
C
      DO 10 I=1,NSUB
         READ (11,*) NWUC(I),SMSBF(I),
     &               (NDIS(I,J),SQM(I,J),SMRT(I,J),SVRT(I,J),J=1,3)
10       CONTINUE
C
      READ (11,*) NAF,ST,TT,SW,STIM,TIO,TMO
C
      RETURN
      END
C
```

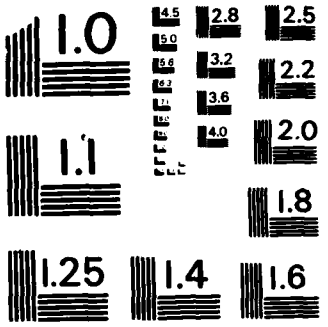
```
C*************************************************************************
C
      SUBROUTINE INITIAL
C
C     *** SUBROUTINE INITIAL TRANSFORMS AND CHECKS THE INPUT DATA
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
      DO 20 I=1,NSUB
          SREL(I)=EXP(-1.0/SMSBF(I))
          DO 10 J=1,3
              SMRTSQ=SMRT(I,J)*SMRT(I,J)
              IF (NDIS(I,J).EQ.1) THEN
                  SMU(I,J)=ALOG(SMRTSQ/SQRT(SVRT(I,J)+SMRTSQ))
                  SSGSQ(I,J)=ALOG((SVRT(I,J)+SMRTSQ)/SMRTSQ)
                  SSG(I,J)=SQRT(SSGSQ(I,J))
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  SVRT(I,J)=1.0/SMRTSQ
                ENDIF
10            CONTINUE
20        CONTINUE
C
      CALL INITOUT
      CALL ERRCHK
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE INITOUT
C
C     *** SUBROUTINE INITOUT PRINTS THE INPUT DATA TO THE OUTPUT DEVICE
C         IN A LABELED FORMAT.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
C     *** LOCAL VARIABLE DEFINITIONS
C         CNDIS(I,J) = ALPHANUMERIC IDENTIFIER FOR DISTRIBUTIONAL FORM
C                      OF MAINTENANCE ACTION J ON SUBSYSTEM I
C                      'N/A' = NOT APPLICABLE
C                      'LGN' = LOGNORMAL
C                      'EXP' = EXPONENTIAL
C
      CHARACTER*3 CNDIS(30,3)
C
      DO 20 I=1,NSUB
          DO 10 J=1,3
              IF (NDIS(I,J).EQ.0) THEN
                  CNDIS(I,J)='N/A'
                ELSEIF (NDIS(I,J).EQ.1) THEN
                  CNDIS(I,J)='LGN'
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  CNDIS(I,J)='EXP'
                ENDIF
10            CONTINUE
20        CONTINUE
C
      WRITE (12,30)
30    FORMAT (1X,'*** INITIAL DATA ***'//)
C
      WRITE (12,40) TI
40    FORMAT (1X,'PDF/CDF REPAIR TIME INCREMENT:  ',F5.2)
      WRITE (12,50) TM
50    FORMAT (1X,'PDF/CDF MAXIMUM REPAIR TIME:    ',F5.2/)
C
      WRITE (12,70) NSUB
70    FORMAT (1X,'TOTAL NUMBER OF SUBSYSTEMS:     ',I5/)
C
```

AD-A167 149 AN ANALYTICAL METHODOLOGY FOR PREDICTING REPAIR TIME DISTRIBUTIONS OF ADV..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. D C DIETZ 3/3

UNCLASSIFIED DEC 85 AFIT/GOR/OS/85D-3 F/G 15/5 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

```
      WRITE (12,80)
80    FORMAT (1X,T31,'REMOVE AND REPLACE',T65,'REPAIR IN PLACE',T99,
     &        'CAN NOT DUPLICATE'/)
      WRITE (12,90)
90    FORMAT (1X,'SUBSYS',2X,'  SUBSYS',2X,'SUBSYS',
     &        3(4X,'  DIST',2X,'  COND',2X,'  MEAN',2X,'  VAR-'))
      WRITE (12,100)
100    FORMAT (1X,'  CODE',2X,'    MSBF',2X,'   REL',
     &        3(4X,'  TYPE',2X,'  PROB',2X,'  TIME',2X,' IANCE')/)
C
      DO 120 I=1,NSUB
          WRITE (12,110) NWUC(I),SMSBF(I),SREL(I),
     &           (CNDIS(I,J),SQM(I,J),SMRT(I,J),SVRT(I,J),J=1,3)
110        FORMAT (1X,I6,1X,F9.3,2X,F6.3,3(7X,A3,3(2X,F6.3)))
120       CONTINUE
C
      WRITE (12,130)
130   FORMAT (//1X,'AVAILABILITY/SORTIE GENERATION PARAMETERS'/)
      WRITE (12,140) NAF
140   FORMAT (1X,'AIRCRAFT FORCE SIZE:              ',I6)
      WRITE (12,150) ST
150   FORMAT (1X,'AIRCRAFT SORTIE TIME:             ',F6.2)
      WRITE (12,160) TT
160   FORMAT (1X,'AIRCRAFT TURN TIME:               ',F6.2)
      WRITE (12,170) SW
170   FORMAT (1X,'SORTIE LAUNCH WINDOW:             ',F6.2)
      WRITE (12,180) STIM
180   FORMAT (1X,'MAXIMUM LAUNCHES PER PERIOD TI:   ',F6.2/)
      WRITE (12,190) TIO
190   FORMAT (1X,'AVAIL/SORT GEN TIME INCREMENT:    ',F6.2)
      WRITE (12,200) TMO
200   FORMAT (1X,'AVAIL/SORT GEN MAXIMUM TIME:      ',F6.2///)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE ERRCHK
C
C     *** SUBROUTINE ERRCHK CHECKS THE INPUT DATA FOR ILLEGAL VALUES
C         AND RELATIONAL INCONSISTENCIES.  IF ILLEGAL VALUES OR
C         INCONSISTENCIES ARE FOUND, AN ERROR MESSAGE IS DISPLAYED AND
C         THE PROGRAM IS TERMINATED.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
      NERR=0
C
      CALL MULTERR(TM,TI,'CDF MAX TIME   ','CDF TIME INCR  ',NERR)
C
      DO 60 I=1,NSUB
          DO 40 J=1,3
              IF ((NDIS(I,J).NE.0).AND.(NDIS(I,J).NE.1)
     &            .AND.(NDIS(I,J).NE.2)) THEN
                  WRITE (12,20) J,NWUC(I)
20                FORMAT (1X,'INPUT ERROR -- NDIS FOR ACTION ',I1,
     &                    ' ON SUBSYSTEM ',I2,' NOT 0, 1, OR 2')
                  NERR=NERR+1
              ENDIF
              IF ((NDIS(I,J).EQ.0).AND.(SQM(I,J).NE.0.0)) THEN
                  WRITE (12,30) J,NWUC(I)
30                FORMAT (1X,'INPUT ERROR -- SQM FOR ACTION ',I1,
     &                    ' ON SUBSYSTEM ',I2,' MUST BE 0.0')
                  NERR=NERR+1
              ENDIF
40          CONTINUE
          IF (ABS(SQM(I,1)+SQM(I,2)+SQM(I,3)-1.0).GT.0.001) THEN
              WRITE (12,50) NWUC(I)
50            FORMAT (1X,'INPUT ERROR -- SUM OF SQM FOR SUBSYSTEM ',
     &                I2,' NOT EQUAL TO 1.0')
              NERR=NERR+1
          ENDIF
60      CONTINUE
C
      CALL MULTERR(ST,TI,'SORTIE TIME    ','CDF TIME INCR  ',NERR)
      CALL MULTERR(TT,TI,'TURN TIME      ','CDF TIME INCR  ',NERR)
      CALL MULTERR(SW,TI,'SORTIE WINDOW  ','CDF TIME INCR  ',NERR)
      CALL MULTERR(TIO,TI,'AVAIL TIME INCR','CDF TIME INCR  ',NERR)
      CALL MULTERR(TMO,TIO,'AVAIL MAX TIME ','AVAIL TIME INCR',NERR)
C
```

```
      IF (NERR.GT.0) THEN
          WRITE (12,70) NERR
70        FORMAT (/1X,I2,' INPUT ERRORS DETECTED: ',
     &             'PROGRAM WILL NOT RUN')
        ENDIF
C
      RETURN
      END
C
C*******************************************************************************
C
      SUBROUTINE MULTERR(XM,XI,CXM,CXI,NERR)
C
C     *** SUBROUTINE MULTERR VERIFIES THAT XI IS AN EVEN MULTIPLE OF XM.
C         IF XI IS NOT A MULTIPLE OF XM, AN ERROR MESSAGE IS PRINTED AND
C         THE ERROR COUNTER IS INCREASED BY ONE.
C
C     *** LOCAL VARIABLE DEFINITIONS
C         CXM, CXI = IDENTIFIERS OF OFFENDING VARIABLES
C
      CHARACTER*15 CXM,CXI
C
      IF (ABS(AMOD(XM+0.0001,XI)).GT.0.001) THEN
          WRITE (12,10) CXM,CXI
10        FORMAT (1X,'INPUT ERROR -- ',A15,' NOT A MULTIPLE OF ',A15)
          NERR=NERR+1
        ENDIF
C
      RETURN
      END
C
```

```
C*******************************************************************************
C
      SUBROUTINE CHNGDAT
C
C     *** SUBROUTINE CHNGDAT INTERACTIVELY MODIFIES THE INPUT DATA.
C         THE MODIFIED DATA CAN BE USED FOR A SINGLE PROGRAM RUN OR TO
C         PERMANENTLY REPLACE THE INPUT DATA FILE.
C
      COMMON/INIT/TI,TM,NSUB,NMUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
C     *** LOCAL VARIABLE DEFINITIONS
C         MSEL = MENU SELECTION NUMBER
C
20    WRITE (*,30)
30    FORMAT ('1'/'1','***  DATA CHANGE MENU  ***'//
     &          ' 1.  CHANGE DISTRIBUTION TIME INCREMENT'/
     &          ' 2.  CHANGE DISTRIBUTION MAXIMUM TIME'/
     &          ' 3.  CHANGE SUBSYSTEM DATA'/
     &          ' 4.  CHANGE CONCEPT OF OPERATIONS'/
     &          ' 5.  RECORD CHANGES TO PERMANENT FILE'/
     &          ' 6.  EXIT TO MAIN MENU'//
     &          ' ENTER SELECTION NUMBER:')
C
      READ (*,*) MSEL
C
      IF (MSEL.EQ.1) THEN
        WRITE (*,40) TI
40      FORMAT ('1'/'1','CURRENT TIME INCREMENT:  ',F5.2//
     &          ' ENTER NEW TIME INCREMENT:')
        READ (*,*) TI
      ELSEIF (MSEL.EQ.2) THEN
        WRITE (*,50) TM
50      FORMAT ('1'/'1','CURRENT MAXIMUM TIME:  ',F5.2//
     &          ' ENTER NEW MAXIMUM TIME:')
        READ (*,*) TM
      ELSEIF (MSEL.EQ.3) THEN
        CALL SUBCHNG
      ELSEIF (MSEL.EQ.4) THEN
        CALL CONCHNG
      ELSEIF (MSEL.EQ.5) THEN
        CALL RECORD
      ELSEIF (MSEL.EQ.6) THEN
        GOTO 60
      ENDIF
C
      GOTO 20
C
60    RETURN
      END
```

```
C
C*******************************************************************************
C
      SUBROUTINE SUBCHNG
C
C     *** SUBROUTINE SUBCHG INTERACTIVELY CHANGES SUBSYTEM DATA.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
C     *** LOCAL VARIABLE DEFINITIONS
C         NWUCC      = WORK UNIT CODE OF SUBSYTEM TO BE CHANGED
C         MSEL       = MENU SELECTION NUMBER
C         NCHG       = INDICATOR FOR ADDITIONAL CHANGES (1=YES, 0=NO)
C         CNDIS(I,J) = ALPHANUMERIC IDENTIFIER FOR DISTRIBUTIONAL FORM
C                      OF MAINTENANCE ACTION J ON SUBSYSTEM I
C                      'N/A' = NOT APPLICABLE
C                      'LGN' = LOGNORMAL
C                      'EXP' = EXPONENTIAL
C
      CHARACTER*3 CNDIS(30,3)
C
20    WRITE (*,30)
30    FORMAT ('1'/'1','ENTER WORK UNIT CODE OF SUBSYSTEM TO CHANGE:')
      READ (*,*) NWUCC
C
      DO 150 I=1,NSUB
C
40        IF (NWUC(I).EQ.NWUCC) THEN
              DO 50 J=1,3
                  IF (NDIS(I,J).EQ.0) THEN
                      CNDIS(I,J)='N/A'
                    ELSEIF (NDIS(I,J).EQ.1) THEN
                      CNDIS(I,J)='LGN'
                    ELSEIF (NDIS(I,J).EQ.2) THEN
                      CNDIS(I,J)='EXP'
                    ENDIF
50                CONTINUE
```

```
            WRITE (*,60) NWUC(I),SMSBF(I),
     &           (CNDIS(I,J),SQM(I,J),SMRT(I,J),SVRT(I,J),J=1,3)
60          FORMAT ('1'/'1','CURRENT DATA FOR SUBSYSTEM ',I2//
     &           ' 1.  MEAN SORTIES BETWEEN FAILURES: ',F9.3//
     &           ' MAINTENANCE ACTION 1:  REMOVE AND REPLACE'/
     &           ' 2.  FORM OF REPAIR TIME DISTRIBUTION:     ',A3/
     &           ' 3.  CONDITIONAL PROBABILITY:           ',F6.3/
     &           ' 4.  MEAN REPAIR TIME:                  ',F6.3/
     &           ' 5.  REPAIR TIME VARIANCE:              ',F6.3//
     &           ' MAINTENANCE ACTION 2:  REPAIR IN PLACE'/
     &           ' 6.  FORM OF REPAIR TIME DISTRIBUTION:     ',A3/
     &           ' 7.  CONDITIONAL PROBABILITY:           ',F6.3/
     &           ' 8.  MEAN REPAIR TIME:                  ',F6.3/
     &           ' 9.  REPAIR TIME VARIANCE:              ',F6.3//
     &           ' MAINTENANCE ACTION 3:  CAN NOT DUPLICATE'/
     &           ' 10. FORM OF REPAIR TIME DISTRIBUTION:     ',A3/
     &           ' 11. CONDITIONAL PROBABILITY:           ',F6.3/
     &           ' 12. MEAN REPAIR TIME:                  ',F6.3/
     &           ' 13. REPAIR TIME VARIANCE:              ',F6.3//
     &           ' ENTER NUMBER OF ITEM TO CHANGE:')
C
            READ (*,*) MSEL
C
            IF (MSEL.EQ.1) THEN
                WRITE (*,70)
70              FORMAT (/' ENTER NEW MSBF:')
                READ (*,*) SMSBF(I)
              ENDIF
C
            DO 130 J=1,3
                IF (MSEL.EQ.4*(J-1)+2) THEN
                    WRITE (*,80)
80                  FORMAT (/' ENTER NEW FORM OF DISTRIBUTION ',
     &                   ' (0=NONE, 1=LOGNORMAL, 2=EXPONENTIAL):')
                    READ (*,*) NDIS(I,J)
                    IF (NDIS(I,J).EQ.0) THEN
                        SQM(I,J)=0.0
                        SMRT(I,J)=0.0
                        SVRT(I,J)=0.0
                      ELSEIF (NDIS(I,J).EQ.2) THEN
                        SVRT(I,J)=1.0/(SMRT(I,J)*SMRT(I,J))
                      ENDIF
                  ELSEIF (MSEL.EQ.4*(J-1)+3) THEN
                    WRITE (*,90)
90                  FORMAT (/' ENTER NEW CONDITIONAL PROBABILITY:')
                    READ (*,*) SQM(I,J)
                  ELSEIF (MSEL.EQ.4*(J-1)+4) THEN
                    WRITE (*,100)
                    FORMAT (/' ENTER NEW MEAN REPAIR TIME:')
                    READ (*,*) SMRT(I,J)
```

```
                    ELSEIF (MSEL.EQ.4*(J-1)+5) THEN
                      IF (NDIS(I,J).EQ.2) THEN
                          WRITE (*,110)
110                       FORMAT (' EXPONENTIAL DISTRIBUTION:  ',
     &                            'VARIANCE DETERMINED BY MEAN')
                        ELSE
                          WRITE (*,120)
120                       FORMAT (/' ENTER NEW REPAIR TIME VARIANCE:')
                          READ (*,*) SVRT(I,J)
                        ENDIF
                      ENDIF
130                 CONTINUE
C
                  WRITE (*,140) NWUC(I)
140               FORMAT (/' DO YOU WISH TO CHANGE ANOTHER ITEM FOR ',
     &                    'SUBSYSTEM ',I2,'?  (1=YES, 0=NO)')
                  READ (*,*) NCHG
                  IF (NCHG.EQ.1) THEN
                      GOTO 40
                    ELSE
                      GOTO 160
                    ENDIF
C
                ENDIF
C
150       CONTINUE
C
160   RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE CONCHNG
C
C     *** SUBROUTINE CONCHNG INTERACTIVELY CHANGES CONCEPT OF OPERATIONS
C         DATA.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO,NERR
C
C     *** LOCAL VARIABLE DEFINITIONS
C         MSEL = MENU SELECTION NUMBER
C         NCHG = INDICATOR FOR ADDITIONAL CHANGES (1=YES, 0=NO)
C
20    WRITE (*,30) NAF,ST,TT,SW,STIM,TIO,TMO
30    FORMAT ('1'/'1','CURRENT CONCEPT OF OPERATIONS DATA'//
     &            ' 1.  AIRCRAFT FORCE SIZE:                    ',I6/
     &            ' 2.  AIRCRAFT SORTIE TIME:                   ',F6.2/
     &            ' 3.  AIRCRAFT TURN TIME:                     ',F6.2/
     &            ' 4.  SORTIE LAUNCH WINDOW:                   ',F6.2/
     &            ' 5.  MAXIMUM LAUNCHES PER TIME INTERVAL:     ',F6.2/
     &            ' 6.  AVAIL/SORTIE GEN TIME INCREMENT:        ',F6.2/
     &            ' 7.  AVAIL/SORTIE GEN MAXIMUM TIME:          ',F6.2//
     &            ' ENTER NUMBER OF ITEM TO CHANGE:')
C
      READ (*,*) MSEL
C
      IF (MSEL.EQ.1) THEN
          WRITE (*,40)
40        FORMAT (/' ENTER NEW AIRCRAFT FORCE SIZE:')
          READ (*,*) NAF
        ELSEIF (MSEL.EQ.2) THEN
          WRITE (*,50)
50        FORMAT (/' ENTER NEW AIRCRAFT SORTIE TIME:')
          READ (*,*) ST
        ELSEIF (MSEL.EQ.3) THEN
          WRITE (*,60)
60        FORMAT (/' ENTER NEW AIRCRAFT TURN TIME:')
          READ (*,*) TT
        ELSEIF (MSEL.EQ.4) THEN
          WRITE (*,70)
70        FORMAT (/' ENTER NEW SORTIE LAUNCH WINDOW:')
          READ (*,*) SW
        ELSEIF (MSEL.EQ.5) THEN
          WRITE (*,80)
80        FORMAT (/' ENTER NEW MAX NUMBER OF LAUNCHES PER INTERVAL:')
          READ (*,*) STIM
```

```
        ELSEIF (MSEL.EQ.6) THEN
          WRITE (*,90)
90        FORMAT (/' ENTER NEW AVAIL/SORTIE GEN TIME INCREMENT:')
          READ (*,*) TIO
        ELSEIF (MSEL.EQ.7) THEN
          WRITE (*,100)
100       FORMAT (/' ENTER NEW AVAIL/SORTIE GEN MAXIMUM TIME:')
          READ (*,*) TMO
        ENDIF
C
      WRITE (*,110)
110   FORMAT (/' DO YOU WISH TO CHANGE ANOTHER DATA ITEM?  ',
     &       '(1=YES, 0=NO)')
      READ (*,*) NCHG
      IF (NCHG.EQ.1) GOTO 20
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE RECORD
C
C     *** SUBROUTINE RECORD PERMANENTLY WRITES THE CHANGED DATA TO THE
C         INPUT DATA FILE
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SS6(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO,NERR
C
      REWIND (11)
C
      WRITE (11,10) TI,TM,NSUB
10    FORMAT (1X,2(F4.2,2X)//1X,I2/)
C
      DO 30 I=1,NSUB
         WRITE (11,20) NWUC(I),SMSBF(I),
     &                 (NDIS(I,J),SQM(I,J),SMRT(I,J),SVRT(I,J),J=1,3)
20       FORMAT (1X,I2,2X,F9.3,3(2X,I1,3(1X,F5.3)))
30     CONTINUE
C
      WRITE (11,40) NAF,ST,TT,SW,STIM,TIO,TMO
40    FORMAT (/1X,I2,2X,2(F4.2,2X),F5.2,2X,2(F4.2,2X),F5.2/)
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE CALCULATE
C
C     *** SUBROUTINE CALCALUTE COMPUTES AN ANALYTICAL MEAN AND
C         VARIANCE FOR THE REPAIR TIME DISTRIBUTION.  IT ALSO COMPUTES
C         THE VALUE OF THE PROBABILITY DENSITY FUNCTION AND CUMULATIVE
C         DISTRIBUTION FUNCTIONS (SINGLE FAILURE AND ADJUSTED FOR
C         MULTIPLE FAILURE) AT EACH TIME INCREMENT TI UP TO A
C         MAXIMUM REPAIR TIME TM.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO,NERR
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
     &            ,CUMAA(100),PDM
C
C     *** LOCAL VARIABLE DEFINITIONS
C         APF = PROBABILITY OF AIRCRAFT FAILURE ASSUMING ONLY ONE
C               SUBSYSTEM FAILS
C
      DATA A0/0.0014102102/,A1/.10861372/
C
      ARA=1.0
      APF=0.0
      AMRTA=0.0
      AVRTA=0.0
C
      DO 10 I=1,NSUB
          ARA=ARA*SREL(I)
          APF=APF+(1.0-SREL(I))
10      CONTINUE
C
      AMSBF=-1.0/ALOG(ARA)
      PDM=A0+A1/AMSBF
C
      DO 30 I=1,NSUB
          DO 20 J=1,3
              SPM(I,J)=((1.0-SREL(I))/APF)*SQM(I,J)
              AMRTA=AMRTA+SPM(I,J)*SMRT(I,J)
              IF (NDIS(I,J).EQ.1) THEN
                  AVRTA=AVRTA
     &                  +SPM(I,J)*EXP(2*SMU(I,J)+2*SSGSQ(I,J))
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  AVRTA=AVRTA+SPM(I,J)*2*SMRT(I,J)*SMRT(I,J)
                ENDIF
20          CONTINUE
30      CONTINUE
C
```

```
      AVRTA=AVRTA-AMRTA*AMRTA
C
      DO 40 IT=NINT(1000.0*TI),NINT(1000.0*TM),NINT(1000.0*TI)
          T=FLOAT(IT)/1000.0
          K=NINT(T/TI)
          DEN(K)=DENSITY(T)
          CUMA(K)=CUMUL(T)
          CUMAA(K)=ACUMUL(K)
40      CONTINUE
C
      CALL CALCOUT
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION DENSITY(T)
C
C     *** FUNCTION DENSITY RETURNS THE VALUE OF THE AIRCRAFT REPAIR TIME
C         PROBABILITY DENSITY FUNCTION ASSOCIATED WITH REPAIR TIME T.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO,NERR
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
     &            ,CUMAA(100),PDM
C
C     *** LOCAL VARIABLE DEFINITIONS
C         TDENSITY = TEMPORARY VARIABLE FOR STORING ITERATIVE WEIGHTED
C                    SUM OF SUBSYSTEM DENSITIES
C
      TDENSITY=0.0
C
      DO 20 I=1,NSUB
          DO 10 J=1,3
              IF (NDIS(I,J).EQ.1) THEN
                  TDENSITY=TDENSITY+SPM(I,J)*
     &                     EXP(-((ALOG(T)-SMU(I,J))**2)/(2*SSGSQ(I,J)))
     &                     /(T*2.5066283*SSG(I,J))
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  TDENSITY=TDENSITY+SPM(I,J)*
     &                     EXP(-T/SMRT(I,J))/SMRT(I,J)
                ENDIF
10            CONTINUE
20        CONTINUE
C
      DENSITY=TDENSITY
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION CUMUL(T)
C
C     *** FUNCTION CUMUL RETURNS THE VALUE OF THE AIRCRAFT REPAIR TIME
C         CUMULATIVE DISTRIBUTION FUNCTION ASSOCIATED WITH REPAIR TIME
C         T.
C
      COMMON/INIT/TI,TM,NSUB,NMUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO,NERR
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
     &            ,CUMAA(100),PDM
C
C     *** LOCAL VARIABLE DEFINITIONS
C         TCUMUL = TEMPORARY VARIABLE FOR STORING ITERATIVE WEIGHTED
C                  SUM OF SUBSYSTEM CDF VALUES
C
      TCUMUL=0.0
C
      DO 20 I=1,NSUB
          DO 10 J=1,3
              IF (NDIS(I,J).EQ.1) THEN
                  TCUMUL=TCUMUL+SPM(I,J)*PLGN(I,J,T)
                ELSEIF (NDIS(I,J).EQ.2) THEN
                  TCUMUL=TCUMUL+SPM(I,J)*(1.0-EXP(-T/SMRT(I,J)))
                ENDIF
10            CONTINUE
20        CONTINUE
C
      CUMUL=TCUMUL
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION PLGN(I,J,T)
C
C     *** FUNCTION PLGN RETURNS THE CUMULATIVE PROBABILITY ASSOCIATED
C         WITH REPAIR TIME T FOR A LOGNORMAL SUBSYTEM REPAIR TIME
C         DISTRIBUTION FOR MAINTENANCE ACTION J ON SUBSYTEM I.
C
      COMMON/INIT/TI,TM,NSUB,NMUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
      DATA A0/0.797884560593/,A1/-0.531923007300/
      DATA A2/0.319152932694/,A3/-0.151968751364/
      DATA A4/0.059054035642/,A5/-0.019198292004/
      DATA A6/0.005198775019/,A7/-0.001075204047/
      DATA A8/0.000124818987/
      DATA B0/0.999936657524/,B1/0.000535310849/
      DATA B2/-0.002141268741/,B3/0.005353579108/
      DATA B4/-0.009279453341/,B5/0.011630447319/
      DATA B6/-0.010557625006/,B7/0.006549791214/
      DATA B8/-0.002034254874/,B9/-0.000794620820/
      DATA B10/0.001390604284/,B11/-0.0006760904986/
      DATA B12/-0.000019538132/,B13/0.000152529290/
      DATA B14/-0.000045255659/
C
      X=(ALOG(T)-SMU(I,J))/SSG(I,J)
      V=ABS(X)/2.0
C
      IF (V.GE.3.0) THEN
          Z=1.0
        ELSEIF (V.LT.1.0) THEN
          W=V*V
          Z=(((((((A8*W+A7)*W+A6)*W+A5)*W+A4)*W+A3)*W+A2)*W+A1)*W+A0)
     &      *V*2
        ELSEIF (V.GE.1.0) THEN
          V=V-2.0
          Z=((((((((((((B14*V+B13)*V+B12)*V+B11)*V+B10)*V+B9)*V+B8)
     &      *V+B7)*V+B6)*V+B5)*V+B4)*V+B3)*V+B2)*V+B1)*V+B0
        ENDIF
C
      IF (X.GT.0.0) THEN
          PLGN=(Z+1.0)/2.0
        ELSE
          PLGN=(1.0-Z)/2.0
        ENDIF
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      FUNCTION ACUMUL(K)
C
C     *** FUNCTION ACUMUL RETURNS THE ADJUSTED CUMULATIVE DISTRIBUTION
C         FUNCTION FOR REPAIR TIME INCREMENT K.
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
     &           ,CUMAA(100),PDM
C
C     *** LOCAL VARIABLE DEFINITIONS
C         PD = ESTIMATED DIFFERENCE BETWEEN SINGLE AND MULTIPLE FAILURE
C              CDFS
C
      DATA A0/-0.0013398701/,A1/3.32372128/,A2/-1.8398932/
      DATA A3/-1.3974138/
C
      PD=PDM*((A3*CUMA(K)+A2)*CUMA(K)+A1)*CUMA(K)+A0
C
      IF (PD.GT.0.0) THEN
          ACUMUL=CUMA(K)-PD
        ELSE
          ACUMUL=CUMA(K)
        ENDIF
C
      RETURN
      END
C
```

```
C*************************************************************************
C
      SUBROUTINE CALCOUT
C
C     *** SUBROUTINE CALCOUT WRITES THE RESULTS OF THE ANALYTICAL
C         COMPUTATIONS TO THE OUTPUT DEVICE IN A LABELED FORMAT.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SS6SQ(30,3),SS6(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
      COMMON/CALC/ARA,AMSBF,SPM(30,3),AMRTA,AVRTA,DEN(100),CUMA(100)
     &           ,CUMAA(100),PDM
C
C     *** LOCAL VARIABLE DEFINITIONS
C         LINE = CHARACTER ARRAY FOR GRAPHICAL PLOT OF REPAIR TIME
C                DISTRIBUTION
C
      CHARACTER*1 LINE(100)
C
      WRITE (12,10)
10    FORMAT ('1','*** ANALTYICAL RESULTS ***'//)
C
      WRITE (12,20) ARA
20    FORMAT (1X,'AIRCRAFT RELIABILITY:                    ',F7.4)
      WRITE (12,30) AMSBF
30    FORMAT (1X,'AIRCRAFT MEAN SORTIES BETWEEN FAILURES:  ',F7.4/)
      WRITE (12,40) AMRTA
40    FORMAT (1X,'SINGLE FAILURE MEAN REPAIR TIME:         ',F7.4)
      WRITE (12,50) AVRTA
50    FORMAT (1X,'SINGLE FAILURE VARIANCE OF REPAIR TIME:  ',F7.4//)
C
     WRITE (12,60)
60     FORMAT (1X,'PDF(T)',2X,'CDF(T)',2X,'AD CDF',2X,'  TIME')
     WRITE (12,70)
70     FORMAT (1X,T32,20('+',4X),'+')
C
```

```
      DO 100 IT=NINT(1000.0*TI),NINT(1000.0*TM),NINT(1000.0*TI)
          T=FLOAT(IT)/1000.0
          K=NINT(T/TI)
          DO 80 L=1,100
              LINE(L)=' '
              IF (L.EQ.NINT(100.0*DEN(K))) THEN
                  LINE(L)='P'
                ELSEIF (L.EQ.NINT(100.0*CUMA(K))) THEN
                  LINE(L)='C'
                ELSEIF (L.EQ.NINT(100.0*CUMAA(K))) THEN
                  LINE(L)='A'
                ELSEIF (L.EQ.100) THEN
                  LINE(L)='+'
                ENDIF
80            CONTINUE
            WRITE (12,90) DEN(K),CUMA(K),CUMAA(K),T,LINE
90          FORMAT (1X,3(F6.4,2X),F5.2,T32,'+',100A1)
100       CONTINUE
C
        WRITE (12,70)
        WRITE (12,110)
110     FORMAT (1X,T31,'0.0',7X,'0.1',7X,'0.2',7X,'0.3',7X,'0.4',7X,
     &          '0.5',7X,'0.6',7X,'0.7',7X,'0.8',7X,'0.9',7X,'1.0'//)
C
        RETURN
        END
C
```

```
C*************************************************************************
C
      SUBROUTINE TRANSLATE(ARA,CUM)
C
C     *** SUBROUTINE TRANSLATE DETERMINES THE AIRCRAFT AVAILABILITY AND
C         SORTIE GENERATION RATE ASSOCIATED WITH THE ANALYTICAL REPAIR
C         TIME CDF.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &           ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &           ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &           ,STIM,TIO,TMO,NERR
C
      COMMON/TRAN/TK(500),QSK(500),QTK(500),QRK(500),RAK(500),AVLK(500)
     &           ,SRATEK(500),AVLA,AVLM,TSOR,SRATE,TREP,RRATE
C
C     *** LOCAL VARIABLE DEFINITIONS
C         SSTE(I) = QUANTITY OF AIRCRAFT COMPLETING A SORTIE IN I TIME
C                   INCREMENTS
C         TSTE(I) = QUANTITY OF AIRCRAFT COMPLETING TURN OPERATIONS IN I
C                   TIME INCREMENTS
C         RSTE(I) = QUANTITY OF AIRCRAFT COMPLETING REPAIRS IN I TIME
C                   INCREMENTS
C         RTIP(I) = PROBABILITY OF AIRCRAFT REPAIR IN TIME INCREMENT I
C         NS      = NUMBER OF TIME INCREMENTS IN A SORTIE
C         NT      = NUMBER OF TIME INCREMENTS IN A TURN OPERATION
C         NR      = NUMBER OF POSSIBLE TIME INCREMENTS IN A REPAIR
C                   OPERATION
C         RA      = QUANTITY OF READY AIRCRAFT
C         SOUT    = QUANTITY OF AIRCRAFT COMPLETING SORTIES
C         TOUT    = QUANTITY OF AIRCRAFT COMPLETING TURN OPERATIONS
C         ROUT    = QUANTITY OF AIRCRAFT COMPLETING REPAIRS
C         SIN     = QUANTITY OF AIRCRAFT BEGINNING SORTIES
C         TIN     = QUANTITY OF AIRCRAFT BEGINNING TURN OPERATIONS
C         RIN     = QUANTITY OF AIRCRAFT BEGINNING REPAIRS
C         WT      = TIME OF DAY (FOR COMPARISON WITH SORTIE WINDOW)
C         QS      = QUANTITY OF AIRCRAFT FLYING SORTIES
C         QT      = QUANTITY OF AIRCRAFT BEING TURNED
C         QR      = QUANTITY OF AIRCRAFT BEING REPAIRED
C
      DIMENSION SSTE(500),TSTE(500),RSTE(500),RTIP(500),CUM(100)
C
      NS=ST/TI
      NT=TT/TI
      NR=TM/TI
C
      DO 10 I=1,NS
         SSTE(I)=0.0
10      CONTINUE
      DO 20 I=1,NT
         TSTE(I)=0.0
20      CONTINUE
```

```
      DO 30 I=1,NR
          RSTE(I)=0.0
30      CONTINUE
C
      RTIP(1)=CUM(1)
      DO 40 I=2,NR-1
          RTIP(I)=CUM(I)-CUM(I-1)
40      CONTINUE
      RTIP(NR)=1.0-CUM(NR-1)
C
      AVLA=0.0
      AVLM=1.0
      TSOR=0.0
      TREP=0.0
      RA=NAF
      KI=NINT(TIO/TI)
      K=0
      NTI=0
C
      DO 60 IT=NINT(1000.0*TI),NINT(1000.0*TMO),NINT(1000.0*TI)
C
          T=FLOAT(IT)/1000.0
C
          CALL OUT(NS,SSTE,SOUT)
          CALL OUT(NT,TSTE,TOUT)
          CALL OUT(NR,RSTE,ROUT)
C
          RIN=(1.0-ARA)*SOUT
          TIN=ARA*SOUT+ROUT
          RA=RA+TOUT
          WT=T-IFIX(T/24.0)*24.0-0.001
          IF ((WT.GT.0.0).AND.(WT.LE.SW)) THEN
              IF (RA.LT.STIM) THEN
                  SIN=RA
                  RA=0.0
                ELSE
                  SIN=STIM
                  RA=RA-STIM
                ENDIF
            ELSE
              SIN=0.0
            ENDIF
C
          SSTE(NS)=SIN
          TSTE(NT)=TIN
          DO 50 I=1,NR
              RSTE(I)=RSTE(I)+RIN*RTIP(I)
50          CONTINUE
C
          CALL SUM(NS,SSTE,QS)
          CALL SUM(NT,TSTE,QT)
          CALL SUM(NR,RSTE,QR)
```

```
C
            AVL=(QS+RA)/NAF
            AVLA=AVLA+AVL
            AVLM=AMIN1(AVLM,AVL)
            TSOR=TSOR+SIN
            TREP=TREP+RIN
C
            NTI=NTI+1
            IF (NTI.EQ.KI) THEN
                NTI=0
                K=K+1
                TK(K)=T
                QSK(K)=QS
                QTK(K)=QT
                QRK(K)=QR
                RAK(K)=RA
                AVLK(K)=AVL
                SRATEK(K)=24.0*TSOR/(T*NAF)
              ENDIF
C
60      CONTINUE
C
        AVLA=AVLA*TI/TMO
        SRATE=24.0*TSOR/(TMO*NAF)
        RRATE=24.0*TREP/(TMO*NAF)
C
        CALL TRANOUT
C
        RETURN
        END
C
```

```
C*************************************************************************
C
      SUBROUTINE OUT(NX,XSTE,XOUT)
C
C     *** SUBOUTINE OUT RETURNS THE VALUE IN THE FIRST INCREMENT OF THE
C         ARRAY XOUT AND ADVANCES ALL OTHER INCREMENTS BY ONE POSITION.
C
C     *** LOCAL VARIABLE DEFINITIONS
C         XSTE(I) = QUANTITY OF AIRCRAFT COMPLETING ACTIVITY X IN I
C                   TIME INCREMENTS
C         NX      = NUMBER OF TIME INCREMENTS IN XSTE
C         XOUT    = QUANTITY OF AIRCRAFT COMPLETING ACTIVITY X AFTER ONE
C                   TIME INCREMENT
C
      DIMENSION XSTE(NX)
C
      XOUT=XSTE(1)
C
      DO 10 I=1,NX-1
          XSTE(I)=XSTE(I+1)
10      CONTINUE
      XSTE(NX)=0.0
C
      RETURN
      END
C
C*************************************************************************
C
      SUBROUTINE SUM(NX,XSTE,QX)
C
C     *** SUBROUTINE SUM DETERMINES THE TOTAL QUANTITY OF AIRCRAFT
C         ENGAGED IN ACTIVITY X.
C
C     *** LOCAL VARIABLE DEFINITIONS
C         XSTE(I) = QUANTITY OF AIRCRAFT COMPLETING ACTIVITY X IN I TIME
C                   INCREMENTS
C         NX      = NUMBER OF TIME INCREMENTS IN XSTE
C         QX      = TOTAL QUANTITY OF AIRCRAFT ENGAGED IN ACTIVITY X
C
      DIMENSION XSTE(NX)
C
      QX=0.0
      DO 10 I=1,NX
          QX=QX+XSTE(I)
10      CONTINUE
C
    RETURN
    END
C
```

```
C*************************************************************************
C
      SUBROUTINE TRANOUT
C
C     *** SUBROUTINE TRANOUT WRITES THE AVAILABLITY AND SORTIE
C         GENERATION RESULTS TO THE OUTPUT DEVICE IN A LABELED FORMAT.
C
      COMMON/INIT/TI,TM,NSUB,NWUC(30),SMSBF(30),SREL(30)
     &            ,NDIS(30,3),SQM(30,3),SMRT(30,3),SVRT(30,3)
     &            ,SMU(30,3),SSGSQ(30,3),SSG(30,3),NAF,ST,TT,SW
     &            ,STIM,TIO,TMO,NERR
C
      COMMON/TRAN/TK(500),QSK(500),QTK(500),QRK(500),RAK(500),AVLK(500)
     &            ,SRATEK(500),AVLA,AVLM,TSOR,SRATE,TREP,RRATE
C
      WRITE (12,5)
5     FORMAT ('1','**** AVAILABILITY AND ',
     &        'SORTIE GENERATION RESULTS ****'//)
      WRITE (12,10)
10    FORMAT (1X,2X,'  TIME',2X,'!---  AIRCRAFT QUANTITIES ---!',2X,
     &        ' AVAIL',2X,'SOR GEN')
      WRITE (12,20)
20    FORMAT (1X,10X,'SORTIE',2X,'  TURN',2X,'REPAIR',2X,' READY',10X,
     &        '  RATE'/)
      DO 40 K=1,NINT(TMO/TIO)
         WRITE (12,30) TK(K),QSK(K),QTK(K),QRK(K),RAK(K),AVLK(K),
     &                 SRATEK(K)
30       FORMAT (1X,7F8.3)
40     CONTINUE
C
      WRITE (12,50) AVLA
50    FORMAT (//1X,'AVERAGE AVAILABILITY:      ',F9.4)
      WRITE (12,60) AVLM
60    FORMAT (1X,'MINIMUM AVAILABILITY:      ',F9.4/)
C
      WRITE (12,70) TSOR
70    FORMAT (1X,'TOTAL SORTIES LAUNCHED:    ',F9.4)
      WRITE (12,80) SRATE
80    FORMAT (1X,'SORTIE GENERATION RATE:    ',F9.4/)
C
      WRITE (12,90) TREP
90    FORMAT (1X,'TOTAL MAINTENANCE EVENTS:  ',F9.4)
      WRITE (12,100) RRATE
100   FORMAT (1X,'MAINTENANCE RATE:          ',F9.4)
      WRITE (12,*)
C
      RETURN
      END
C
C*************************************************************************
```

Appendix E

Sample Output for Repair Time Distribution Model (Version 2.0)

INITIAL DATA

PDF/CDF REPAIR TIME INCREMENT: 0.20
PDF/CDF MAXIMUM REPAIR TIME: 8.00

TOTAL NUMBER OF SUBSYSTEMS: 24

			REMOVE AND REPLACE				REPAIR IN PLACE				CAN NOT DUPLICATE			
SUBSYS CODE	SUBSYS MSBF	SUBSYS REL	DIST TYPE	COND PROB	MEAN TIME	VAR-IANCE	DIST TYPE	COND PROB	MEAN TIME	VAR-IANCE	DIST TYPE	COND PROB	MEAN TIME	VAR-IANCE
11	133.000	0.993	LGN	0.030	1.270	0.370	LGN	0.966	2.220	0.640	LGN	0.004	3.130	0.910
12	241.000	0.996	LGN	0.278	2.720	0.790	LGN	0.662	1.700	0.490	LGN	0.060	0.700	0.200
13	149.000	0.993	LGN	0.544	2.080	0.600	LGN	0.386	2.050	0.590	LGN	0.070	2.180	0.630
14	141.000	0.993	LGN	0.456	2.330	0.680	LGN	0.299	2.430	0.700	LGN	0.245	1.530	0.440
23	165.000	0.994	LGN	0.428	3.120	0.900	LGN	0.494	1.480	0.430	LGN	0.078	2.110	0.610
24	207.000	0.995	LGN	0.490	2.830	0.820	LGN	0.436	2.260	0.660	LGN	0.074	2.220	0.640
41	417.000	0.998	LGN	0.**2	3.310	0.960	LGN	0.199	1.720	0.500	LGN	0.359	2.350	0.680
42	265.000	0.996	LGN	0.803	1.320	0.380	LGN	0.173	2.970	0.860	LGN	0.024	2.900	0.840
44	700.000	0.999	LGN	0.618	1.200	0.350	LGN	0.333	1.520	0.440	LGN	0.049	2.570	0.750
45	450.000	0.998	LGN	0.327	3.110	0.900	LGN	0.587	2.200	0.640	LGN	0.086	1.450	0.420
46	168.000	0.994	LGN	0.428	3.080	0.890	LGN	0.421	2.780	0.810	LGN	0.151	1.780	0.520
47	1000.000	0.999	LGN	0.523	1.800	0.520	LGN	0.315	1.710	0.500	LGN	0.162	1.480	0.430
49	3300.000	1.000	LGN	0.857	3.230	0.940	N/A	0.000	0.000	0.000	LGN	0.143	1.000	0.290
51	480.000	0.998	LGN	0.583	1.510	0.440	LGN	0.183	1.040	0.300	LGN	0.234	1.020	0.300
55	7200.000	1.000	LGN	0.389	1.120	0.320	LGN	0.222	1.130	0.330	LGN	0.389	0.370	0.110
62	2000.000	1.000	LGN	0.298	1.030	0.300	LGN	0.386	1.270	0.370	LGN	0.316	0.950	0.280
63	475.000	0.998	LGN	0.329	1.190	0.350	LGN	0.309	0.950	0.280	LGN	0.362	1.180	0.340
64	975.000	0.999	LGN	0.220	1.700	0.490	LGN	0.381	1.310	0.380	LGN	0.399	0.890	0.260
65	1600.000	0.999	LGN	0.685	1.290	0.370	LGN	0.137	0.920	0.270	LGN	0.178	0.840	0.240
71	622.000	0.998	LGN	0.497	1.260	0.370	LGN	0.222	0.970	0.280	LGN	0.281	1.120	0.320
74	36.500	0.973	LGN	0.359	1.350	0.390	LGN	0.094	1.260	0.370	LGN	0.547	1.040	0.300
75	80.000	0.988	LGN	0.274	1.630	0.470	LGN	0.089	1.680	0.490	LGN	0.637	1.010	0.290
76	295.000	0.997	LGN	0.635	2.280	0.660	LGN	0.184	1.710	0.500	LGN	0.181	1.480	0.430
97	11000.000	1.000	LGN	0.867	2.570	0.750	LGN	0.133	2.100	0.620	N/A	0.000	0.000	0.000

AVAILABILITY/SORTIE GENERATION PARAMETERS

AIRCRAFT FORCE SIZE: 24
AIRCRAFT SORTIE TIME: 2.40
AIRCRAFT TURN TIME: 0.40
SORTIE LAUNCH WINDOW: 16.00
MAXIMUM LAUNCHES PER PERIOD TI: 2.00

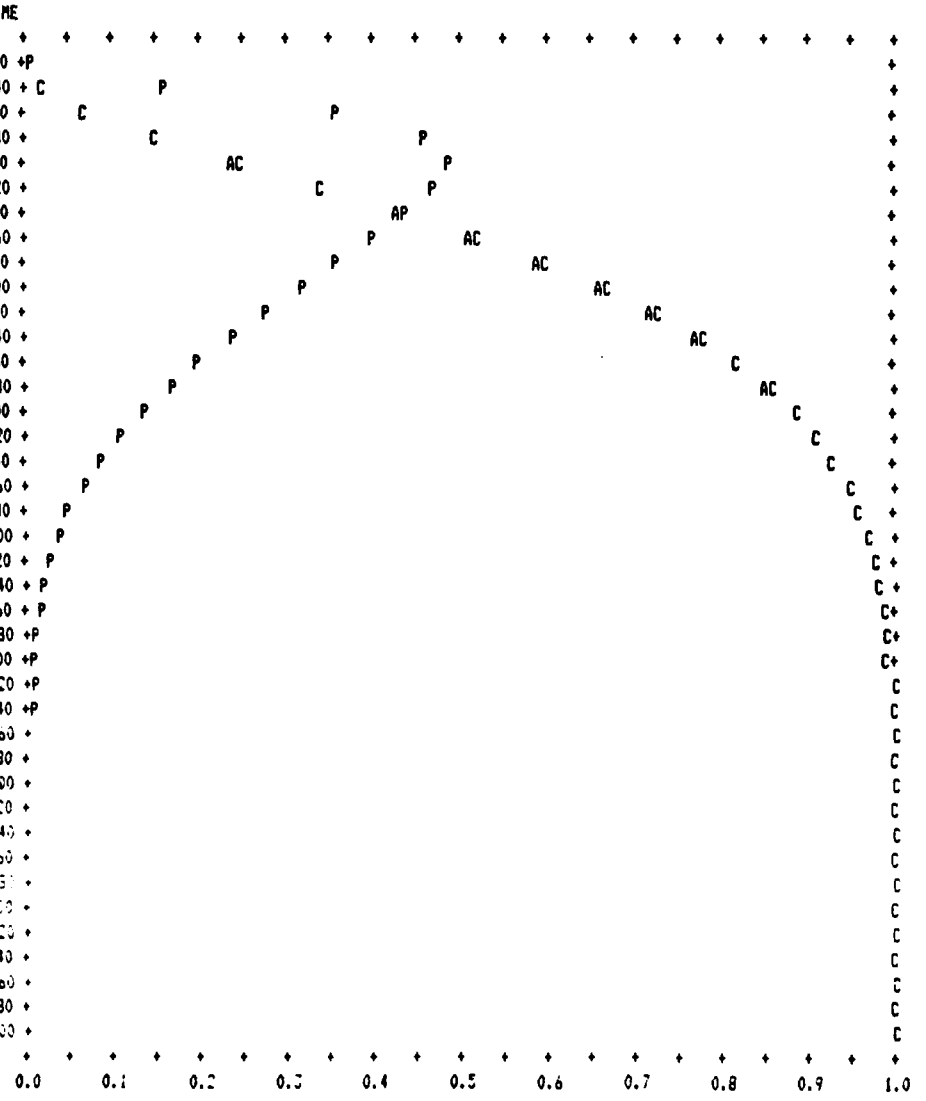
AVAIL/SORT GEN TIME INCREMENT: 2.00
AVAIL/SORT GEN MAXIMUM TIME: 48.00

ANALYTICAL RESULTS

AIRCRAFT RELIABILITY: 0.9004
AIRCRAFT MEAN SORTIES BETWEEN FAILURES: 9.5324

SINGLE FAILURE MEAN REPAIR TIME: 1.7439
SINGLE FAILURE VARIANCE OF REPAIR TIME: 0.9492

PDF(T)	CDF(T)	AD CDF	TIME
0.0139	0.0006	0.0006	0.20
0.1616	0.0155	0.0155	0.40
0.3556	0.0681	0.0667	0.60
0.4633	0.1517	0.1472	0.80
0.4900	0.2480	0.2405	1.00
0.4745	0.3449	0.3351	1.20
0.4424	0.4367	0.4255	1.40
0.4041	0.5215	0.5095	1.60
0.3634	0.5982	0.5864	1.80
0.3218	0.6668	0.6555	2.00
0.2803	0.7270	0.7167	2.20
0.2400	0.7790	0.7699	2.40
0.2021	0.8231	0.8154	2.60
0.1674	0.8600	0.8536	2.80
0.1365	0.8903	0.8851	3.00
0.1097	0.9149	0.9107	3.20
0.0871	0.9345	0.9312	3.40
0.0683	0.9500	0.9475	3.60
0.0530	0.9620	0.9602	3.80
0.0407	0.9714	0.9700	4.00
0.0311	0.9785	0.9775	4.20
0.0235	0.9839	0.9832	4.40
0.0177	0.9880	0.9876	4.60
0.0133	0.9911	0.9908	4.80
0.0099	0.9934	0.9933	5.00
0.0074	0.9951	0.9951	5.20
0.0055	0.9964	0.9964	5.40
0.0040	0.9973	0.9973	5.60
0.0030	0.9980	0.9980	5.80
0.0022	0.9985	0.9985	6.00
0.[illegible]	[illegible]	[illegible]	6.20
[illegible]	[illegible]	[illegible]	6.40
[illegible]	[illegible]	[illegible]	6.60
[illegible]	[illegible]	[illegible]	6.80
[illegible]	[illegible]	[illegible]	7.00
[illegible]	[illegible]	[illegible]	7.20
[illegible]	[illegible]	[illegible]	7.40
0.0012	0.9990	0.9990	7.60
0.0001	0.9999	0.9999	7.80
0.0000	0.9999	0.9999	8.00



AVAILABILITY AND SORTIE GENERATION RESULTS

TIME	AIRCRAFT QUANTITIES				AVAIL	SOR GEN
	SORTIE	TURN	REPAIR	READY		RATE
2.000	20.000	0.000	0.000	4.000	1.000	10.000
4.000	18.899	3.753	1.348	0.000	0.787	8.725
6.000	19.016	3.562	1.422	0.000	0.792	8.373
8.000	22.008	0.627	1.364	0.000	0.917	8.584
10.000	18.699	3.699	1.601	0.000	0.779	8.355
12.000	19.015	3.501	1.484	0.000	0.792	8.245
14.000	19.068	3.525	1.407	0.000	0.795	8.181
16.000	18.705	3.673	1.622	0.000	0.779	8.255
18.000	3.601	3.487	1.526	15.386	0.791	7.338
20.000	0.000	0.210	0.443	23.347	0.973	6.604
22.000	0.000	0.027	0.036	23.936	0.997	6.004
24.000	0.000	0.001	0.002	23.997	1.000	5.504
26.000	20.000	0.000	0.000	4.000	1.000	5.849
28.000	18.899	3.753	1.348	0.000	0.787	5.964
30.000	19.016	3.562	1.422	0.000	0.792	6.077
32.000	22.008	0.628	1.364	0.000	0.917	6.274
34.000	18.699	3.699	1.601	0.000	0.779	6.342
36.000	19.015	3.501	1.484	0.000	0.792	6.417
38.000	19.068	3.525	1.407	0.000	0.795	6.490
40.000	18.705	3.673	1.622	0.000	0.779	6.604
42.000	3.601	3.487	1.526	15.386	0.791	6.290
44.000	0.000	0.210	0.443	23.347	0.973	6.004
46.000	0.000	0.027	0.036	23.936	0.997	5.743
48.000	0.000	0.001	0.002	23.997	1.000	5.504

AVERAGE AVAILABILITY: 0.8656
MINIMUM AVAILABILITY: 0.7697

TOTAL SORTIES LAUNCHED: 264.1691
SORTIE GENERATION RATE: 5.5035

TOTAL MAINTENANCE EVENTS: 26.3086
MAINTENANCE RATE: 0.5481

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Vita

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