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## THESIS

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AN ANALYSIS OF THREE AVCAL INVENTORY MODELS  
USING THE TIGER SIMULATION MODEL

by

Mark David Sullivan

September 1984

Thesis Advisor:

F.R. Richards

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|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|--------------------------------------------------------------------------|-------|------------------|--------|-------|------|--------------------------|------------|--|
| 1. REPORT NUMBER                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 2. GOVT ACCESSION NO.    | 3. RECIPIENT'S CATALOG NUMBER                                            |       |                  |        |       |      |                          |            |  |
| 4. TITLE (and Subtitle)<br><br>An Analysis of Three AVCAL Inventory Models Using the TIGER Simulation Model                                                                                                                                                                                                                                                                                                                                                                                      |                          | 5. TYPE OF REPORT & PERIOD COVERED<br>Master's Thesis;<br>September 1984 |       |                  |        |       |      |                          |            |  |
| 7. AUTHOR(s)<br><br>Mark David Sullivan                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                          | 6. PERFORMING ORG. REPORT NUMBER                                         |       |                  |        |       |      |                          |            |  |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br><br>Naval Postgraduate School<br>Monterey, California 93943                                                                                                                                                                                                                                                                                                                                                                                       |                          | 8. CONTRACT OR GRANT NUMBER(s)                                           |       |                  |        |       |      |                          |            |  |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br><br>Naval Postgraduate School<br>Monterey, California                                                                                                                                                                                                                                                                                                                                                                                                 |                          | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS              |       |                  |        |       |      |                          |            |  |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)                                                                                                                                                                                                                                                                                                                                                                                                                      |                          | 12. REPORT DATE<br>September 1984                                        |       |                  |        |       |      |                          |            |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                          | 13. NUMBER OF PAGES<br>157                                               |       |                  |        |       |      |                          |            |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                          | 15. SECURITY CLASS. (of this report)<br>Unclassified                     |       |                  |        |       |      |                          |            |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                          | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE                               |       |                  |        |       |      |                          |            |  |
| 16. DISTRIBUTION STATEMENT (of this Report)<br><br>Approved for public release; distribution unlimited                                                                                                                                                                                                                                                                                                                                                                                           |                          |                                                                          |       |                  |        |       |      |                          |            |  |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)                                                                                                                                                                                                                                                                                                                                                                                                       |                          |                                                                          |       |                  |        |       |      |                          |            |  |
| 18. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                          |                                                                          |       |                  |        |       |      |                          |            |  |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br><br><table border="0"> <tr> <td>AVCAL</td> <td>inventory models</td> </tr> <tr> <td>RIMAIR</td> <td>TIGER</td> </tr> <tr> <td>ACIM</td> <td>operational availability</td> </tr> <tr> <td>simulation</td> <td></td> </tr> </table>                                                                                                                                                                          |                          |                                                                          | AVCAL | inventory models | RIMAIR | TIGER | ACIM | operational availability | simulation |  |
| AVCAL                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | inventory models         |                                                                          |       |                  |        |       |      |                          |            |  |
| RIMAIR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | TIGER                    |                                                                          |       |                  |        |       |      |                          |            |  |
| ACIM                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | operational availability |                                                                          |       |                  |        |       |      |                          |            |  |
| simulation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                          |                                                                          |       |                  |        |       |      |                          |            |  |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br><p>This thesis investigates the effectiveness of three Aviation Consolidated Allowance List (AVCAL) inventory models in achieving aircraft system operational availability. The three models studied are the Aviation Supply Office (ASO) Model, the Repairables Integrated Model for Aviation (RIM-AIR), and the Availability Centered Inventory Model (ACIM). TIGER, a simulation model developed</p> |                          |                                                                          |       |                  |        |       |      |                          |            |  |

by Naval Seas Systems Command, is amended to accommodate simulation of multiple aircraft sorties with a realistic parts pipeline operation. AVCAL model inventory levels are compared over a ninety day period utilizing availability statistics computed by TIGER.

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An Analysis of Three AVCAL Inventory Models Using the TIGER  
Simulation Model

by

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Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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# ABSTRACT

This thesis investigates the effectiveness of three Aviation Consolidated Allowance List (AVCAL) inventory models in achieving aircraft system operational availability. The three models studied are the Aviation Supply Office (ASO) Model, the Repairables Integrated Model for Aviation (RIM-AIR), and the Availability Centered Inventory Model (ACIM). TIGER, a simulation model developed by Naval Seas Systems Command, is amended to accommodate simulation of multiple aircraft sorties with a realistic parts pipeline operation. AVCAL model inventory levels are compared over a ninety day period utilizing availability statistics computed by TIGER.

*Additional keywords: TIGER simulation model*

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#### ACKNOWLEDGEMENTS

I wish to thank Peter Evanovich and Barbara Measell, from the Center for Naval Analyses, for their patient help in data collection and model research. I also wish to thank my thesis advisor, Professor Russell Richards, for his helpful guidance through the entire evolution of this thesis. A special thanks goes to my wife, Mary, and my children, Christine, Timothy, and Sean. Only with their constant support and understanding was I able to complete this work.

## I. INTRODUCTION

### A. BACKGROUND

Navy ships, Marine Air Groups (MAG) and shore activities receive AViation Coordinated Allowance Lists (AVCAL) to support assigned aircraft for a prescribed period of time (usually ninety days for ship and MAGs). AVCALS for carrier deployed squadrons are especially crucial because operational commitments will often exceed projected flight time estimates and because the repair/resupply pipeline can be extremely lengthy. These lists are produced by Aviation Supply Office (ASO) prior to the assignment of aviation elements to a ship or MAG. AVCAL's consist of Allowance Requirements Registers (ARR's), which contain the projection of the range (which parts?) and depth (how many?) of spare assemblies and parts necessary to support the aircraft and associated support equipment at the Organizational (O) and Intermediate (I) levels.

One of the key measures of effectiveness of a squadron's performance is the aircraft operational availability. Operational availability has many definitions, but here availability refers to the expected percentage of time that a weapon system or individual equipment will be ready to perform satisfactorily in an operating environment.

The Organizational (squadron) level maintenance concept is based on "remove and replace". Weapon Replaceable Assemblies (WRAs) are designed for rapid removal from the aircraft. Parts that can be repaired at the intermediate level are inducted to the Aviation Intermediate Maintenance Department (AIMD) on the carrier. If a spare part is available, a replacement part is issued to the squadron. Parts that cannot be repaired on-ship, are sent off-ship to the depot level repair facility. A replacement part is re-ordered for the part placed in the off-ship supply pipeline.

#### B. PURPOSE

This study will examine three inventory models currently used to determine AVCALs. Model effectiveness will be compared using simulated aircraft systems, representing systems found on Navy E-2C Hawkeye aircraft. These parts are also items that are found on the E-2C Mission-Essential Subsystem Matrices (MESM), OPNAV Instruction 5442.4H [Ref. 1]. After inventory levels are computed, operational availability is estimated by simulation of aircraft flights on the TIGER program.

#### C. AIRCRAFT DATA

This thesis will concentrate only on repairable parts, although consumables are also normally included in AVCAL computation. Parts included in this study are WRAs from

the avionics portion of the E-2C aircraft, coded for removal at the squadron level and repairable at the intermediate level. The majority of the parts are complicated, expensive pieces that cannot be stocked indiscriminately at high levels.

Equipment data was taken from Center for Naval Analyses computer tapes of Navy wide E-2C parts data for the year 1981. Item unit costs, failure rates, and BCM (beyond the capability of maintenance) rates reflect 1981 levels. Only a limited number of parts were considered due to the limitations of the TIGER simulation program.

AVCAL budget levels are based on predicted quarterly aircraft operating hours. However, a recent E-2C squadron operating level exceeded 1500 total hours in a quarter of high tempo operations on deployment, thus exceeding historical operating levels by almost 50%. This is not uncommon and suggests that it is important to have inventory levels designed to achieve maximum availability while meeting imposed budget constraints.

#### D. MAJOR TOPICS

Chapter II discusses the TIGER simulation model used to compare inventory level effectiveness. The TIGER model is examined, along with major changes introduced to the model for this study. TIGER is a flexible program that allows for sensitivity analysis by easy modification of part parameters and system configuration. Aircraft sorties are simulated

over a period of ninety days and the resulting system availability is calculated.

Chapter III outlines one of the major inventory models presently used to compute AVCAL, the ASO Manual Model. Chapter IV continues with an outline of the RIMAIR Model, and Chapter V covers the ACIM Model. Chapter VI presents test results for the three models studied and Chapter VII presents a thesis summary, conclusions derived from the analysis, and recommendations.

## II. THE TIGER SIMULATION PROGRAM

### A. INTRODUCTION

TIGER is the generic name for a family of computer programs developed for Naval Sea Systems Command in 1979 which can be used to evaluate, by simulation, a complex system in order to estimate various reliability, readiness, and availability measures. Originally designed for testing ship and shipboard weapon systems, TIGER has been amended several times at the Naval Postgraduate School. Major changes were undertaken by J. Leather in 1980 [Ref. 2], and P. O'Reilly in 1981 [Ref. 3].

During the course of this study several significant changes were made to the TIGER program. Several subroutines were changed and two subroutines were added. This chapter will outline the general features of TIGER and then detail the changes made in this study. The TIGER Manual [Ref. 4] is the primary reference source for all input, output, and optional features contained in the TIGER program. Only those options pertinent to this study will be outlined here.

### B. MAIN FEATURES OF TIGER

#### 1. Simulation

TIGER uses Monte Carlo simulation techniques to evaluate the system model under consideration. Random

numbers drawn from Naval Postgraduate School's LLRANDOMII [Ref. 5] were used to generate equipment failure times, repair times and other random numbers used in the simulation. Based on the system configuration of equipment, the system up and down times were determined. Based on these times, system measures of performance were calculated. The simulation was repeated a specified number of times and the results averaged.

The configuration of the system being modeled is defined in a top-down breakdown of the system into subsystem(s), groups and equipments. Each type of equipment is given a unique identifying number and its characteristics (MTBF, MITTR, BCM rate, unit cost) are stated.

Events are significant mission occurrences. TIGER recognizes the following types of events:

- Equipment Failure (UP to DOWN)
- Equipment Repair (DOWN to UP)
- End of Phase Period Within Mission
- Beginning of Mission
- End of Mission

These five types of events are stored in sequential order according to time occurrence. The first event becomes the next step at which computations within TIGER are done.

The concept of phases is essential to the operation of TIGER. A phase is a specified length of time that is characterized by a set of equipment operating rules. For this study two phase types were utilized:

Phase Type (1) is the flight phase. Equipments were subject to failure during this phase. Parts that failed during the flight phase could not be repaired until the beginning of the next ondeck phase. Parts being repaired ondeck continued to be repaired. If one part in the aircraft system failed during flight, other parts on the aircraft were still subject to failure.

Phase type (2) is the ondeck phase. Equipments were not subject to failure during the ondeck (repair) phase. Aircraft parts that failed during the previous flight phase were taken off the aircraft, replaced with a spare if available, and the failed part was placed in the repair pipeline. If no spare was available the aircraft system was considered to be in a degraded mode; that is, flight was possible but system capabilities were decreased depending on the essentiality of the failed parts.

Parts in the repair pipeline continue to be ordered, shipped, and repaired during all phases.

## 2. TIGER Statistics

The statistics calculated by TIGER are system reliability, readiness, and availability. The reliability estimator used in TIGER is the ratio of the number of successful missions to the total number of attempted missions. A successful mission occurs when no system failure occurs during the course of the mission. For a system composed of high failure rate parts such as those in

this study, there is no statistical chance of completing a mission of ninety days without a system failure. For this reason the reliability statistic was not used.

The average readiness estimator (RED (EST)) used in TIGER is the ratio of readiness (RED) uptime during the entire mission to total calendar time of the entire mission.

$$\text{Red uptime} = \text{Calendar time} - \text{Red downtime}$$

$$\text{Red downtime} = \text{Downtime prior to mission abort} + \text{time after mission abort}$$

This statistic was not used because it provides no indication of system availability after the first system failure.

The most informative statistic is the average availability, AVA AVERAGE (EST), or simply AVA. The availability parameter is the probability that the system will be in a satisfactory operating condition. It is estimated in TIGER as:

$$\text{AVA} = \frac{\text{Total Uptime for all phases}}{\text{Total Simulation Time}}$$

For the scenario used in this paper AVA would include downtime for an aircraft system during both the flight phase and the ondeck phase. Since this study is primarily concerned with aircraft system availability airborne, and it is assumed that the scheduled launches would continue even with degraded systems (a more likely event than waiting on deck for 100% system availability), a new statistic was introduced.

The new availability parameter, AVMUP, measures the availability of the aircraft system only during flight phases.

$$\text{AVMUP} = \frac{\text{Summation of all Flight Phase Uptime}}{\text{Summation of Total Flight Phase Time}}$$

Although AVMUP approximates the AVA value, the only time the two statistics are equal is when the ratio, A; where

$$A = \text{Flight Phase Uptime/Flight Phase Downtime}$$

is equal to the ratio, B; where

$$B = \frac{\text{Repair (ondeck) Phase Uptime}}{\text{Repair (ondeck) Phase Downtime}}$$

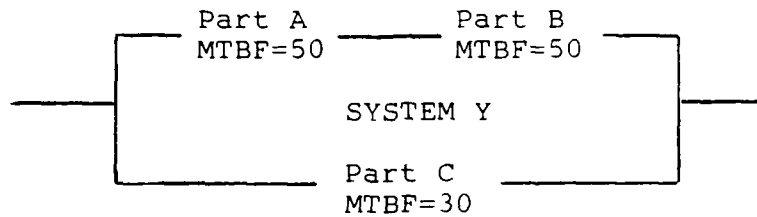
There are many scenarios in which these two ratios will not be equal. For example, a system with high failure rate parts will tend to have a lower A ratio. But these same parts may not decrease ratio B to the same degree if adequate spares are available. AVMUP emphasizes part criticality and reliability more than AVA. For this study, AVMUP was consistently several percentage points less than AVA.

Another set of statistics used in this thesis was the Critical Equipments Summary produced by TIGER. This is an optional printout that points out parts that are "worst offenders". Parts that caused the system to go to a down status or parts that failed while the system was already in a down status are listed in this output.

Table I provides an example of this summary. It depicts the events in a 90 hour mission, using a three part system, System Y. At time 8.96 hours, Part A fails, but since System Y is still up, no system downtime is recorded. At time 34.04 hours, part B fails, causing System Y to fail. TIGER counts

TABLE I

## Critical Equipments Computation



1. TIGER events occurring in 90 hour mission, System Y

| <u>Time</u> | <u>Event</u>  | <u>System Status</u> | <u>Total System Downtime</u> |
|-------------|---------------|----------------------|------------------------------|
| 0.00        | Mission start | UP                   | 0.00                         |
| 8.96        | Part A fails  | UP                   | 0.00                         |
| 34.04       | Part B fails  | DOWN                 | 0.00                         |
| 61.02       | Part C fails  | DOWN                 | 26.98                        |
| 90.00       | Mission end   | DOWN                 | 55.96                        |

2. Breakdown of total system downtime among Critical Equipments contributing to system downtime.

| <u>Period of<br/>Total System<br/>Downtime</u> | <u>Number of<br/>Parts Down</u> | <u>System Downtime Divided<br/>Among Down Parts</u> |          |          |
|------------------------------------------------|---------------------------------|-----------------------------------------------------|----------|----------|
|                                                |                                 | <u>A</u>                                            | <u>B</u> | <u>C</u> |
| 34.04-61.02<br>(26.98)                         | 2 (A,B)                         | 13.49                                               | 13.49    | 0.00     |
| 61.02-90.00<br>(28.98)                         | 3 (A,B,C)                       | 9.66                                                | 9.66     | 9.66     |
| Total Downtime                                 |                                 | 23.15                                               | 23.15    | 9.66     |
| Percent of Total<br>System Downtime            |                                 | 41.37                                               | 41.37    | 17.26    |

both parts A and B as critical equipments because both contribute to system downtime. At time 34.04, system downtime begins and continues until the end of the mission at time 90.0. Thus total system downtime is

$$90.0 - 34.04 = 55.96 \text{ hours}$$

At time 61.02, Part C fails. Part C is also considered to be a critical equipment for the period from 61.02 to 90.0 (28.98 hours) even though System Y is in a down status during this period. As shown in Part 2 of Table I, TIGER divides system downtime during the period 34.04 to 61.02 (26.98 hours) between the two parts (A and B) that are in a down status. Parts A and B are each credited with  $1/2$  of 26.98 hours, or 13.49 hours each during this period. TIGER then divides the system downtime for the period 61.02 to 90.0 (28.98 hours) between parts A, B and C because all three parts are in a down status during this period. Parts A, B, and C are each credited with  $1/3$  of 28.98 hours, or 9.66 hours each during this period.

Therefore, total system downtime is divided between the three parts A, B, and C as follows: A: 23.15 hours, B: 23.15 hours, and C: 9.66 hours. These hourly total are also converted to percentages of total system downtime by part. Parts that are large contributors to system downtime can be easily identified through the Critical Equipments Summary and inventory models can then be analyzed to isolate possible weaknesses. Explanations of the other TIGER statistics can be found in the TIGER Manual [Ref. 4].

### 3. TIGER Subroutines

TIGER in its present form at the Naval Postgraduate School is written in FORTRAN, utilizing subroutines as major subdivisions of the program. A short summary of the purpose of each subroutine is presented below.

MAIN Program: The majority of data is input. TIGER statistics are calculated once after each mission completion and again after all missions are completed.

Subroutine PACK: Equipment configuration data and phase operating rules are input. Inventory levels are computed.

Subroutine RUN: TIGER next event calculations are done. This subroutine is called at the start of each new phase within a mission.

Subroutine TTE: Random numbers are generated to provide times for part failures or repairs. Inventory levels are monitored. Major changes to this subroutine were made for this study.

Subroutine STATUS: Equipment(s) are reviewed after each event for status (up or down) of the main system and all parts.

Subroutine STANDBY: TIGER program arrays are indexed.

Subroutine EVENT: Events (part failures, repair, etc.) are sorted to find earliest time. Major changes to this subroutine were made for this study.

Subroutine APPLE: Statistics generated during a mission are summarized.

Subroutine SPARES: This subroutine is used to input inventory levels to the main program.

Subroutine ASPARE: ASO Manual inventory levels are computed. This is a new Subroutine.

Subroutine RIMAIR: RIMAIR inventory levels are computed. This is a New Subroutine.

## C. TIGER CHANGES

### 1. Aircraft Sortie Simulation

One of the major changes made to TIGER permitted the simulation of multiple aircraft sorties over a period of ninety days. Since TIGER was originally designed to test ship systems that underwent a few lengthy phases, variable dimensions had to be changed to allow for the many more phases that were required. With these new changes a 24-hour period may be divided up into as many as four phases. Figure 2.1 shows a sample combination of phases that can be arranged. This combination was then replicated once for each day in the mission.

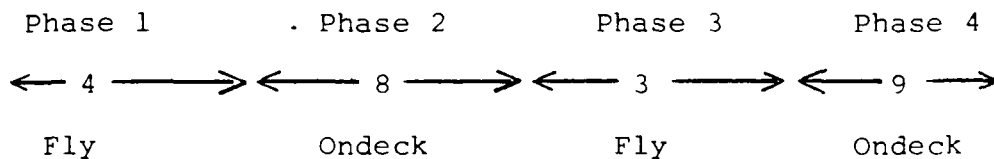


Figure 2.1. Phase Sequence Combination.

During each phase a number of aircraft may be operated. Since this version of TIGER does not allow for separate aircraft (systems) to be operated in different phase sequences, aircraft were operated simultaneously. For this study three aircraft were operated in "series" operation. That is, three identical aircraft systems were operated

with the requirement that all aircraft must be in an up status for the combined trio system of aircraft to be in up status.

## 2. Equipment: Repair and Resupply

TIGER was modified so that parts that failed and were removed from the aircraft, known as carcasses, could be tracked through the repair and resupply system. The inventory algorithms studied assumed a one-for-one repair policy; for each part turned in, another is issued. Figure 2.2 shows a schematic of the overall repair and resupply pipeline. When a part fails, it has two different pipelines it can follow.

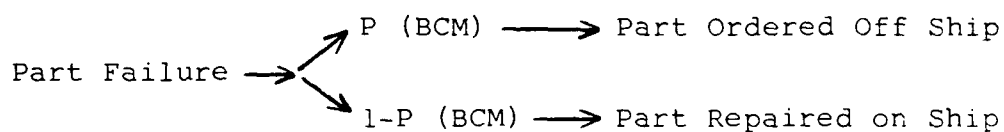


Figure 2.2. Part Pipelines.

With a probability =  $P$  (BCM), it will be considered "beyond the capability of local maintenance". In this case the part will be shipped to the depot level repair center off-ship, and a replacement part will be ordered. The time to receive a replacement part is known as the order and shipping time, OST. This time can vary depending on the stock level of the part at the depot, the location of the ship, and whether or not resupply to the carrier is possible (wartime scenario). Tiger will assign an exponentially

distributed OST, with mean equal to the SRTIM parameter of the part. SRTIM is defined as the off-ship order and shipping time of the specific part type. This time is placed in a new event time queue, RFITIM. Each part type has its own RFITIM queue that tracks all parts placed in the pipeline.

The exact number of parts in the pipeline is limited to the number of parts originally stocked. This computation is done through the NOP (number of parts) array. Whenever the NOP level equals the original inventory level, no more parts are available until a part is resupplied or repaired. The RFITIM queue is sorted to find the earliest repair time.

The failed part can also be placed in the repair pipeline, with a probability of  $1-P$  (BCM). This corresponds to the part being repaired at the ship repair facility, the Aviation Intermediate Maintenance Department (AIMD). The part is assigned an exponentially distributed repair time, with mean equal to the REPTIM parameter of the part. REPTIM is defined as the on-ship repair time for the specific part type. This time is also placed in the RFITIM event queue. This queue runs independently of the main TIGER event chain, known as ETIME; but RFITIM does follow phase type rules outlined previously.

### 3. New TIGER Subroutines

Two new subroutines were introduced into TIGER. The first, ASPARE, calculates inventory levels based on ASO

Manual instructions for AVCAL determination. The second subroutine, RIMAIR, calculates inventory levels based on RIMAIR policy instructions. Both algorithms were used by Boatwright [Ref. 6]. Later chapters will examine these inventory policies.

Major changes were also made to the TTE and EVENT subroutines in order to include new repair algorithms (discussed in II.C.2), and new phase sequence rules (discussed in II.C.1). Input data cards were changed. A full listing of input card formats used in this study can be found in Appendix A. Appendices B and C contain example input data sets which are read into TIGER from separate files. A complete listing of TIGER as utilized in this study is included in Appendix D.

#### 4. TIGER Validation

The complexity of the TIGER program makes extensive validation difficult. Two simple scenarios were chosen in order to validate this version of TIGER. Scenario One involved a single flight phase of 100 hours, with a mission time of 100 hours. Two parts, each with a MTBF = 100 hours, were arranged, first in a series configuration and then in a parallel configuration. This short mission time allows for the possibility of a successful (no failure) mission.

With this simple equipment configuration, derivation of the mathematical expression for the theoretical system availability is given in Ref. 7. The average availability can be found from the expression:

$$AVA = E(T)/MT, \quad (1)$$

where MT is the mission time = 100 hours. This assumes that no repair is possible during the 100 hour mission.  $E(T)$ , the expected lifetime, is

$$E(T) = \int_0^{\infty} t f(t) dt. \quad (2)$$

For component analysis,

$$f(t) = d(F(t))/dt = d(1 - R(t))/dt, \quad (3)$$

where  $R(t)$  is the survivor or reliability function. For a series system the reliability is

$$R(t) = R_1(t) * R_2(t), \quad (4)$$

where  $R_1(t)$  and  $R_2(t)$  are the reliability functions for components 1 and 2. Assuming exponential failure times, Eq. (4) becomes

$$\begin{aligned} R(t) &= \text{EXP}(-\lambda_1 t) * \text{EXP}(-\lambda_2 t); \\ &= \text{EXP}(-(\lambda_1 + \lambda_2)t) = \text{EXP}(-\lambda^* t); \end{aligned} \quad (5)$$

where  $\lambda^* = \lambda_1 + \lambda_2 = 1/50$ .

Substituting (5) into (3),  $f(t)$  can be expressed as

$$f(t) = \lambda^* \text{EXP}(-\lambda^* t). \quad (6)$$

Substituting (6) into (2) now gives

$$E(T) = \int_0^{\infty} t \lambda^* \text{EXP}(-\lambda^* t) dt. \quad (7)$$

The above expression assumes an infinite operating period. In our problem, time is truncated at 100 hours. Therefore if  $t$  is the system failure time, the mission lifetime is:

$$T = \begin{cases} t & \text{if } t \leq 100 \\ 100 & \text{if } t > 100 \end{cases}$$

Thus, for our case, equation (7) is modified as follows:

$$\begin{aligned} E(T) &= \int_0^{100} t\lambda^* \text{EXP}(-\lambda^* t) dt + 100 \int_{100}^{\infty} \lambda^* \text{EXP}(-\lambda^* t) dt \\ &= 29.78 + 13.53 = 43.31. \end{aligned}$$

Finally,

$$\text{AVA (series)} = 1/100 (43.31) = 0.4331.$$

For a parallel configuration system, its reliability,  $R(t)$ , can be expressed as follows:

$$R(t) = R_1(t) + R_2(t) - R_1(t) * R_2(t). \quad (8)$$

The last term in (8),  $R_1(t) * R_2(t)$ , is the series reliability term (43.31) computed above. Also note that for this problem  $R_1(t)$  equals  $R_2(t)$  because the two components have identical MTBFs. Substituting 43.31 for the last term in (8),  $E(t)$  is computed as in the series system above to be

$$\begin{aligned} &= 2 * \left[ \int_0^{100} t\lambda_1 \text{EXP}(-\lambda_1 t) dt + 100 \int_{100}^{\infty} \lambda_1 \text{EXP}(-\lambda_1 t) dt \right] - 43.31 \\ &= 2 * (63.21) - 43.31 = 83.11. \end{aligned}$$

This gives:

$$\text{AVA (parallel)} = (83.11)/100 = 0.8311.$$

Scenario Two involved a single flight phase of 5000 hours, utilizing the same two systems. A phase of 5000 hours ensures the failure of the system and an estimate can only be made of the expected lifetime of the system. For the series system, the expected lifetime is

$$E(t) = \int_0^{5000} t\lambda^* \text{EXP}(-\lambda^* t) dt + 5000 \int_{5000}^{\infty} \lambda^* \text{EXP}(-\lambda^* t) dt.$$

Therefore,

$$E(t) = 50.0 + 0.0 = 50.0 \text{ hours.}$$

For the parallel system, the expected lifetime is

$$\begin{aligned} E(t) &= \int_0^{\infty} t(2\lambda_1 \text{EXP}(-\lambda_1 t) + \lambda^* \text{EXP}(-\lambda^* t)) dt \\ &= 2 * (100.0) - 50.0 = 150.0 \text{ hours.} \end{aligned}$$

Results for validation runs are shown for both scenarios in Table II. One thousand iterations were done for each run.

TABLE II  
TIGER Validation Results

Scenario 1    (100 Hours)

| Run               | Seed | AVA (series) | AVA (parallel) |
|-------------------|------|--------------|----------------|
| 1                 | 2222 | 0.4294       | 0.8269         |
| 2                 | 1245 | 0.4360       | 0.8444         |
| 3                 | 1357 | 0.4341       | 0.8453         |
| Theoretical Value |      | 0.4331       | 0.8331         |

Scenario 2    (5000 Hours)

| Run               | Seed | E (Lifetime Series) | E (Lifetime Parallel) |
|-------------------|------|---------------------|-----------------------|
| 4                 | 2222 | 50.3                | 149.8                 |
| 5                 | 1245 | 50.7                | 153.4                 |
| 6                 | 1357 | 49.5                | 144.9                 |
| Theoretical Value |      | 50.0                | 150.0                 |

### III. ASO MODEL

#### A. MODEL DESCRIPTION

The Navy Aviation Supply Office Manual model for determining the AVCAL is based on the repair/resupply pipeline displayed in Figure 3.1. Failure of parts in a ninety-day period create a demand, QTRDEM. With a probability equal to  $P$ , parts are beyond the capability of shipboard maintenance (BCM), or with a probability  $1-P$  are determined to be repairable onboard ship.

The BCM'ed parts are sent off-ship, either to be disposed of or to be repaired at the depot repair maintenance facility ashore. In either case a replacement part is ordered through the requisition pipeline. The order and shipping time (OST) is the time from order until receipt of a new part. A part repairable at the shipboard level experiences a delay in the repair pipeline called the turn around time (TAT). The average number of parts in this pipeline is the mean repair pipeline (MRP). When parts are received from either pipeline they are placed back into the local (retail) inventory.

The following assumptions are made in the model [Ref. 8]:

Demand is a Poisson process.

Demand rates are stationary over time (no surge or cyclic demand rates).

OST and TAT are independent of demand.

The repair pipeline is never saturated.

Items are requisitioned on a one-for-one basis (S-1, S ordering policy).

All demands are satisfied by either immediate replacement from supply, shipboard repair, or requisition (back order).

Part cannibalization does not occur.

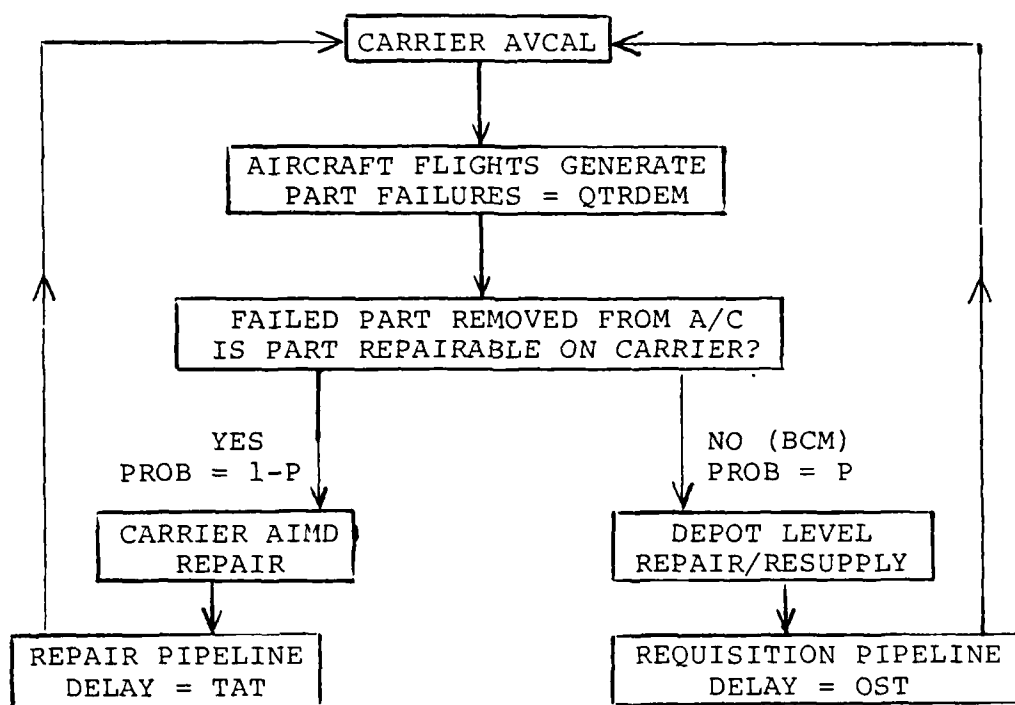


Figure 3.1. ASO Repair/Resupply Model.

These assumptions are very generous, but the net affect is that this model is a fairly simple one. The first assumption leads to demand over a given period  $t$  being distributed as Poisson, with mean =  $(QTRDEM * t)$ . It can be shown [Ref. 9] that the two "pipelines", ship repair and off-ship requisition, are independent Poisson processes with means  $(P * QTRDEM) * t$  and  $(1-P) * QTRDEM * t$ , respectively. The number of items in the ship repair pipeline is also Poisson, with mean  $RPQ$ .

#### B. INVENTORY DETERMINATION

The Navy Aviation Supply Office's (ASO) Provisioning Manual [Ref. 10] furnishes policy and procedures for determining AVCAL range and depth levels. Although the process of generating a complete AVCAL is quite complex, the basic guidelines used for repairables are concise. Navy 3M data, contractor usage data, and laboratory results are combined to predict failure rates. The ASO Manual refers to failure rate prediction as "the most important function of provisioning" in the determination of the AVCAL.

The Outfitting Directive, issued by the Type Commander, specifies the Type/Series/Model of aircraft to be supported, the number of aircraft, and the number of flight hours per month per aircraft. The Allowance Requirement Registers (ARRs), which make up the AVCAL, are divided into three major parts:

Part I Attrition Support

Part II Rotatable Pool Items

Part III Special Support Requirements

This study will deal only with the first two parts. The following data elements are used to construct ARR's:

Maintenance Cycle (MC): Normally 100 hours for aircraft and installed equipment.

Units per Component/Aircraft (UPA): Number of parts of type X installed on each aircraft. An individual UPA exists for each part type X.

Planned Operating Hours: Planned aircraft utilization per month in hours.

Number of Aircraft: Number of aircraft supported by this ARR.

Maintenance Replacement Factor (MRF): For repairable items, the number of times that an item will be BCM at organizational (squadron) and Intermediate (AIMD) levels during one MC.

$$MRF = \# \text{ BCM's} / (MC * UPA)$$

Rotatable Pool Factor (RPF): Predicted number of removal/IMA repair cycles in one MC.

$$RPF = (\text{Predicted \# of repairs}) / (MC * UPA)$$

Turn Around Time (TAT): Average number of days between removal of a repairable item for processing at the AIMD and return to Ready For Issue (RFI) condition. This estimate includes time to schedule, fault isolate, disassemble, repair, assemble, and test a repairable assembly.

The candidates for inclusion in the AVCAL are chosen as follows. The attrition quantity in any ninety day period is determined as follows:

- (1) Compute Flight Hour Factor (FHF) for aircraft:

$$FHF = (\text{avg. \# of Aircraft}) * (\text{Operating Hrs./Qtr.})$$

- (2) Compute Expected number of Maintenance Cycles per quarter:

$$\# \text{ of MC} = FHF / 100$$

(3) Compute Attrition Quantity (D):

$$D = \text{MRF} * \text{UPA} * (\# \text{ of MC})$$

1. Attrition Rules

Attrition items are stocked to replace those parts that are BCM'ed at the organizational or intermediate level. The range rules for attrition parts depend on whether the part is also included in the rotatable pool quantity. If a part is supported in the rotatable pool, it must have a demand (D) greater than or equal to one per quarter to be eligible for the attrition portion of the AVCAL.

If the part is not supported in the rotatable pool, the range rules for attrition are different. These low demand items may still qualify for the attrition allowance under the following guidelines:

a. Items with a unit cost of \$5000 or more will qualify if the predicted demand is equal to or greater than one in a six month period. This equates to an attrition quantity of at least 0.50 before any units will be carried in the AVCAL.

b. Items with a unit cost of less than \$5000 will qualify if the predicted demand is equal to or greater than one in a nine month period. This equates to an attrition quantity of at least 0.34 before a quantity of one will be carried in the AVCAL.

Attrition quantities are used to determine attrition range candidates as noted above. Once a candidate has been

selected, the depth or amount to be stocked is computed by rounding the attrition quantity to the nearest integer. A minimum of one is stocked for all range qualifying candidates.

## 2. Rotatable Pool Rules

The rotatable pool portion of the AVCAL allowance was intended to support the fast moving, critical parts and assemblies required to support the aircraft. These items must be capable of repair at the intermediate level (AIMD). The raw pool quantity (RPQ) is the average number of units repaired by the AIMD in a 90 day period and is given by:

$$RPQ = (RPF * TAT * UPA * (\# \text{ of MC/in 90 days}))/90$$

It should be noted that the value for TAT is an averaged value that is truncated to a maximum of twenty days. This data element will be further discussed later in the chapter. Using RPQ as the mean, the Poisson distribution is used to find the depth which will provide 90% protection against being short at least one unit in ninety days. This depth, called the rotatable pool allowance (RPA), provides 90% protection for those parts which have carcasses tied up in the repair pipeline. Therefore,

$$P(X \leq RPA) = 0.9 ,$$

where  $X$  = # of units of a part being repaired in the shipboard pipeline. Under the assumption that  $X$  is Poisson distributed,

$$P(X \leq RPA) = \sum_{X=0}^{RPA} \frac{\text{EXP}(-RPQ) * (RPQ)^X}{X!}$$

Using these calculations, an RPQ of 0.11 is the minimum value that will require an RPA of one. Below the 0.11 level a stock quantity of zero satisfies the 90% protection, and no part is stocked for the pool.

### C. MODEL LIMITATIONS

The ASO model is the oldest of the three models discussed in this thesis. It is the only model developed before data automation and powerful computers became widespread in the Navy. This partially explains the model's simple approach to the inventory problem. Procedures are simple enough that inventory levels could be calculated by hand for each part, one at a time, with the use of one short table from the ASO Manual. One noteworthy weakness in the model is the omission of the concept of budget. The only direct reference to dollar amounts is in the use of \$5000 as a cutoff amount for attrition allowance. But even this figure has become completely arbitrary because there is no provision for its change or update and because it applies to inventories with parts typically ranging in price from a few hundred dollars to over several hundred thousand dollars.

Mitchell [Ref. 11] pointed out that limiting TAT to twenty days is not a true reflection of the real repair pipeline operation. A breakdown of the TAT elements is shown below in Figure 3.2. The limit values were developed at ASO in a study conducted in 1977 [Ref. 12]. The limit values tend to understate the problems encountered in the repair pipeline. The

values are applied across all parts, although the complex equipments encounter longer times than the simple parts.

|      | TAT element         | Limit (days) |
|------|---------------------|--------------|
| IP:  | In-process time     | 1            |
| SKD: | Scheduling time     | 3            |
| RPR: | Repair time         | 8            |
| AWP: | Awaiting parts time | 20           |
| TAT: | Total time          | 20           |

Figure 3.2. TAT Elements.

The ASO model is tasked to achieve material availability goals and stockage criteria promulgated in OPNAVINST 4441.12A [Ref. 13]. For ships, the objective for overall AVCAL performance is to fill 75% of all demands and to provide overall availability of 85% for items stocked. But as noted in the Navy Fleet Materials Support Office RIM-AIR Study [Ref. 14], the ASO model has historically failed to do this. Fleet aircraft availability is often achieved only through a constant process of selective cannibalization of squadron aircraft parts. For example, in an E-2C squadron with four aircraft aboard a carrier, one aircraft is designated the "parts locker" in order to overcome shortcomings in both the repair and requisition pipelines.

There is a disadvantage in the ASO criteria that attrition and repair demand be segregated. Separate range criteria are applied to determine attrition and repair pool support. This splitting of demand results in non-stockage of items that would have been stocked had demand been combined. This contributes to the overall conservative approach that characterizes ASO Manual AVCAL levels.

#### IV. RIMAIR MODEL

##### A. MODEL DESCRIPTION

During the Seventies all DOD budget policies came under close scrutiny by civilian government leaders. The DOD Retail Inventory Management and Stockage Policy (RIMSTOP) Study was issued in 1976 to set guidelines for retail level inventory support provided by the military services [Ref. 14]. Out of RIMSTOP originated DOD Directive 4140.44 (Supply Management of the Intermediate and Consumer Levels of Inventory), and DOD Instructions 4140.45 (consumable items), 4140.46 (repairable items) and 4140.47 (war reserves). DODI 4140.46 [Ref. 15] dictates that:

"the following levels will be computed for each repairable item to be stocked at the intermediate level on a demand-supported basis:

(1) Repair Cycle Level (RCL). The RCL is a function of the anticipated number of maintenance replacements that will be repaired locally and the item's repair cycle time.

(2) Order and Shipping Time Level (OSTL). The OSTL is a function of the anticipated number of maintenance replacements that will require supply from external sources and the item's order and shipping time.

(3) Safety Level (SL). The SL is a function of the capabilities that the repair cycle time will be exceeded, the order and shipping time will be exceeded, the maintenance replacement rate will be higher than forecasted, and a number of maintenance replacements, anticipated for repair at the activity, will require resupply from external sources.

(4) Operating Level (OL). The OL is an Economic Order Quantity (EOQ) and is a function of the cost to order and the cost to hold an item of inventory.

(5) Replenishment. Replenishment action will be taken when the asset position reaches the reorder point."

In addition, DODI 4140.47 (Secondary Item War Reserve Requirements Development) authorizes increments to the order and ship time, repair cycle and safety levels to satisfy wartime recurring demands over and above the peacetime demands. An additional Resupply Delay Time (RDT) level is also authorized to provide material coverage of anticipated delays in the wartime retail level supply pipeline.

Commander, Naval Supply Systems Command (COMNAVSUPSYSCOM) proposed a pipeline model that would adhere to these DOD policies while attaining Navy availability goals. This model was designated Repairables Integrated Model for Aviation (RIMAIR). In addition to the levels mentioned above, RIMAIR added a level of stock that assures a self-supporting capability for a prescribed period of time, known as an "endurance delta". The same assumptions stated for the ASO model apply to this model.

RIMAIR produces a total depth of stock that equals:

$$OL + RCL_w + \text{MAX} \left\{ \begin{array}{l} OST_p + EDT \\ OST_w + RDT \end{array} \right\} + SL,$$

where

OL = operating level;

$RCL_w$  = repair cycle level computed with a wartime flying hour program;

$OST_p$  = order and ship time level computed with a peacetime flying hour program;

EDP = endurance period support level to assure self-supporting capability to satisfy wartime demands for a prescribed period of time;

$OST_w$  = order and ship time level computed with a wartime flying hour program;

RDT = resupply delay time level;

SL = total safety level based on the sum of RCL and the MAX computation.

The peacetime operating stock (POS) levels may be separated from the total depth:

$$POS = OL + RCL_p + OST_p + SL_p$$

The endurance delta represents the difference between  $OST_p + EDP$  and  $OST_w + RDT$  [Ref. 14].

## B. INVENTORY DETERMINATION

### 1. Steady-state Supply Effectiveness

Appendices C and D of the FMSO RIM-AIR Study [Ref. 14] provide the mathematical background for this model. Initially assume no stock is carried. The repair and requisition processes can be modeled mathematically as stochastic queuing processes in which non-RFI (failed) units arrive, wait for a RFI replacement then leave. The average number of items in a queuing process is given by the following relationship:

$$L = \lambda * W$$

where  $L$  = average number of units in process

$\lambda$  = average arrival rate

$W$  = average waiting time in process

The number of requirements for a RFI replacement in the requisition process is the requisition pipeline. The number of non-RFI units in the repair process is called the repair pipeline. Given the above relationship, the average number of non-RFI units in the repair and requisition pipelines may be expressed as follows:

$$\begin{aligned} L_T &= L_{REP} + L_{REQ} \\ &= \lambda_{REP} * W_{REP} + \lambda_{REQ} * W_{REQ} \\ &= \frac{RPF * MC_{90}}{90} * TAT + \frac{MRF * MC_{90}}{90} * OST \end{aligned}$$

where

$L_T$  = total non-RFI units waiting for replacement

$L_{REP}$  = non-RFI units in the repair process

$L_{REQ}$  = non-RFI units in the requisition process

$\lambda_{REP}$  = arrival rate for repair process

$\lambda_{REQ}$  = arrival rate for requisition process

$W_{REP}$  = waiting time for repair process

$W_{REQ}$  = waiting time for requisition process

$MC_{90}$  = waiting cycle program for 90 days

The actual number of units in the repair and requisition pipelines at some point in time is a random variable. The following assumptions are made in order to postulate a probability function for this random variable:

The arrival process is Poisson.

The repair times have a distribution which is independent of the arrival process.

The arrival rates and services rates are stationary over time.

Arrivals are always single units.

Every arrival enters either the repair or requisition process and completes service before departing.

Given these assumptions, the number of units  $N$  in the repair and requisition pipelines will be Poisson distributed with mean  $L_T$  for repairables. That is, the probability that  $N = n$ , is found from the expression:

$$P(N=n) = \text{EXP}(-L_T) * (L_T)^n / (n!).$$

The probability that there are no backorders, called the protection, is computed as follows:

$$\text{Protection} = \sum_{n=0}^S P(N=n) ,$$

where  $S$  = stock quantity.

When the number of units in the repair or requisition processes is strictly less than the stock quantity, there is at least one RFI unit available in stock to satisfy a demand should one occur. Since demands are assumed to always be for one unit, only one unit needs to be in stock when a demand occurs in order to satisfy that demand. The probability of satisfying a demand is called the fill rate (FR) and is computed as follows:

$$FR = \sum_{n=0}^{S-1} P(n)$$

The expected number of satisfied demands is found by multiplying the fill rate by the expected number of demands. The expected demands (D) for a 90 day period is computed as follows:

$$D = (MRF + RPF) * MC_{90}$$

Thus, the expected gross supply effectiveness, which is the percentage of demands satisfied immediately from stock, can be computed as follows:

Expected Supply Effectiveness =

$$\frac{\sum_{i=1}^m FR_i * D_i}{\sum_{j=1}^Q D_j} \quad (1)$$

where

- m = number of stocked items
- Q = number of installed items
- i = index of stocked items
- j = index of installed items

Expected net supply effectiveness is obtained by summing expected demand over stocked items in the denominator.

## 2. Optimization

The objective of the optimization of this model is to find an inventory that gives the maximum possible effectiveness for a given cost. The effectiveness measure used is the expected gross supply effectiveness derived above. Expected units demanded for installed items remain constant.

The optimization maximizes expected supply effectiveness.

The problem may be stated as follows:

$$\text{Maximize } \sum_{i=1}^m E_i * D_i * FR_i$$

$$\text{subject to } \sum_{i=1}^m C_i * S_i = B$$

where

- $i$  = item index;
- $E_i$  = Item essentiality code;
- $D_i$  = Expected demand;
- $FR_i$  = Fill rate per item;
- $C_i$  = Unit price;
- $S_i$  = Stock Quantity;
- $B$  = Cost target.

RIMAIR uses the method of Lagrange multipliers to solve this problem. Formulating the Lagrangian function from the problem above gives:

$$L(\lambda, \bar{S}) = \sum_{i=1}^m E_i * D_i * FR_i - \lambda * \left( \sum_{i=1}^m C_i * S_i - B \right)$$

Because of the discrete nature of the demand distribution, the stockage levels are determined using finite differences. Observe that  $L(\lambda, \bar{S})$  is separable in the items. Thus the Lagrange function can be written as:

$$L(\lambda, \bar{S}) = \sum_{i=1}^m L_i(S_i; \lambda) + B \lambda$$

where  $L_i(S_i; \lambda) = E_i * D_i * FR_i(S_i) - \lambda C_i S_i$ .

For a given value of  $\lambda$  the stockage level for item  $i$  is then the largest integer  $S_i$  such that:

$$\Delta L_i(S_i; \lambda) = L_i(S_i+1; \lambda) - L_i(S_i; \lambda) > 0$$

This is found to be the largest integer  $S$  such that

$$p_i(S_i) > \frac{\lambda * C_i}{E_i * D_i} \quad (2)$$

where  $p_i(S_i)$  is the probability density function of the Poisson pipeline distribution, given earlier as  $P(N=n)$ .

The "optimal" stockage level corresponds to the solution to this equation when  $\lambda = \lambda^*$  where  $\lambda^*$  is that value such that  $\sum C_i * S_i = B$ . (Due to the discrete nature of the items the required budget may never exactly equal  $B$  and consequently, the Lagrange solution may not be optimal. It will produce, however, an undominated solution for each budget amount actually consumed.)

The procedure outlined above for finding  $\bar{S}^*$  can be applied with any value of  $\lambda$ . When used with  $\lambda^*$ , it produces the solution to the original problem. When used with any other  $\lambda$ , it produces an inventory that still maximizes the Lagrangian function with respect to  $\bar{S}$  but does not satisfy the budget constraint. The process then becomes one of finding the correct  $\lambda$ , until the cost is close to the target  $B$ .

The RIMAIR implementation of the solution procedure as applied to the stockage level for the  $i$ th item is summarized

below:

- a. Select the Lagrange multiplier.
- b. Find the largest integer which is less than or equal to  $L_T$  as an initial value for  $S_i$ .
- c. If

$$p(S_i) < \frac{\lambda * C_i}{E_i * D_i}$$

do not stock the item. This situation is depicted in Figure 4.1, Case A. The Poisson density function  $p(S_i)$  is everywhere less than the value for  $\lambda * C_i / E_i * D_i$ . Therefore the optimal stockage level equals zero. If

$$p(S_i) > \lambda * C_i / E_i * D_i$$

go on to step d. The second situation is shown in Figure 4.1, Case B.  $S_i$  is initially set equal to 2 (the largest integer less than or equal to the mean  $L_T = 2.5$ ).

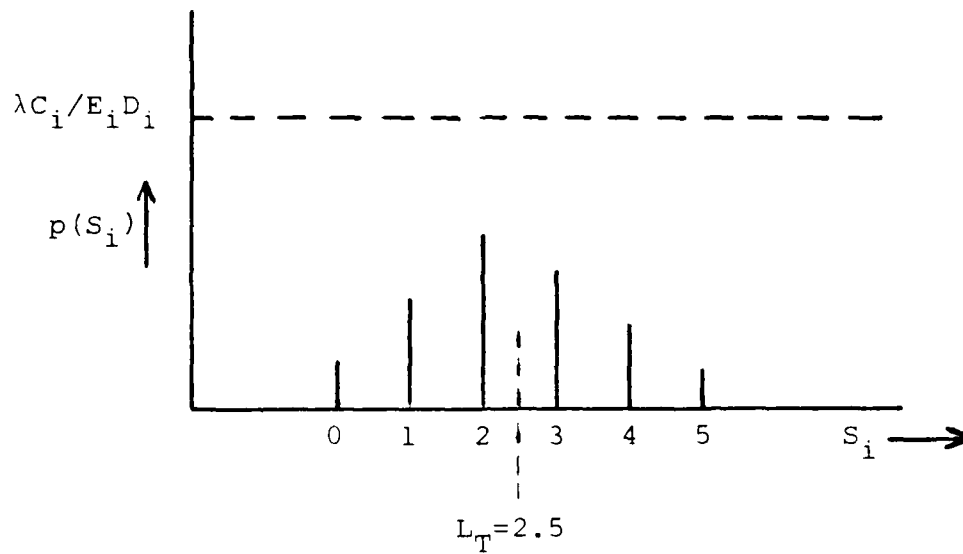
- d. Increment  $S_i$  by one.
- e. If

$$p(S_i) < \frac{\lambda * C_i}{E_i * D_i}$$

select  $S_i$  as  $S_i^*$  and stop; otherwise go to step d. In Case B,  $S_i=4$  would be chosen as  $S_i^*$ . (Note that this implementation will select  $S_i^*$  to be one larger than that which would be generated by Equation 2.)

- f. Compare the optimal stockage level to external constraints and adjust accordingly.

Case A: Zero Stockage Level



Case B: Positive Stockage Level

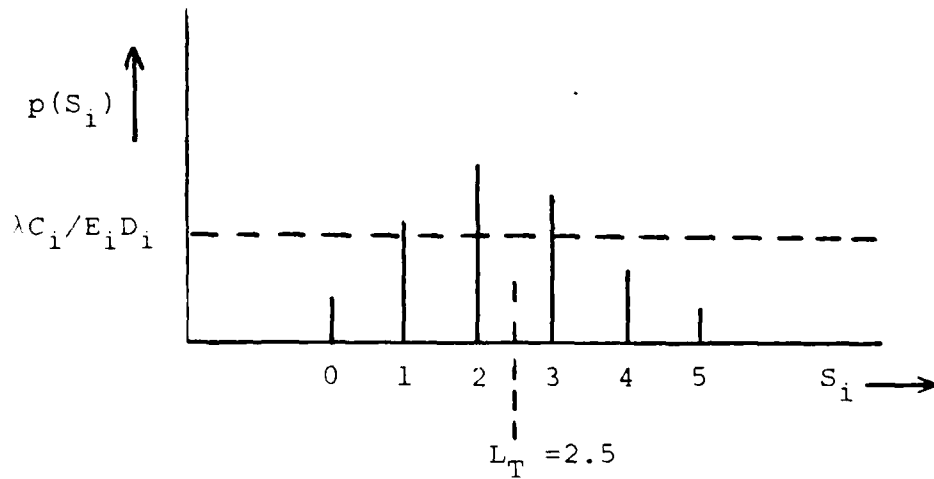


Figure 4.1. RIMAIR Stockage Level Options.

g. Iterate through all items, and compare the final total inventory cost with the budget target B. If the total cost is not within preassigned limits return to step a. For example, if total cost is not within plus or minus 1% of target budget, begin at step a with a new lambda value and try to get total cost within 1% limits.

This procedure simultaneously produces the range and depth criteria. That is, if the optimal stockage level is greater than zero, then the item is stocked.

### 3. External Constraints

Step (f) includes comparing stockage levels to constraints external to the original Lagrange problem. The maximum constraint is the sum of a ninety-nine percent protection on the mean basic pipeline (BP) and the operating level. BP is defined as:

$$BP = L_T + \text{ENDURANCE LEVEL} \quad (3)$$

Since the basic pipeline quantity is assumed to be Poisson distributed with mean BP, the 0.99 protection level would be the smallest quantity S such that:

$$\sum_{X=0}^S \text{EXP}(-BP) * (BP)^X / X! \geq 0.99 \quad (4)$$

The operating level is computed as follows:

$$OL = \sqrt{(2 * A * Y) / (IC)} \quad (5)$$

Where: Y= annual demands

C= unit price

2A/I= constant (approximately 559)

The maximum constraint is the sum of S from (4) and OL from (5) above.

The minimum constraint is the sum of (3) and (5) above.

### C. MODEL LIMITATIONS

The RIMAIR model corrected several of the deficiencies of the ASO model. It was recognized that the ASO model's attrition allowance, which was theoretically provided to support wartime mobilization operations with resupply delayed or cut off, was in fact supporting the number of items in the wholesale resupply pipeline during normal operations. The RIMAIR model includes the addition of stock to the attrition portion of the allowance to support the expected order and shipping time experienced during peacetime, and the addition of a wholesale resupply pipeline to the repair cycle pipeline for the purpose of providing Poisson protection to the entire pipeline.

One of the potential strengths of the RIMAIR model is the inclusion of the item essentiality code parameter  $E_i$ . This code was developed to reflect the relative importance of parts to total system availability. Suggestions for use of this parameter are addressed in Boatwright [Ref. 6]. An ideal code would be influenced by the part's MTBF, by the system configuration (whether or not the part had backups), and by the role that the part played in contributing to aircraft mission completion.

Incorporation of these concepts into the essentiality code is difficult. For this study an item essentiality code equal to one was assumed for all parts. One reason for this was because all parts were considered equally essential for aircraft mission performance.

The Lagrange multiplier provided control for budget levels as discussed above. By decreasing lambda the inventory cost would increase, or by increasing lambda the inventory cost would decrease. This budget control function was discrete. The actual inventory cost could vary from the target budget by as much as the cost of a single part.

The RIMAIR algorithm was included within the TIGER program as a separate subroutine. First, RIMAIR inventory levels are computed in the subroutine and second, TIGER simulates aircraft flights with these RIMAIR stocks as input. Lambda values are included in the input data file, external to the TIGER program. Lambda values are changed and new budget levels are then examined to see if they meet the target budget.

The RIMAIR and ASO models share some of the same weaknesses because they are based on the same underlying assumptions. The problem that the ASO model encountered with TAT, discussed in III.C, is also present in RIMAIR. This points out that there are problems in the inventory decision process that exist above the model level. In this case, it is with the Navy process of data collection of TAT.

Another comparison can be made between the two models as far as workload required to support it. The RIMAIR model increases the workload compared to the ASO model because RIMAIR introduces two new parameters, the item essentiality code and the lambda value. The problem with the essentiality code, as mentioned above is how to assign it; faulty coding can result in unbalanced AVCALs. Time must be spent assigning and updating these codes. Since the lambda value is assigned external to the RIMAIR subroutine, time is spent checking budget levels and resetting lambda values. One improvement to the present algorithm would be to include a loop in the program that would change the lambda value depending on proximity to target budget.

Both the ASO and RIMAIR models are retail level, single echelon models. This means that they calculate AVCALs only for the organizational level facility. Multi-echelon models have been developed that spell out stock levels at organizational, intermediate and depot level facilities. The next chapter will examine one of these multi-echelon models, ACIM, that can also be used for the single-echelon case.

## V. ACIM MODEL

### A. MODEL DESCRIPTION

The Naval Sea Systems Command's Availability Inventory Model (ACIM) was developed after the Chief of Naval Operations directed that "a sophisticated availability-based sparing technique be developed and applied on a selected basis for equipments which require a level of readiness above that which standard policies can provide [Ref. 16]."

In response to this CNO direction, the Chief of Naval Material issued NAVMATINST 3000.2. This instruction established Operational Availability ( $A_o$ ) as the primary measure of material readiness for Navy weapons systems and established policy for  $A_o$  analytical techniques. Subsequently CHNAVMAT recommended, and CNO approved, a standard availability centered optimization model for use by all program managers in determining consumer level stockage quantities for selected equipments. This ACIM model develops repair parts allowances to achieve a specified  $A_o$  at the minimum possible inventory cost.

This thesis will investigate ACIM model version 2.0, developed by CACI-Inc Federal and implemented by Henry J. Watras for use on the NPS IBM 3033. This chapter will describe the ACIM model as it applies to AVCAL determination

in this thesis. A more detailed analysis of this model can be found in McDonnell [Ref. 17] and in the ACIM Handbook [Ref. 16].

The underlying assumptions of the ACIM model are listed below.

1. Included parts are organized in terms of an equipment with topdown breakdown. Multiple units of a part within a given next higher assembly are represented only once in the breakdown. However, if the same part appears in different locations in the structure, each appearance is treated as a unique item in the operation of the model.

2. External demands upon supply are stationary and compound-Poisson distributed.

3. All stockage locations use a continuous review, (S-l,S) ordering policy.

4. Mean times to repair are defined as constants which include all equipment repair related down times that are not supply related.

5. Component failures are independent.

6. No further demands for parts can occur when one or more parts are in down status. That is, when a part fails the system does not operate again until the failed part is replaced.

A top-down breakdown is one which starts with the highest level unit, in this case the E-2C aircraft. The next level down is the WRA level, which are the individual parts discussed in this study. Below the WRA level is the Shop Replaceable Assembly (SRA) level, the sub-SRA level, and on down until the smallest diode or resistor has been itemized. This multi-level approach is also called a multi-indentured approach. For this study only WRA level

inventories will be computed although ACIM can compute stocks down to the lowest level.

The ACIM definition of availability is the same as that used in the TIGER simulation model; namely,

$$A_o = \frac{\text{UPTIME}}{\text{UPTIME} + \text{DOWNTIME}}$$

ACIM replaces uptime by MTBF and downtime by Mean Time To Repair (MTTR) plus Mean Supply Response Time (MSRT). So,  $A_o$  can be reexpressed as:

$$A_o = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR} + \text{MSRT}}$$

The MTTR and MTBF parameters are inputs to the ACIM model. The MSRT factor depends on the stockage levels and ACIM uses this dependency to achieve a target value of  $A_o$ . ACIM actually attempts to minimize MSRT in order to maximize  $A_o$ .

## B. INVENTORY DETERMINATION

### 1. ACIM Solution Equations

The model is defined recursively by considering an arbitrary item in the system and an arbitrary facility. The system is the aircraft, and the items are the individual parts (WRAs). The structure of the model is given by the following set of definitions and equations:

a. Let  $i$  be an arbitrary item in equipment  $e$  (which may be  $e$  itself). Let  $u = 0$  represent an arbitrary facility in the support system.

- b.  $M_{iu} = DEL_{iu} + R_{iu}$ ,  
 $M_{iu}$  = mean time to return a failed item  $i$  at location  $u$  to a serviceable condition;  
 $DEL_{iu}$  = expected delay per demand for item  $i$  at location  $u$ , experienced in the repair and requisition pipelines;  
 $R_{iu}$  = mean time to repair item  $i$  at user location  $u$  (for on-equipment repair);  
= 0 if location  $u$  does not operate the equipment.

c.  $DEL_{iu} = \frac{1}{Y_{iu}} \sum_{X \geq S_{iu}} (X - S_{iu}) * p(X; Y_{iu} * T_{iu})$ ,

- where  $S_{iu}$  = stock level of item  $i$  at location;  
 $Y_{iu}$  = expected number of demands upon inventory for item  $i$  at location  $u$ ;  
 $p(X; Y_{iu} * T_{iu})$  = probability of  $X$  units of stock reduction for item  $i$  at location  $u$ ; the distribution may be Poisson, Normal or Negative Binomial, depending on the mean and variance of the part;  
 $T_{iu}$  = mean resupply time (time to replace an inventory loss) for item  $i$  at location  $u$ .

d.  $T_{iu} = P_{iu}(L_{iu} + L'_{iu}) + (1 - P_{iu}) * (R_{iu} + R'_{iu})$ ,

- where  $P_{iu}$  = probability that a demand for item  $i$  upon inventory at location  $u$  results in a loss (discard or sent elsewhere for repair) which must be replaced through resupply;  
 $L_{iu}$  = average resupply lead time assuming stock is available at the resupply source;  
 $L'_{iu}$  = additional resupply lead time due to expected shortages at the resupply source;

$R_{iu}$  = average shop repair cycle time assuming availability of spares for items within  $i$  at the next lower indenture level;

$R'_{iu}$  = additional shop repair cycle time due to expected shortages of spares for items within  $i$  at the next lower indenture level.

The values of  $L_{iu}$ ,  $R_{iu}$ ,  $T_{iu}$ , and  $Y_{iu}$  are inputs to the model.

$$e. L' = \begin{cases} D_{iv} & \text{for } u = 0 \\ D_{io} & \text{for } u = 1, 2, \dots, U; \end{cases}$$

where  $v$  is the resupply source for location 0 and  $v=0$  if the location 0 has no resupply source.

$$f. R'_{iu} = \sum_{j \in i} Y_{ji} M_{ju} / \sum_{j \in i} Y_{ju},$$

where  $j$  identifies items within  $i$  at the next lower indenture level;  $j = 0$  if  $i$  has no subordinate parts.

$$g. A_{eu} = 1 / (1 + Y_{eu} * M_{eu}),$$

where  $A_{eu}$  = fraction of time equipment  $e$  is available for use at location  $u$  (defined only for locations  $u$  which operate the equipment).

## 2. Objective Function

The overall objective of ACIM is to determine stockages levels for all items and all stockage facilities so that the expected operational availability of the equipment is maximized for a given inventory budget or, conversely, to find levels which achieve a given operational availability at least cost. This objective can be explicitly stated as follows:

Find values for  $S_k$  for all items  $k$  and locations  $v$  in the

support system which minimize  $DEL = DEL_{eu}$  for all user locations  $u$  subject to:

$$\sum_{k,v} c_k S_k \leq B,$$

where  $c_k$  = unit cost of item  $k$ ;

$B$  = given budget for spares procurement.

A similar statement can be written for the converse objective of achieving a given value for  $A_{eu}$  at least cost.

The ACIM solution to the problem defined above is found by a recursive procedure based upon equations b-g. First, however, a subproblem is defined and a solution procedure is given for the subproblem. A recursive application of the subproblem is then used to solve the original problem.

The subproblem is set up as follows. Substituting equation d in c, the expected delay per demand is given by

$$DEL_{iv} = DEL(S_{iv}, L'_{iv}, R'_{iv})$$

where the stock level  $S_{iv}$ , additional resupply time  $L'_{iv}$ , and additional repair cycle time,  $R'_{iv}$ , are considered as decision variables for an arbitrary item  $i$  and arbitrary location  $v$  in the support system. Suppose that values for  $S_i$  are given for all items and locations  $v$ . The subproblem is to find a particular item and location such that a one unit increase in its stock level will yield the largest decrease in  $DEL_{eu}$  per dollar investment for some user location  $u$ .

The solution of this subproblem is based upon a recognition that the family of functions  $D_{iv}$  are hierarchically related (by equations e and f), each is a function of three decision variables, and functions at the bottom of the hierarchy depend only upon the stock levels,  $S_{iv}$ .

Therefore, a marginal analysis solution procedure can be applied as follows:

Define

$$\Delta_S D_{iv} = D(S_{iv}, L'_{iw}, R'_{iv}) - D(S_{iv} + 1, L'_{iv}, R'_{iv}) ;$$

$$\Delta_L D_{iv} = D(S_{iv}, L'_{iv}, R'_{iv}) - D(S_{iv}, L'_{iv}^*, R'_{iv}) ;$$

$$\Delta_R D_{iv} = D(S_{iv}, L'_{iv}, R'_{iv}) - D(S_{iv}, L'_{iv}, R'_{iv}^*) ;$$

where

$L'_{iv}^*$  = least value of  $L'_{iv}$  obtainable by a unit increase in stock of some part  $w_{ei}$  at the supply source for  $v$ ;

$R'_{iv}^*$  = least value of  $R'_{iv}$  obtainable by a unit increase in stock of some part  $r_{ei}$  at location  $v$ .

Letting  $w^*$  represent the part which satisfies  $L'_{iv}^*$  and  $r_{iv}^*$  the part which satisfies  $R'_{iv}^*$ , find the largest of

(a)  $\Delta_S D_{iv}/c_i$ , (b)  $\Delta_L D_{iv}/c_{w^*}$ , and (c)  $\Delta_R D_{iv}/c_{r^*}$  ;

and let

$$\begin{aligned} D_{iv}^* &= D(S_{iv} + 1, L'_{iv}, R'_{iv}) ; \\ &= D(S_{iv}, L'_{iv}^*, R'_{iv}) ; \\ &= D(S_{iv}, L'_{iv}, R'_{iv}^*) ; \end{aligned}$$

according to which of (a), (b), or (c) is largest, respectively.

With the above definitions and using equations b, e, and f, a recursion is given by:

$$L'_{iv}^* = D_{iz}^* \quad (z = \text{supply source for } v);$$

$$R'_{iv}^* = \left( \sum_{j \in i} Y_{jv} M_{jv} + Y_{jv} M_{jv}^* \right) / \sum_{j \in i} Y_{jv};$$

$$M_{jv} = D_{jv}^* + R_{jv};$$

where  $j$  identifies parts within  $i$  at the next lower indenture, and  $j' = r^*$  or contains  $r^*$  as a lower level part. The recursion is initiated for items  $i$  and the location  $v$  where  $L'_{iv}$  and  $R'_{iv}$  are both zero and hence  $D_{iv}^* = D(S_{iv} + 1)$ .

Justification that this procedure solves the subproblem follows from convexity properties of the functions  $D_{iv}$ . The solution to the original problem is given by repeated application of the subproblem.

If the solution to the subproblem results in the availability target or budget target being met or exceeded, the original problem is solved. Otherwise a new subproblem is solved to find the next item which will result in the largest decrease in DEL per dollar investment. This process continues to build up the stockage levels until one of the two targets has been achieved.

Unlike the RIMAIR and ASO models, which were subroutines of TIGER, ACIM was run as a separate program using batch processing. The ACIM program is made up of three

subprograms that operate in sequence. The first program (Preprocessor) calculates stockage levels according to designated comparison policies. The second (Main) program of the model calculates levels according to ACIM. Stockage levels calculated by the first and second programs are passed to the third program (Postprocessor) which produces three output reports: a cost-effectiveness report, a levels by items summary, and a statistical summary report.

### 3. Input Data

Input data for ACIM is organized in the following three data sets:

#### Systems Factors

Format A - Options and Default Values  
Format L - Site data

#### Item Data - Format I

One other data set can be used as an option, the Additional Item Data set, which further defines individual parts with respect to MSRT and repair cycle times, and also provides for user inserted site provisioning stocks at up to ten sites. Data elements for each of the three data sets along with an example of each record are provided on the following pages.

Format A - Options and Default Values. There is one record in this format. Figure 5.1 shows the Format A data elements along with a sample record. Data elements are defined as follows:

Format A - Option and Default Value Data Elements

| <u>COLS</u> | <u>DATA ELEMENT</u>        | <u>UNITS</u> |
|-------------|----------------------------|--------------|
| 1           | Format Identification (A)  |              |
| 3-16        | Run identification         |              |
| 18-27       | Run options                |              |
| 28-31       | Equipment MTTR             | Days         |
| 32-35       | Availability target        | Fraction     |
| 37-43       | Investment target          | \$000        |
|             | C-E Report Controls        |              |
| 45-47       | Units                      |              |
| 48-51       | Availability               | Fraction     |
| 52-56       | Investment                 |              |
| 58-59       | Part number field size     |              |
|             | User MSRT                  |              |
| 62-65       | Navy                       | Days         |
| 66-69       | DLA                        | Days         |
| 70-73       | Depot procurement leadtime | Days         |
| 74-76       | Depot repair cycle         | Days         |
| 77-80       | Scrap rate                 | Fraction     |

Format A Record Example

```

A E2C                                .083.999      420
000000000111111111122222222223333333333334444
1234567890123456789012345678901234567890123

```

```

1                                17.517.5 360 83 .10
444444555555555556666666666777777777778
4567890123456789012345678901234567890

```

Figure 5.1. Format A Data Elements and Record Example.

Format Identification. An "A" is inserted in the first column to identify this data as format A.

Run Identification. Text entered in this field is printed at the top of all output reports to identify the particular run of the model.

Options. Entries in these fields control various features or operations of the model. Currently, the first four of the ten option fields are defined as follows:

- a. MEC input type.
- b. MEC use.
- c. Default MSRT.
- d. Levels format.

Equipment MTTR. Enter MTTR in days. This is the time required to accomplish the repair assuming all required repair parts are immediately available.

$A_0$  Target. Enter the operational availability target as a fraction (including the decimal point). The model will build up stockages until this target or the investment target is reached. Enter .99 if reaching the investment target first is desired.

Investment Target. Enter the investment target, in thousands of dollars, in this field. Enter a large number (e.g., "9" in all columns) if reaching the  $A_0$  target first is desired.

Cost Effectiveness. These fields are used to control the production of the Cost-Effectiveness Report. As a unit

is added to stock, a line of data may appear on the Cost-Effectiveness Report if any one of the conditions based upon the following data occurs:

a. Delta Units. A line of data is produced for every nth unit added to stock, where n is specified in this field.

b. Delta  $A_0$ . A line of data is produced whenever the achieved  $A_0$  exceeds an integral multiple of this value.

c. Delta \$. A line of data is produced whenever the achieved investment first exceeds an integral multiple of this value.

Part Number Field Size. In the Part Number/Nomenclature field of the Item Data Records, the left-hand side is used for Part Number and right-hand side is used for Nomenclature. The number of positions used for the Part Number is specified in this field.

Response Times. The average length of time, in days, required for a user of the equipment to obtain resupply from a higher supply source. One entry is for Navy COG items and one for DLA COG items. CNO current policy is to enter a value of 17.5 days for both items.

Depot PLT. A default value for depot procurement lead time (total time required to procure material from a manufacturer) is entered here, in days. This value is used whenever the PLT field in the Additional Item Data file is left blank.

Depot Repair Cycle. A default value for the depot repair cycle, in days, is entered in this field. This value is used whenever the depot repair cycle field in the Additional Item Data file is left blank.

Scrap Rate. A standard scrap rate is entered in this field as a fraction (e.g., 0.05). This is used as a default whenever the corresponding field in the Additional Item Data file is left blank.

Format L - Site Data. There is one record in the "L" format for each different kind of user or higher level maintenance/supply activity in the support system for the equipment. Figure 5.2 shows the Format L data elements along with a sample record. In this study only one level is examined, and so only one Format L Record is entered.

Identification. An "L" is entered in column 1 to identify this format.

Site Name. Enter any text that identifies the site.

Indenture Level. Enter 1 for a single echelon case.

Echelon Code. Enter 0 for organization site.

Stockage Facility. Enter any mark if the site maintains inventory levels. For this study the carrier maintains inventory.

Repair Facility. Enter any mark if the site performs maintenance. For this study the carrier AIMD performs it.

# Format L - Site Data Elements

| <u>COLS</u> | <u>DATA ELEMENT</u>       | <u>UNITS</u> |
|-------------|---------------------------|--------------|
| 1           | Format Identification (L) |              |
| 3-16        | Site Name                 |              |
| 18          | Indenture Level           |              |
| 20          | Echelon Code              |              |
| 22          | Stockage facility         |              |
| 24          | Repair facility           |              |
| 26-29       | Lead time                 | Days         |
| 31-34       | Repair Cycle              | Days         |
| 36-38       | No. of locations          |              |
| 40-42       | No. of equipments         |              |
| 44-45       | Comparison policy         |              |
| 47-48       | ACIM Policy               |              |
| 50-54       | Availability target       | Fraction     |
| 56-69       | Operating factor          | Fraction     |
| 61          | Levels output format      |              |

## Format L Record Example

```

L CVN          1 0 X          1
0000000001111111111222222222233333333334
1234567890123456789012345678901234567890

  1  2  0
4444444445555555555666666666677777777778
1234567890123456789012345678901234567890

```

Figure 5.2. Format L Data Elements and Record Example.

Lead Time. The average length of time required, in days, for this site to obtain resupply from a higher supply source assuming that supplies are immediately available at the supply source. Enter 17.5 days.

Repair Cycle. Enter the average repair cycle, in days, for items that are normally repaired at this site.

Number of Locations. Enter the number of different users at this site (one for this study).

Comparison Policy. Not Applicable.

ACIM Policy. Code "O" for Optimization (ACIM starts all stocks at zero).

Operating Factor. Leave blank.

Levels Output Format. Leave blank.

Format I - Item Data. There is one record of this format in the Item Data file for each item in the equipment parts breakdown. The first record must always represent the equipment as a whole. Figure 5.3 shows the Format I data elements along with a sample record. The data elements are defined as follows:

Identification. Enter an "I" to identify this format.

Reference Number. The entry in this field is used to identify the item and its position in the parts breakdown of the equipment. Optional entry.

Indenture. The first record, representing the equipment as a whole, must have an Indenture Code of 1. All candidates

# Format I - Item Data Elements

| <u>COLS</u> | <u>DATA ELEMENTS</u>        | <u>UNITS</u> |
|-------------|-----------------------------|--------------|
| 1           | Format identification (I)   |              |
| 2-11        | Reference number            |              |
| 12          | Indenture                   |              |
| 14-42       | Part number/nomenclature    |              |
| 43-44       | Cognizance                  |              |
| 45-50       | Number per next higher assy | \$/cents     |
| 60-64       | SMR&R codes                 |              |
| 65-71       | Best Replacement factor     | per year     |
| 72-75       | Minimum Replacement unit    |              |
| 76          | Military essentiality code  |              |
| 77          | Override code               |              |
| 78          | Override amount             |              |

## Format I Record Example

```

1          1072          HF POWER AMP
000000000111111111122222222223333333333
123456789012345678901234567890123456789

```

```

1R 6      3494000 0G 8.4050      11
44444444445555555555666666666677777777778
01234567890123456789012345678901234567890

```

Figure 5.3. Format I Data Elements and Record Example.

after the first should be assigned a code of 2.

Part Number. Enter the NIIN/NICN or other part or stock number for item identification purposes. Part number field size is defined in Format A. The rest of the field entries are for Nomenclature.

Nomenclature. Enter textual data that identifies or describes the item.

Cognizance Code. Enter a code identifying the management cognizance of the item.

Number Per Next Higher Assembly. Enter the number of units of the item in the equipment.

Unit Cost. Enter the estimated unit procurement cost of the item in dollars and cents. There is an implied decimal point between columns 57 and 58 (cents occupy columns 58-59).

SM&R Codes. The Source, Maintenance and Recoverability codes are given. Entries for the maintenance codes are mandatory, others are optional.

Application Replacement Factor. Enter the actual anticipated number of times that the item will be replaced during one year of operation. This value represents an average over all items (of this type) in the system.

Minimum Replacement Unit (MRU). Enter a value for the MRU if different than 1. For this study 1 was used.

Military Essentiality Code (MEC). Enter a 1.

Override Code. The only override code used was Y, which was assigned to indenture level 1 equipment (total system). This code includes the item in all model processes but a zero stock level is assigned.

Override Quantity. Not applicable.

### C. MODEL LIMITATIONS

The ACIM model is the most flexible model of the three inventory models discussed so far. ACIM's flexibility lies in its ability to solve either of the following problems for multi-echelon or single echelon supply systems:

1. Select a minimum cost collection of spares for a system so that the system will achieve a given availability target.

2. For a given budget select a collection of spares that will produce maximum availability for the system.

For this study ACIM was usually operated with a budget constraint. This was primarily due to the fact that the RIMAIR algorithm provided for control of the budget only. Therefore, the two models were compared on a equal budget basis. After running ACIM at a specific budget level the resulting inventory levels are manually input into the input data file for the TIGER simulation model.

ACIM, like the other two models, is a steady-state model. This means that the model operates on the assumption that all flows through the repair and requisition

pipelines have stabilized. The inventory system is assumed to be operating at a constant rate over a long period of time. This means that the model cannot be used to investigate surge demand periods.

This model does have a few computational approximations that should be noted. The first concerns ACIM's approximation of availability. ACIM assumes that no failures can occur after the first failure occurs. In actual aircraft systems, a single part failure will usually only degrade the system performance rather than cause the entire system to shut down. Parts usually continue to operate and continue to experience failures after one part fails. In addition, the process of minimizing MSRT does not yield the same stockage decisions as maximizing availability. For some systems the results may be similar, but for other systems there may be large differences.

Another peculiarity of the model is that it assumes that the yearly operating tempo input for a system represents operating tempo per "available year". For example, if an aircraft is scheduled for 1000 flight hours per year and 50% availability target is assigned, ACIM tacitly assumes it flies 500 hours per year.

When using the ACIM model to match a target budget (or availability), the iterative process only approximates the target goal. The ACIM algorithm will always exceed the target because it adds an item to the inventory until the

target is reached. Due to the discrete nature of the problem, the budget goal may be exceeded by an amount almost equal to the least expensive part; and that may be significant.

The ACIM model does present a significant increase in the workload required for data input. The exact topdown breakdown of parts, parts parameters, and maintenance facility information is required. Nevertheless, ACIM appears to be a useful tool and can be expanded to encompass many repair facilities at different levels, handling inventory problems of very complex systems.

## VI. TEST RESULTS

### A. INTRODUCTION

This chapter presents TIGER simulation results evaluating availability performance using inventory levels generated by the three models. The parts used for this evaluation were arranged in two systems which had identical part lists but which had different configurations.

The three inventory models were examined in three scenarios. The three topics to be covered are:

Fixed Budget. Achieved AVCAL availability is compared among the three inventory models, using a fixed budget constraint for each model.

Variable Budget. Availability is compared between the RIMAIR and ACIM models, while varying the budget over a range of values.

Variable MSRT. The ACIM model availability is analyzed with a variable MSRT parameter.

For each of the three tests it was assumed that spares decisions would be made for three identical aircraft systems. Availability would be computed for a period of ninety days, with each aircraft flying a total of 540 hours during the period. Each day was divided into the following four phases: a 3 hour flight phase, a 9 hour repair phase, a 3 hour flight phase, and a 9 hour repair phase. Aircraft

operated simultaneously during the flight phase, and were repaired simultaneously during the repair phase. This was considered an artificiality that was forced on the author by the nature of the TIGER simulation program (more realistic simulation would allow the aircraft to fly at different times during the day). For each test run, 25 iterations were done.

The system was composed of eight different part types with a total of fourteen individual parts. The size of the system and the number of aircraft used were limited by the TIGER program and by computer time limitations. Table III lists the part parameters according to part type.

TABLE III  
Part Parameters

| Part Type | Unit Cost | # Per A/C | BCM Rate | MTBF |
|-----------|-----------|-----------|----------|------|
| 1         | 34940     | 2         | 0.103    | 257  |
| 2         | 13670     | 2         | 0.180    | 352  |
| 3         | 10550     | 1         | 0.105    | 658  |
| 4         | 21930     | 1         | 0.247    | 667  |
| 5         | 37500     | 3         | 0.112    | 272  |
| 6         | 3520      | 1         | 0.238    | 699  |
| 7         | 38850     | 1         | 0.118    | 196  |
| 8         | 5060      | 3         | 0.258    | 1124 |

Note: BCM Rate is fraction of repairs that result in BCM action. MSRT in days.

Aircraft parts were arranged in two different configurations, corresponding to system configurations defined in OPNAVINST 5442.4H. The first configuration places the parts in series, corresponding to aircraft mission Code C, Full Fleet Defense. As defined in this mission, all WRA's are required to be in an operational (up) status for the aircraft to be capable of performing its mission. The second configuration corresponds to aircraft mission Code D, Expanded AAW Control. Here the requirements for WRA operational availability are more complex than the series layout. Basically there is some redundancy built into the second system, referred to as the parallel system, shown in Figure 6.1.

System Configuration (By Part Type) for Mission Code D

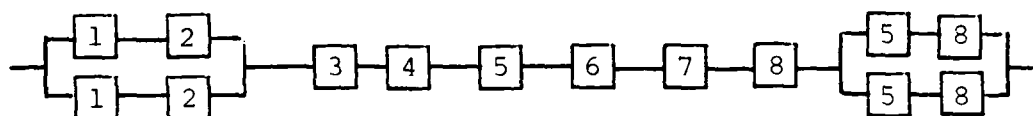


Figure 6.1. System Configuration (Mission Code D).

Aircraft parts were chosen from part candidates in the E-2C aircraft under the following criteria:

- \* Each part comprised an individual WRA.
- \* Each part was listed on the E-2C Mission Essential Subsystem Matrices (MESM).
- \* Most parts had low MTBFs.
- \* Each part was coded for removal at the 0 level and repair at the I level.

#### B. FIXED BUDGET ANALYSIS

The object of this portion of the study was to examine the effectiveness of the individual inventory models when all three models were constrained to the same budget level. The variable inputs to the TIGER program were the different AVCAL levels computed by each inventory model. Using TIGER generated aircraft availability, the capabilities and weaknesses of each model algorithm were examined. Both the series and parallel system configurations were used with each of the three inventory models.

A serious attempt was made to ensure that the three models were compared on an equal basis. This proved to be a difficult problem because of the differences among the models. The major difficulty was trying to equate the part parameters across the three models. The RIMAIR and ASO models are very similar so the parameters were matched for these two models first. Both models are subroutines of the TIGER program, and both use the same data input file. The ACIM model parameters were then matched to the ASO/RIMAIR parameters.

Since the ACIM model recommended using a benchmark value of 17.5 days for MSRT, this value was converted to hours (420) and used for both the Order and Shipping Time and the Repair Time in the RIMAIR/ASO models (SRTIM and REPTIM variables in TIGER). ACIM does not utilize these separate pipeline times, but only considers a single supply delay time (MSRT). A Mean Time to Repair equal to 0.083 days was input for ACIM, and the equivalent (2.0 hours) was input to TIGER. All other parameters were as listed in Table III.

The next step was to generate AVCAL stock levels for all three models at a fixed budget level. This was accomplished by first using the ASO algorithm to arrive at a benchmark budget level. Using the parameters discussed above, the total ASO inventory cost was \$673,280. Next the RIMAIR model was run, varying the lambda value to arrive at a total inventory cost that was close to the ASO budget. The total RIMAIR inventory cost was \$668,700 (within 1% of ASO budget). The ACIM target budget was set to a value equal to that of the ASO budget, and the ACIM model arrived at a total inventory cost of \$675,300.

The resulting availability figures for both system configurations are summarized in Table IV. The effectiveness of both the RIMAIR and ACIM models appears to be better than that of the ASO model. ACIM seems to perform better in the

series system than RIMAIR, with both about equal in the parallel system.

TABLE IV  
Fixed Budget Summary

| Model  | Budget    | No. of Parts Stocked by Type |   |   |   |   |   |   |   |
|--------|-----------|------------------------------|---|---|---|---|---|---|---|
|        |           | 1                            | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| ASO    | \$673,280 | 5                            | 5 | 1 | 1 | 7 | 1 | 3 | 3 |
| RIMAIR | \$668,700 | 4                            | 5 | 2 | 3 | 5 | 3 | 4 | 4 |
| ACIM   | \$675,300 | 5                            | 5 | 2 | 2 | 6 | 3 | 3 | 3 |

#### Model Availability

| Model  | Series |        | Parallel |        |
|--------|--------|--------|----------|--------|
|        | AVA    | AVMUP  | AVA      | AVMUP  |
| ASO    | 0.5643 | 0.5304 | 0.6963   | 0.6788 |
| RIMAIR | 0.6358 | 0.5950 | 0.8562   | 0.8348 |
| ACIM   | 0.7611 | 0.7129 | 0.8312   | 0.8120 |

The poor performance of the ASO model in comparison to the other two models can be explained by examining the inventory decisions made by the ASO algorithm. First, the critical parts of the series system are found by examining the Critical Equipments list on the ASO model TIGER output. The results of this list are summarized along with a part budget breakdown in Table V. The two most obvious oversights are denoted by the starred rows. ASO spent only 2.09% of the

total budget on part types #3 and #6. Yet these two part types together accounted for 37.08% of the total unavailability of the system. The ASO model failed to observe that these two lower priced, high MTBF WRAs were availability bargains compared to the more expensive, low MTBF WRAs, such as part type #5.

TABLE V  
Critical Equipments Analysis of the ASO Model

| Part Type | Part Cost | # Stocked/<br>% Total Budget | Part Contribution To<br>System Unavailability |
|-----------|-----------|------------------------------|-----------------------------------------------|
| 3         | \$10550   | 1 / 1.57%                    | 21.48% *                                      |
| 7         | \$38850   | 3 / 17.31%                   | 15.98%                                        |
| 6         | \$ 3520   | 1 / 0.52%                    | 15.60% *                                      |
| 1         | \$34940   | 5 / 25.95%                   | 15.25%                                        |
| 5         | \$37500   | 7 / 38.99%                   | 13.52%                                        |
| 4         | \$21930   | 1 / 3.26%                    | 11.39%                                        |
| 2         | \$13670   | 5 / 10.15%                   | 5.76%                                         |
| 8         | \$ 5060   | 3 / 2.25%                    | 1.02%                                         |

Further analysis of the individual ASO stock levels shows that part types #3, #4, and #6 were stocked to a level of only one unit. These three parts qualified for a single spare each under the rotatable pool criteria, but none of the parts qualified for a spare under the attrition allowance portion of the AVCAL. This minimum stock level for these three parts was the major contributor to the poor performance of the ASO model. The ASO model failed to include unit cost

or cost effectiveness tradeoff analysis in computing stock levels, instead inventory levels were decided totally on the basis of MTBF and TAT.

For each case studied, the computed measure of availability, AVA, was several percentage points higher than AVMUP. As noted in Chapter II, AVMUP measures only the availability of the system during flight hours. AVMUP does not consider the operational status of the system during the repair (ondeck) phase. For the next two topics, AVMUP will be used as the primary measure of effectiveness.

#### C. VARIABLE BUDGET ANALYSIS

In the previous section each AVCAL model was studied at a single specified budget level. A more important question concerns the performance of these models over a range of budget levels. With an increase or decrease in budget level, the decision maker must adjust AVCAL levels accordingly. The ASO model was not included in this analysis since it does not lend itself easily to a variable budget analysis and because the ASO Manual does not provide any guidance for adjusting levels. It was also decided that the lack of any cost effectiveness measures in the ASO algorithm would cause the model to perform poorly at all budget levels.

With only the RIMAIR and ACIM models to compare, the test was arranged as follows. Part parameters remained as depicted in Table III, and mission times also remained the same.

Budget levels were varied from the benchmark budget used in VI.B above. Using the benchmark budget of \$668,700 as 100%, test budgets were varied from a low of \$521,810 (63%) to a high of \$797,370 (119%). As before, the RIMAIR model was run first, varying the lambda value to arrive at an appropriate budget level. Using the resulting RIMAIR budget as a target budget, ACIM was then run. Inventory levels computed at each budget level are summarized in Table VI.

Using these inventory levels, model effectiveness was studied using both the series and parallel systems. Table VII summarizes system availability (AVMUP) for both models over the range of budgets. Budget percentages listed are those from the RIMAIR case. The average difference between the RIMAIR budget and the ACIM budget was 0.63%, with a maximum difference of 1.11%.

The results of this test were that both inventory models achieved similar operational availability. At lower level budgets the RIMAIR model did somewhat better than the ACIM model. Starting at about 80% of the benchmark budget level, ACIM performed equally well, and sometimes better. ACIM performed much better than RIMAIR at the 100% level for the series system. Considering the variability of the TIGER outputs, no model could be considered superior for all budget levels.

TABLE VI  
AVCAL Stock Levels For Variable Budget

RIMAIR Model

| Total Cost<br>AVCAL | % Benchmark<br>Budget | Stock Level By Part Type |   |   |   |   |   |   |   |
|---------------------|-----------------------|--------------------------|---|---|---|---|---|---|---|
|                     |                       | 1                        | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| \$423,210           | 63.29 %               | 3                        | 3 | 2 | 2 | 3 | 2 | 2 | 3 |
| \$521,810           | 78.03 %               | 3                        | 4 | 2 | 2 | 4 | 3 | 3 | 4 |
| \$578,680           | 86.54 %               | 4                        | 4 | 2 | 3 | 4 | 3 | 3 | 4 |
| \$629,850           | 94.19 %               | 4                        | 5 | 2 | 3 | 5 | 3 | 3 | 4 |
| \$708,700           | 105.98 %              | 5                        | 5 | 2 | 3 | 5 | 3 | 4 | 5 |
| \$759,870           | 113.63 %              | 5                        | 6 | 2 | 3 | 6 | 3 | 4 | 5 |
| \$797,370           | 119.24 %              | 5                        | 6 | 2 | 3 | 7 | 3 | 4 | 5 |

ACIM Model

| Total Cost<br>AVCAL | % Benchmark<br>Budget | Stock Level By Part Type |   |   |   |   |   |   |   |
|---------------------|-----------------------|--------------------------|---|---|---|---|---|---|---|
|                     |                       | 1                        | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| \$423,170           | 63.28 %               | 3                        | 3 | 1 | 1 | 4 | 2 | 2 | 2 |
| \$524,890           | 78.49 %               | 4                        | 4 | 2 | 1 | 5 | 2 | 2 | 3 |
| \$585,670           | 87.58 %               | 4                        | 4 | 2 | 2 | 5 | 2 | 3 | 3 |
| \$626,690           | 93.72 %               | 4                        | 4 | 2 | 2 | 6 | 3 | 3 | 3 |
| \$714,150           | 106.80 %              | 5                        | 5 | 2 | 2 | 6 | 3 | 4 | 3 |
| \$767,260           | 114.74 %              | 5                        | 5 | 3 | 2 | 7 | 3 | 4 | 4 |
| \$802,200           | 119.96 %              | 6                        | 5 | 3 | 2 | 7 | 3 | 4 | 4 |

D. VARIABLE MSRT ANALYSIS

For this portion of the study, the MSRT input to the ACIM model was varied in order to investigate the effect of a variable resupply and repair time on the effectiveness of a fixed budget inventory model. This analysis did not include the RIMAIR model because of the difficulties invo

TABLE VII

## RIMAIR vs. ACIM Performance For Variable Budget

| % Benchmark<br>BUDGET | SERIES AVMUP |        | PARALLEL AVMUP |        |
|-----------------------|--------------|--------|----------------|--------|
|                       | RIMAIR       | ACIM   | RIMAIR         | ACIM   |
| 63.29 %               | 0.3657       | 0.2960 | 0.6334         | 0.5152 |
| 78.03 %               | 0.4519       | 0.4461 | 0.7678         | 0.5696 |
| 86.54 %               | 0.5391       | 0.5579 | 0.7591         | 0.7941 |
| 94.19 %               | 0.6089       | 0.6029 | 0.8378         | 0.7867 |
| 100.00 %              | 0.5950       | 0.7129 | 0.8348         | 0.8120 |
| 105.98 %              | 0.6821       | 0.7552 | 0.8678         | 0.8824 |
| 113.63 %              | 0.7122       | 0.7733 | 0.8343         | 0.8850 |
| 119.24 %              | 0.7964       | 0.7764 | 0.8813         | 0.8741 |

with keeping RIMAIR's budget constant while the supply times were being varied. Each time the supply time was changed in the RIMAIR model, a new lambda value had to be found to keep the inventory cost near the target budget. This proved extremely difficult because of the sensitivity of the lambda value to changes in supply time.

The methodology used for this test was as follows. The MSRT input parameter in ACIM was varied from 12 to 41 days, while maintaining a constant target budget of \$544,000. Inventory levels were computed and then run on the TIGER program. TIGER parameters for repair and resupply times were matched to the corresponding MSRTs used in the ACIM program. System availability was analyzed for the series system only.

The ACIM Statistical Summary Report includes an achieved operational availability figure that theoretically could be achieved for a series system, given the inventory levels selected. These availability predictions, along with availabilities calculated from TIGER simulations, are compared in Table VIII. Several items should be noted regarding these results. ACIM projected availability is overly optimistic for low MSRT values, and then underestimates availability for high MSRT values.

Nother noteworthy item was that the ACIM AVCAL stock levels varied slightly depending on the MSRT. When MSRT was increased, inventory levels for part types #4 and #7 decreased by one unit each, while part types #2 and #5 increased by 1 unit and 2 units respectively. The reason for this change is not clear. Once again it was observed that ACIM only approximates its target budget. As MSRT increased, ACIM overshot its target by a greater margin. Initially ACIM was within \$4,000 of target, but this margin jumped to \$32,000 (6% over target) at the maximum MSRT value of 41 days.

TABLE VIII

## ACIM Performance For Variable MSRT

| MSRT<br>(DAYS) | ACIM Forecast<br>Availability | TIGER<br>AVMUP | AVCAL By Part Type |   |   |   |   |   |   |   |
|----------------|-------------------------------|----------------|--------------------|---|---|---|---|---|---|---|
|                |                               |                | 1                  | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 12             | 0.7922                        | 0.6821         | 4                  | 4 | 2 | 2 | 4 | 2 | 3 | 3 |
| 17.5           | 0.607                         | 0.5359         | 4                  | 4 | 2 | 1 | 5 | 2 | 3 | 3 |
| 24             | 0.365                         | 0.3422         | 4                  | 4 | 2 | 1 | 5 | 2 | 3 | 3 |
| 30             | 0.224                         | 0.2953         | 4                  | 4 | 2 | 1 | 5 | 2 | 3 | 3 |
| 36             | 0.145                         | 0.3086         | 4                  | 4 | 2 | 1 | 6 | 2 | 2 | 3 |
| 41             | 0.112                         | 0.2535         | 4                  | 5 | 2 | 1 | 6 | 2 | 2 | 3 |

Note: ACIM Target Budget = \$544,000  
 12 Day MSRT Inventory Cost = \$548,000  
 41 Day MSRT Inventory Cost = \$576,000

## VII. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

### A. SUMMARY AND CONCLUSIONS

Three areas of study were covered in testing inventory model effectiveness. The first area, fixed budget analysis, showed dramatic differences in model effectiveness. Budget allocation for the ASO model was much less efficient than either the RIMAIR or ACIM models. The ASO model, unlike the other two, made no attempt to determine optimum allocation of monetary resources. The ASO model also has no provisions to increase or decrease inventory levels according to budgetary constraints, except by manual additions or deletions to individual part stocks.

Examination of the Critical Equipments Summary of TIGER was useful in discovering inventory model weaknesses. This summary provides a list of parts that contribute to system downtime. Parts are listed according to the percentage of downtime that each part contributed. By matching these downtime percentages against part budget allocation percentages, inventory decisions can be evaluated.

The second area of study examined the RIMAIR and ACIM models in a variable budget analysis. Budget levels were varied from 63% to 120% of a benchmark budget level. Results of this test were inconclusive. Neither model showed complete

superiority at all budget levels. Similarities were noted in individual part stock levels of both models, resulting in similar availability statistics.

The third area of study concentrated on what effects varying MSRT had on ACIM effectiveness. Test results generally agreed with inventory theory. Availability decreased as MSRT was increased from 12 to 41 days. ACIM calculated availability differed from that derived in the TIGER simulation. Also noteworthy was the change in individual part stock levels as MSRT was increased. With a fixed target budget, ACIM had different part priorities depending on the length of MSRT.

This thesis investigated inventory model effectiveness as measured by aircraft system operational availability (AVMUP). One advantage to the use of AVMUP was that it allowed for simulated operation of aircraft systems in a degraded mode. That is, if one WRA failed the rest of the system WRAs continued to operate even if the system was in a down status. For complex aircraft systems the assumption of independent failures may not be a completely correct one, but it allows for simpler calculations.

Some of the advantages and disadvantages of each of the three inventory models are summarized below:

ASO Model.

Advantages.

1. Easy input data preparation.
2. Simple algorithm to determine stock levels (included as subroutine in TIGER).

Disadvantages.

1. Does not optimize budget allocation.
2. No provision for increasing or decreasing inventory levels to match budget constraints.
3. Separates pipeline demand into two parts. Low failure rate items may not qualify under either separate criteria.

RIMAIR Model.

Advantages.

1. Inventory levels can be varied to match budget constraints.
2. Provides protection for more portions of the inventory pipeline system than the ASO model.
3. Essentiality code allows for weighting of parts according to their relative criticality.

Disadvantages.

1. Lengthy process involved in changing lambda values to meet budget target when more than one model parameter is varied.
2. Model inherits weaknesses of ASO model because of identical model assumptions.
3. Without a comprehensive essentiality coding scheme, the optimization process only maximizes gross supply effectiveness. This process does not necessarily result in maximum availability.

#### ACIM Model.

##### Advantages.

1. Powerful model which has the capability to compute multi-echelon inventories for multi-indentured systems.
2. Stock levels can be determined for an availability target or a budget target.
3. Attempts to conform to recent CNO directives concerning inventory policies, especially maximizing availability.

##### Disadvantages.

1. Complicated algorithm is used to determine inventory stock levels.
2. Does not differentiate between repair and requisition pieplines.
3. Assumes that failure of one part results in shutdown of all other parts in system.
4. Optimization process only approximates maximization of availability by minimizing MSRT.

#### B. RECOMMENDATIONS

The TIGER model proved to be a capable evaluation tool, although it did have several limitations. Aircraft systems had to be simulated as if they were operated simultaneously. A more realistic simulation would allow for the overlapping of operating cycles. Sort routines in the TIGER TTE subroutine are not efficient and need to be improved. There are many TIGER calculations repeated every mission which are

not always applicable, but there is no easy method to eliminate these unnecessary steps. Input data preparation for TIGER can be tedious, especially for system configuration cards of complex systems.

Integration of the ASO and RIMAIR AVCAL inventory models into the TIGER model allowed for automatic AVCAL determination and simulation. Changes need to be included in the RIMAIR program to permit automatic adjustment of inventory levels to meet budget constraints. Manual adjustments of the lambda value to control budget levels was a slow process that prevented broader testing of the RIMAIR model.

Comparison of inventory model effectiveness must be done with some reservations. All three models assume steady-state inventory flows. The simulations were done in a manner to accommodate these assumptions. Different results may occur if surge demands or cyclic patterns are introduced into the simulation.

Another reservation involves the limited number of system configurations used in this study. None of the three inventory models take into account the configuration of the system. Additional research needs to be done to determine what effects alternate system configurations have on model inventory decisions. More study also needs to be done on the utilization of the item essentiality code parameters of the ACIM and RIMAIR models.

## APPENDIX A

### TIGER DATA CARD FORMATS

The following card formats were utilized in this study. Most cards remain unchanged from the TIGER Manual, but some new cards are presented. Sample input data files are presented in appendices B and C. All data is entered in 80 column, card/card-image format. Data types are real, integer, and alphanumeric. All integer data fields must be right justified. Variable names listed are those that appear in this version of TIGER.

### 1. RIMAIR Parameter Card

New Card. Provides parameters for RIMAIR model algorithm. Budget parameter was not used. Essentiality code (ESS) was set to 1.0. Resupply delay time (RET) set to 0.

| Columns | Format | Variable | Description                                                                                                        |
|---------|--------|----------|--------------------------------------------------------------------------------------------------------------------|
| 1-4     | I4     | NTOTA    | Total no. of part types per A/C                                                                                    |
| 5-8     | F4.0   | XFLAG    | Used to select inventory policy:<br>0.0-Manual input of stock levels<br>1.0-ASO MANUAL policy<br>2.0-RIMAIR Policy |
| 9-16    | F8.0   | BUDGET   | Maximum budget constraint                                                                                          |
| 17-31   | F15.12 | EL       | Lagrange multiplier                                                                                                |
| 32-36   | F5.3   | ESS      | Essentiality code                                                                                                  |
| 37-42   | F6.0   | RET      | Resupply delay time                                                                                                |

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### 2. Part Parameter Card.

New Card. One card is entered for each type equipment, I.

| Columns | Format | Variable | Description                    |
|---------|--------|----------|--------------------------------|
| 1-8     | F8.2   | COST(I)  | Equipment unit cost.           |
| 9-16    | F8.0   | SRTIM(I) | Off-ship order & shipping time |
| 17-21   | I4     | NPET(I)  | No. of parts of type I per A/C |
| 22-30   | F8.4   | BCM(I)   | Fraction of parts BCM'ed       |

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### 3. Flight Hours Data Card.

JTIME is the total time in a 90 day period that an A/C is expected to fly.

| Columns | Format | Variable | Description                                      |
|---------|--------|----------|--------------------------------------------------|
| 1-8     | I8     | JTIME    | Total flight times, summed over a 90 day period. |

#### 4. Timeline Iteration Card.

| Columns | Format | Variable | Description                                             |
|---------|--------|----------|---------------------------------------------------------|
| 1-4     | I4     | JCC      | No. of timeline iterations to be run for the data deck. |
| 5-80    | 19A4   | RUNID    | Alphanumeric run identifier.                            |

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#### 5. Statistical Parameter Card.

To run a predetermined # of missions, set NOPT & NMAX equal to the no. of missions, and PL = 1.0. A value of XK = 1.28 corresponds to 90% lower confidence limit.

| Columns | Format | Variable | Description                                            |
|---------|--------|----------|--------------------------------------------------------|
| 1-4     | I4     | NMAX     | Max no. of missions to be run (may not exceed 1000)    |
| 5-8     | I4     | NOPT     | Optimal no. of missions to be run (may not exceed MAX) |
| 9-12    | F4.0   | PL       | Reliability spec. required                             |
| 13-16   | F4.0   | XK       | Std.Dev. for lower conf. limit                         |
| 17-20   | I4     | ISEED    | Random number seed                                     |
| 21-24   | I4     | NPH      | No. of phase types (max of 6)                          |

## 6. Phase Type and Duration Cards.

This card specifies the type of phase and duration of each phase. A phase is time period with both a repair policy and a system operation policy. Two phase types were used: type 1, flight phase; and type 2, ondeck repair phase. One card corresponds to a 24-hour period. Duration is in hours. System is presently configured for four phases per day.

| Columns | Format | Variable | Description                    |
|---------|--------|----------|--------------------------------|
| 1-2     | F2.0   | XXT(1)   | Phase type no. of first phase  |
| 3-8     | F6.0   | XXT(2)   | Duration of first phase        |
| 9-10    | F2.0   | XXT(3)   | Phase type no. of second phase |
| 11-16   | F6.0   | XXT(4)   | Duration of second phase       |
| 17-18   | F2.0   | XXT(5)   | Phase type no. of third phase  |
| 19-24   | F6.0   | XXT(6)   | Duration of third phase        |
| 25-26   | F2.0   | XXT(7)   | Phase type no. of fourth phase |
| 27-32   | F6.0   | XXT(8)   | Duration of fourth phase       |

## 7. Deployment Scenario Card.

This card determines the scenario under which a simulation can be run. The default values will allow TIGER to simulate a mission under the same conditions under which the inventory models will calculate planned inventory levels. So if the ASO model, for example, plans for a 1000 flight-hour quarter with pipeline times equal to ten days, TIGER will simulate a 90 day mission with these same parameters. By changing the default values on this card, inventory levels will be calculated under parameters entered on previous cards, but TIGER will simulate under conditions defined by this card. This permits investigation of inventory policy during periods of abnormally high tempo flight operations or lengthened pipeline times. NDAYS can be varied from 0-90 days. NWAR is a 2-state variable: 0 means previous inventory parameters will be used, 1 means wartime scenario and new parameters will be used. One of the new wartime parameters is BCMFAC, which increases the BCM rate for all parts. Another is REPFAC, which will increase the on-ship repair time for all parts. NTIME will be the higher system operational time for the war scenario, equal to the flight time expected for one A/C in 90 days.

| Columns | Format | Variable | Description                                                                                                           |
|---------|--------|----------|-----------------------------------------------------------------------------------------------------------------------|
| 1-4     | I4     | NDAYS    | Length of scenario (0-90 days)                                                                                        |
| 5-8     | I4     | NWAR     | Sets wartime scenario:<br>0: original parameters (no change)<br>1: new values for SRTIM, BCM & NTIME will be computed |
| 9-12    | I4     | NOAC     | No. of A/C used in scenario                                                                                           |
| 13-16   | I6     | NTIME    | A/C flight hours in wartime                                                                                           |
| 17-21   | F5.1   | BCMFAC   | Fractional change in BCM rate                                                                                         |
| 22-26   | F5.1   | REPFAC   | Fractional change in on-ship repair times during war                                                                  |

# 8. Printout Option Card.

| Columns | Format | Variable | Description                                                                                                                                                                                                                                                                                                             |
|---------|--------|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1-4     | I4     | KOPT     | Printout option switch:<br>1: management summary<br>printout<br>2: engineering summary<br>printout<br>3: complete details<br>printout (for debugging<br>only)<br>4: disables input data<br>printout<br>5: to specify printout<br>using the KS variables<br>(see below)<br>6: TIGER/MANNING complete<br>details printout |

If KOPT=5, select from the following output options as needed (otherwise leave the fields blank)

|       |    |        |                                                       |
|-------|----|--------|-------------------------------------------------------|
| 5-8   | I4 | KS(1)  | = 1: Input data                                       |
| 9-12  | I4 | KS(2)  | = 1: equip. downtime at<br>time of mission<br>failure |
| 13-16 | I4 | KS(3)  | =1: downtime at end of<br>phase                       |
| 17-20 | I4 | KS(4)  | =1: abort messages                                    |
| 21-24 | I4 | KS(5)  | =1: all events                                        |
| 25-28 | I4 | KS(6)  | =1: ETIME matrix                                      |
| 29-32 | I4 | KS(7)  | =1: not used                                          |
| 33-36 | I4 | KS(8)  | =1: not used                                          |
| 37-40 | I4 | KS(9)  | =1: not used                                          |
| 41-44 | I4 | KS(10) | =1: system & subsystem<br>status                      |
| 45-48 | I4 | KS(11) | =1: TIGER/MANNING<br>debugging                        |
| 49-52 | I4 | KS(12) | =1: status of all groups                              |
| 53-56 | I4 | KS(13) | =1: downtime messages                                 |

#### 9. Phase Repair Card.

This study repair option 0 was used to simulate flight ops and repair option 2 simulated A/C on deck under repair.

| Columns | Format | Variable | Description                                                                                                                                                                                      |
|---------|--------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1-4     | I4     | IFLAG(1) | Repair option for each phase type, up to 6:<br>= 0 if onboard repair allowed in the phase<br>= 1 if no on-board repair allowed in the phase<br>= 2 on-board repair allowed but failure inhibited |
| 5-8     | I4     | IFLAG(2) |                                                                                                                                                                                                  |
| 9-12    | I4     | IFLAG(3) |                                                                                                                                                                                                  |
| 13-16   | I4     | IFLAG(4) |                                                                                                                                                                                                  |
| 17-20   | I4     | IFLAG(5) |                                                                                                                                                                                                  |
| 21-24   | I4     | IFLAG(6) |                                                                                                                                                                                                  |

---

#### 10. Repair Policy Card.

REPOL was set to 1.0. Normally it determines what fraction of repairs will be done on-ship. In this study this fraction was determined by BCM(I) instead. TAD2 specifies how long a system can operate in a down state before system failure. For this study mission allowable downtime = 0. XM and XT were set at their default values = 1.0.

| Columns | Format | Variable | Description                                             |
|---------|--------|----------|---------------------------------------------------------|
| 1-4     | F4.0   | REPOL    | Decimal fraction of repairs to be performed aboard ship |
| 5-12    | F8.2   | TAD2     | Mission Allowable Downtime                              |
| 13-16   | F4.0   | XM       | MTBF multiplier                                         |
| 17-20   | F4.0   | XT       | MTTR multiplier                                         |

# 11. Equipment Type Cards.

These cards define the parameters for each type equipment. X is the time to replace a WRA from the A/C if a spare is on hand, arbitrarily set = 2.0 hours. V is used in this study to specify the onboard repair time at the AIMD level.

| Columns | Format | Variable | Description                                                                     |
|---------|--------|----------|---------------------------------------------------------------------------------|
| 1-4     | I4     | I        | Equipment type numbers, to be assigned sequentially, from 1 to a maximum of 200 |
| 5-20    | 4A4    | DUM(J)   | Equipment type description                                                      |
| 21-28   | F8.0   | X        | Mean time between failure                                                       |
| 29-32   | F4.0   | Y        | Mean time to repair/replace                                                     |
| 33-36   | F4.0   | U        | Duty cycle utilization                                                          |
| 37-40   | F4.0   | V        | AIMD part repair time                                                           |
| 41-44   | F4.0   | W        | Admin delay time (depot/ship)                                                   |
| 45-58   | I4     | IDUM     | Not used                                                                        |

# 12. \*\*\* Blank Card \*\*\* (Signals the end of equip. cards)

# 13. Equipment Cards.

These cards, one for each type equipment list individual parts by number, according to the equipment type. The first number is equipment type, the numbers following it on the same line are the individual parts for each type equipment.

| Columns | Format | Variable | Description                                                                                                   |
|---------|--------|----------|---------------------------------------------------------------------------------------------------------------|
| 1-4     | I4     | NTYPE    | The type no. associated with the part numbers following it                                                    |
| 5-8     | I4     | LOAD(1)  | Part numbers, 19 per line max. Numbers begin at 1 and may not exceed 500. No gaps allowed in numbering parts. |
| 9-12    | I4     | LOAD(2)  |                                                                                                               |
| .       | .      | .        |                                                                                                               |
| .       | .      | .        |                                                                                                               |
| 77-80   | I4     | LOAD(19) |                                                                                                               |

14. \*\*\* Blank Card \*\*\* (Signals the end of equipment cards)

---

15. Spares Model Card.

The only option used on this card was "999." (columns 21-24)

| Column | Format | Variable | Description                                                   |
|--------|--------|----------|---------------------------------------------------------------|
| 21-24  | F4.0   | SX       | Used to call Spares sub-routine to determine allowance levels |

---

16. ACIM Inventory Card.

This card will input ACIM allowance levels. If XFLAG=0.0 is selected on card #1, TIGER will simulate with this input. Any arbitrary inventory levels may be input on this line.

| Column | Format | Variable | Description                                                          |
|--------|--------|----------|----------------------------------------------------------------------|
| 1-2    | I2     | ISPARE   | One allowance is entered for each equipment type, up to a max of 31. |
| 3-4    | I2     | ISPARE   |                                                                      |
| .      | .      | .        |                                                                      |
| .      | .      | .        |                                                                      |
| 61-62  | I2     | ISPARE   |                                                                      |

---

17. System Card.

| Columns | Format | Variable | Description                                                                               |
|---------|--------|----------|-------------------------------------------------------------------------------------------|
| 1-4     | A4     | ID       | Any alphanumeric e.g. SYST, to identify the specific system                               |
| 5-8     | I4     | LL       | Phase Type number (sequential) maximum value is 6                                         |
| 9-12    | I4     | NSS      | No. of subsystems in the phase (varies only from 1 to 31)                                 |
| 13-16   | I4     | ISS      | System identification number, usually last group number on the configuration matrix cards |
| 17-24   | F8.0   | SSTIME   | System allowable downtime. 100000 inhibits aborts.                                        |

#### 18. Subsystem Cards.

One for each subsystem - up to 31. At least 1 subsystem is required.

| Columns | Format | Variable  | Description                                                                                                                                                                                           |
|---------|--------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1-4     | A4     | ID        | Any alphanumeric, e.g., the literal SS1, SS2, ...SS31                                                                                                                                                 |
| 5-8     | I4     | LL        | Phase type number                                                                                                                                                                                     |
| 13-16   | I4     | ISS       | Subsystem identification no. This is a group # for a group defined on a Configuration Matrix Card. Each designated subsystem group must be a group that, upon its failure, causes the system to fail. |
| 17-24   | F8.0   | SSTIME(2) | Subsystem allowable sustained downtime. To inhibit aborts use a value of 100000.                                                                                                                      |

---

#### 19. Configuration Matrix Card.

One card for each group, up to 300 cards.

| Columns | Format | Variable | Description                                                                                                     |
|---------|--------|----------|-----------------------------------------------------------------------------------------------------------------|
| 1-4     | I4     | NRO      | No. of members in the group defined on this card that are required to be operating and in an up status.         |
| 5-8     | I4     | IB(1)    | The group no. assigned to the group of members defined on this card. It may vary from 501 to 1000 in any order. |

Configuration cards cont'd.

| Column | Format | Variable | Description                                                                                                                                                                                                                                                                                           |
|--------|--------|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9-12   | I4     | IB(2)    | The numbers of the equipment & groups which make up the group defined on this card. The max. no. of members in a group is unlimited; but if there are more than 7, a continuation card is required of the same format. The no. required and master group must be identical on all continuation cards. |
| 13-16  | I4     | IB(3)    |                                                                                                                                                                                                                                                                                                       |
| 17-20  | I4     | IB(4)    |                                                                                                                                                                                                                                                                                                       |
| 21-24  | I4     | IB(5)    |                                                                                                                                                                                                                                                                                                       |
| 25-28  | I4     | IB(6)    |                                                                                                                                                                                                                                                                                                       |
| 29-32  | I4     | IB(7)    |                                                                                                                                                                                                                                                                                                       |
| 33-36  | I4     | IB(8)    |                                                                                                                                                                                                                                                                                                       |

---

20. \*\*\* Blank Card \*\*\* (Signals the end of phase configuration cards.)

---

NOTE: For each phase type, a set of the above System, Subsystem and Configuration Matrix Cards are entered, each set separated by a blank card.

---

21. Optional Output Card.

| Columns | Format | Variable | Description                                                                                                                                                                      |
|---------|--------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1-4     | A4     | SPRS     | Place any alphanumeric, e.g., SPR, in this field if a table of spares usage is desired.                                                                                          |
| 5-8     | A4     | APPL     | Place any alphanumeric, e.g., APL, in this field if a summary table of equipment that caused mission failures (unreliability) and system down times (unavailability) is desired. |
| 9-12    | A4     | GMMA     | Not used                                                                                                                                                                         |
| 13-16   | A4     | DEMO     | Not used                                                                                                                                                                         |

## APPENDIX B

### TIGER INPUT DATA FOR SERIES SYSTEM

This appendix contains the input data file representing the series system configuration. The TIGER program reads this file and proceeds with the simulation as defined in the data file. Part parameters for Appendix B are identical with those for the parallel system listed in Appendix C. Input data cards 17, 18, and 19 are the only data cards that are different for the series and parallel system data files.

8 0.0 3000.0 0.000007519801.0 0.0  
 34940. 420. 2 0.103  
 13670. 420. 2 0.180  
 17550. 420. 1 0.105  
 21930. 420. 1 0.247  
 37500. 420. 3 0.112  
 3520. 420. 1 0.238  
 38850. 420. 1 0.118  
 5060. 420. 3 0.258

540 1  
 1 ACIM 675K 17C CODE83A 14AUG84  
 25 25 1.01.281234 2  
 1. 3.0 2. 9.0 1. 3.0 2. 9.0  
 90 0 3 540 1.0 1.0

1. 0.00 1. 1.  
 1HF POWER AMP 257. 2. 1. 420.  
 2HF ANT COUPLER 352. 2. 1. 420.  
 3HF RADIO CCNTRL 658. 2. 1. 420.  
 4HF ANT CIU 667. 2. 1. 420.  
 5ARC158 R/T 272. 2. 1. 420.  
 6IFF R/T 699. 2. 1. 420.  
 7IFF CQDR/DECDR 196. 2. 1. 420.  
 8ARC158 FLT CONV 1124. 2. 1. 420.

1 1 2 15 16 29 30  
 2 3 4 17 18 31 32  
 3 5 19 33  
 4 6 20 34  
 5 7 8 21 22 23 35 36 37  
 6 10 24 38  
 7 11 25 39  
 8 12 13 14 26 27 28 40 41 42

999.

5 5 2 2 6 3 3 3 100000.  
 SYST 1 3 888 100000.  
 SS5 1 555 100000.  
 SS6 1 666 100000.  
 SS7 1 777 100000.  
 7 511 1 2 3 4 5 6 7  
 7 522 8 9 10 11 12 13 14  
 2 555 511 522 15 16 17 18 19 20 21  
 7 611 15 16 17 18 19 20 21  
 7 622 22 23 24 25 26 27 28  
 2 666 611 622 29 30 31 32 33 34 35  
 7 711 29 30 31 32 33 34 35  
 7 722 36 37 38 39 40 41 42  
 2 777 711 722  
 3 999 555 666 777  
 1 888 999

SYST 2 3 888 100000.  
 SS5 2 555 100000.  
 SS6 2 666 100000.  
 SS7 2 777 100000.  
 7 511 1 2 3 4 5 6 7  
 7 522 8 9 10 11 12 13 14  
 2 555 511 522 15 16 17 18 19 20 21  
 7 611 15 16 17 18 19 20 21  
 7 622 22 23 24 25 26 27 28  
 2 666 611 622 29 30 31 32 33 34 35  
 7 711 29 30 31 32 33 34 35  
 7 722 36 37 38 39 40 41 42  
 2 777 711 722  
 3 999 555 666 777

1 888 999  
SPRSAPPL

## APPENDIX C

### TIGER INPUT DATA FOR PARALLEL SYSTEM

This appendix contains the input data file representing the parallel system configuration.

|        |      |   |       |             |     |     |
|--------|------|---|-------|-------------|-----|-----|
| 8      | 0.0  | 3 | 000.0 | 0.000000001 | 1.0 | 0.0 |
| 34940. | 420. | 2 |       | 0.103       |     |     |
| 13670. | 420. | 2 |       | 0.180       |     |     |
| 10550. | 420. | 1 |       | 0.105       |     |     |
| 21930. | 420. | 1 |       | 0.247       |     |     |
| 37500. | 420. | 3 |       | 0.112       |     |     |
| 3520.  | 420. | 1 |       | 0.238       |     |     |
| 38850. | 420. | 1 |       | 0.118       |     |     |
| 5060.  | 420. | 3 |       | 0.258       |     |     |

540 1  
 1 ACIM 5675 FOR CODE83P 15AUG 84  
 25 25 1.01.281234 2  
 1. 3.0 2. 9.0 1. 3.0 2. 9.0  
 90 0 3 540 1.0 1.0

|         |             |         |      |    |    |      |
|---------|-------------|---------|------|----|----|------|
| 1.      | 0.00        | 1.      | 1.   |    |    |      |
| 1HF     | POWER       | AMP     | 257. | 2. | 1. | 420. |
| 2HF     | ANT         | COUPLER | 352. | 2. | 1. | 420. |
| 3HF     | RADIO       | CCNTRL  | 658. | 2. | 1. | 420. |
| 4HF     | ANT         | CIU     | 667. | 2. | 1. | 420. |
| 5ARC158 | R/T         |         | 272. | 2. | 1. | 420. |
| 6IFF    | R/T         |         | 699. | 2. | 1. | 420. |
| 7IFF    | CODR/DECCDR |         | 196. | 2. | 1. | 420. |
| 8ARC158 | FLT CONV    | 1124.   |      | 2. | 1. | 420. |

|   |    |    |    |    |    |    |    |    |    |
|---|----|----|----|----|----|----|----|----|----|
| 1 | 1  | 2  | 15 | 16 | 29 | 30 |    |    |    |
| 2 | 3  | 4  | 17 | 18 | 31 | 32 |    |    |    |
| 3 | 5  | 19 | 33 |    |    |    |    |    |    |
| 4 | 6  | 20 | 34 |    |    |    |    |    |    |
| 5 | 7  | 8  | 9  | 21 | 22 | 23 | 35 | 36 | 37 |
| 6 | 10 | 24 | 38 |    |    |    |    |    |    |
| 7 | 11 | 25 | 39 |    |    |    |    |    |    |
| 8 | 12 | 13 | 14 | 26 | 27 | 28 | 40 | 41 | 42 |

999.  
 5 5 2 2 6 3 3 3  
 SYST 1 4 888 100000.  
 SSS5 1 555 100000.  
 SSS6 1 666 100000.  
 SSS7 1 777 100000.  
 SSS9 1 999 100000.  
 2 5 11 1 3  
 2 5 12 2 4  
 1 5 22 5 11 5 12  
 6 5 33 5 6 7 10 11 12  
 2 5 41 8 13  
 2 5 42 9 14  
 1 5 44 5 41 5 42  
 3 5 55 5 22 5 33 544  
 2 6 11 15 17  
 2 6 12 16 18  
 1 6 22 6 11 6 12  
 6 6 33 19 20 21 24 25 26  
 2 6 41 22 27  
 2 6 42 23 28  
 1 6 44 6 41 6 42  
 3 6 66 6 22 6 33 644  
 2 7 11 29 31  
 2 7 12 30 32  
 1 7 22 7 11 7 12  
 6 7 33 33 34 35 38 39 40  
 2 7 41 36 41  
 2 7 42 37 42  
 1 7 44 7 41 7 42  
 3 7 77 7 22 7 33 744  
 3 9 99 5 55 6 66 7 77



APPENDIX D  
TIGER PROGRAM LISTING

This appendix contains a complete listing of the TIGER program as amended for this study. Input data is contained in a separate file as depicted in Appendix B. For an explanation of the changes made to this program see Chapter II. For a further explanation of the subroutines and options available to TIGER, see the TIGER Manual.

```

C
C MAIN PROGRAM
C
COMMON /ALPHA/DNT2, ENDPHA, ICRI, IFF, IFR, INUM, IOPT, JBB, KEQ, KKK, KZZ
1, KKI, KSI, LLL, LLLAST, NEQ, NPH, NTYPE, NUM, REDAD2, REDAD1(760), RELP, RED2
2, RELPY, REPOL, STHAS, TP, T1, XCUM, T13, UP3, IFFECF, T3, TIME, T3SUM
COMMON /BETA/VRO(6,300), IB(6,300,8), NLINE(6)
COMMON /EXTRA/ KS(20), ISW(31)
COMMON /N/IEQU(500), KEQU(500), ETIME(1000), XMTBF(200), XMTTR(200)
COMMON /NPH/ NSS(6), IFLAG(6), TITLE(6,31), SSTEIME(6,31,2), ISS(6,31)
COMMON /SEQ/ INOABT(760), INMI(760), IAUPL(760), T12(760), UP2(760)
1, IAUPL2(760)
COMMON /TYP/ EX(2,200), ISPAE(3,200), IUSED(3,200), IUSED(3,200)
COMMON /MAX/ MAXNEQ, MAXTYP, MAXI8, MAXSTD
COMMON /GAMMA/ XMTBA, VAR, RELGA(760), T1MA(760), XXT(1442), ITT, ISEED
COMMON /TABORT/ XTABT(1000), RDT
COMMON /TIGAP/ UP4, XNUM, BAPRIN, AVA, XPCAP, RUNID(19), TY: QDN(500)
+ CQUNTB(500), XTCUM
COMMON /DONE/ DONE(3)
OREILLY ADD
C DELETING THEIR PRINTOUTS WITH CHERE
COMMON /XSPARE/ XFLAG, BUDGET, COST(201), REFTIM(31,20), NPET(31), NOAC
COMMON /KSPARE/ JTIME, TOTSPR, COMB(9999), COMBA(9999), SER(360)
COMMON /GEALG/ NOSPRS
C SULLIVAN ACCS
COMMON /YSPARE/ BCM(200), SRTIM(200), EL, ESS, RET, REPTIM(200), NOP(200)
COMMON /ACSTAT/ DTIME, UPLAST, JNDT
C SULLIVAN STOPS
INTEGERR TOTSPR, NOSPRS, COMB, COMBA, SER
OREILLY STOP
DATA BLNK/4H /
C
MAXRUN=1000
MAXNPH=6
MAXSTD=57
MAXNEQ=500
MAXTYP=200
MAXI8=300
MAXSS=31
SULLIVAN CHANGE
MAXSEQ=760
C
CALL OVFLGW
C
OREILLY ADDS
C

```



```

BAPRIN=0.0
DO 70 I=1,MAXNEQ
60 COUNTB(I)=0.0
TYCOON(I)=0.0
KEQU(I)=0
70 ETIME(I)=100000.

NUM=0
IFF=0
IFR=0
UP4=0.0
T3SUM=0.0
SUMX=0.0
SUMX2=0.0
DO 80 I=1,100
80 T1MA(I)=0.0
DO 90 I=1,3
DO 90 J=1,MAXTYP
C SULLIVAN ACD
REPTIM(J) = 100000.
NOP(J) = 0
C
90 IIUSED(I,J)=0
DO 95 I = 1, MAXSS
DO 95 J=1,20
REFITIM(I,J) = 100000.
95 CONTINUE
TOTOT = 0.0
C SULLIVAN STCP
DO 100 I=1,MAXSEQ
TT2(I)=0.0
UP2(I)=0.0
IAUP1(I)=0
IAUP2(I)=0
REDAD1(I)=0.0
INMI(I)=0
100 INGABT(I)=0
IAUP=0
XTCUM=0
IF (JC-1) 110,110,140
110 READ (5,120) NMAX,NOPT,PL,XK,I SEED,NPH
120 FORMAT (2I4,2F4.0,2I4)
130 FORMAT (1X2I6,2XF4.2,2XF5.2,2XI6,2XI4)
140 CONTINUE
CM160 WRITE (6,170) ISEED
170 FORMAT (//1X15HRAN DOM SEED IS ,I4)
IF (NMAX-MAXRUN) 190,190,180
18C NMAX=1000

```

```

NOPT=1000
190 DO 200 I=1,NMAX
200 XTABT(I)=100000.
WRITE (6,130) NMAX,NOPT,PL,XK,ISEED,NPH
IF (MAXAPH-NPH) 1240,210,210
C SULLIVAN CHANGE
C 210 INUM=NCFT
220 FORMAT (1X,5HJCC=,4I10)
240 READ (5,240)(XT(I),I=1,8)
242 READ (5,242) NDAYS,NWAR,NOAC,NTIME,BCMFAC,REPFAC
243 FORMAT (14,I4,I6,F5.1,F5.1)
243 WRITE (6,243) NDAYS,NOAC,NTIME
243 FORMAT (2X,NDAYS:,I4,NUMBER OF A/C ',I4,NTIME ',I6)
244 WRITE (6,244) BCMFAC,REPFAC
244 FORMAT (2X,BCMFAC,REPFAC)
NDMUL=(NDAYS*8)-7
ND SUB = NDAYS * 4
IF (NDAYS-1) 250,250,245
C THIS PORTION DEFINES THE PHASE TYPES AND PHASE INTERVALS. THIS IS
C SET JP FOR 4 DISTINCT PHASE INTERVALS FOR A 24 HOUR PERIOD. THEN
C THE 24 HOUR PERIOD IS REPLICATED FOR NDAYS (NORMALLY 90 DAYS).
245 DO 250 I=9,NDMUL,8
XXT(I)=XT(1)
XXT(I+1)=XT(2)
XXT(I+2)=XT(3)
XXT(I+3)=XT(4)
XXT(I+4)=XT(5)
XXT(I+5)=XT(6)
XXT(I+6)=XT(7)
XXT(I+7)=XT(8)
XXT(I+8)=XT(9)
XXT(I+9)=XT(10)
XXT(I+10)=XT(11)
XXT(I+11)=XT(12)
XXT(I+12)=XT(13)
XXT(I+13)=XT(14)
XXT(I+14)=XT(15)
XXT(I+15)=XT(16)
250 CONTINUE
XXT(I+8)=0.
XXT(I+9)=0.
C SULLIVAN STOP
260 WRITE (6,270)
270 FORMAT (1H1,10X40H,PHASE SEQUENCE TYPE DURATION CUM TIME)
IK=1

```

```

C      IK2=2*IK
C      IK3=IK2-1
C      IXXT=XXT(IK3)
C      TIMA(1)=XXT(2)
C      WRITE(6,280) IK, IXXT, XXT(IK2), TIMA(IK)
C 280 FORMAT (19X14, 2X14, 2XF8.2, 2XF8.2)
C      SULLIVAN CHANGE
C      DO 300 IK=2, NDSUB
C      DO 300 IK=2, 100
C      IK2=2*IK
C      IK3=IK2-1
C      IF (XXT(IK2)) 290, 310, 290
C 290 TIMA(IK)=TIMA(IK-1)+XXT(IK2)
C      IXXT=XXT(IK3)
C      WRITE(6,280) IK, IXXT, XXT(IK2), TIMA(IK)
C 300 CONTINUE
C      SULLIVAN STOP
C 310 CONTINUE
C      IF (JJC-1) 320, 320, 330
C 320 CONTINUE
C      CALL PACK
C      SULLIVAN ACD
C      IF (XFLAG - 1.0) 322, 324, 324
C      COMPUTE TOTAL COST OF ACIM INVENTORY PACKAGE
C 322 COSTOT = 0.0
C      DO 323 JA=1, NTYPE
C      COSTOT = COST(JA)*FLOAT(1SPARE(1, JA)) + COSTOT
C 323 CONTINUE
C 331 FORMAT (6, 331) COSTOT
C 331 FORMAT (2X, 'TOTAL COST OF ACIM INVENTORY = ', F13.0)
C      NWAR IS A VARIABLE: NWAR=1 MEANS WAR-TIME SCENARIO, NWAR=0 PEACE.
C      IN THE WAR-TIME SCENARIO, NO OFF-SHIP SUPPLY IS ACCOMPLISHED, THE
C      BCM-RATE IS INCREASED BY BCMFAC, AND THE ON-SHIP REPAIR TIME IS
C      INCREASED BY REPFAC.
C 324 IF (NWAR - 1) 330, 325, 330
C 325 WRITE(6, 326)
C 326 FORMAT (2X, 'WAR-TIME SCENARIO, NO AT-SEA RESUPPLY,')
C      DO 330 I=1, NTOA
C      SRTIM(I) = 99999.
C      BCM(I) = BCMFAC * BCM(I)
C      REPTIM(I) = REPFAC * REPTIM(I)

```

```

327 WRITE (6,327) SRTIM(I),BCM(I),REPTIM(I)
C SULLIVAN STOP
330 FORMAT (2X,'SRT',F9.2,' BCM',F7.4,' REP',F7.3)
C CONTINUE
JBB=1
REL PY=1.0
REL P=1.0
UP3=0.0
TT3=0.0
REDAD2=0.0
DO 340 I=1,MAXSS
340 ISW(I)=1
ICRI=0
DNT2=0.0
350 STPHAS=0
T1=0.0

C SULLIVAN ADDS
C DTIME IS ACCUMULATED TIME PER MISSION, FLOWN IN A DOWN STATUS.
C DTIME = 0.0
C JNDT = 1 SIGNIFIES TO DTIME COMPUTATION THAT INELIGHT FAILURES
C OCCURRED, CTIME WAS COMPUTED UP TO AND INCLUDING THE END OF THE LAST
C FLIGHT PHASE. NO COMPUTATION IS NEEDED AT REPAIR PHASE START.
C
355 CONTINUE
C
C RDT IS RUNNING DOWNTIME
C
RDT=0.0
IF (KS(8)) 380,380,360
KA B=NUM+1
CHERE WRITE (6,370) KAB
370 FORMAT (IX,16HSTART OF MISSION,15,20H*****
380 KK K=0
390 I=1
400 LL=XXT(I)
IF (LL) 450,450,410
410 ENDPHA=STPHAS+XXT(I+1)
I=I+2
C

```

```

C          CALL RUN
          IX=NUM+1
          IF (XTAET(IX)) 420,420,440
          ALSO CHANGE LABEL 420 BELOW
C 420 WRITE (6,430)
C 430 FORMAT (1X,44HTHE ABORT TIME IS ZERO,CHECK THE INPUT DATA.)
C 440 GO TO 1240
          ST PHAS=ENDPHA
          N=NSS(LL)+1
          GO TO 400

C 450 NUM=NUM+1
C 460 SULLIVAN ADDS
          TOTDT = TOTDT + DTIME
C 470 SULLIVAN STCPS
          IF (IFFEOP) 460,460,480
C 480 IF F=IFF+1
          IF (T3) 470,480,470
C 490 CONTINUE
          T3SUM=T3SUM+T3
          T3=0.0
C 500 XT CUM=XT CUM+XCUM
          UP 4=UP 4+ENDPHA-DNT 2
C 510 IF (XTABT(NUM)-100000.) 500,490,500
          X=ENDPHA
          GO TO 510
          X=X**2
          SUMX2=SUMX2+X2
          IF (ISW(N)) 530,530,520
C 520 IA UP=IALP+1
C 530 IF (NUM-INUM) 330,540,540
C 540 INUM=INUM+50
          OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C 550 OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
          IF (NUM-NMAX) 570,550,570
C 560 WRITE (6,560) NUM
          IF (NUM-NMAX) 570,550,570
C 570 FORMAT (1X,16H A GRAND TOTAL OF,16,24H MISSIONS HAVE BEEN RUN.)
          XNUM=NUM
          XP CAP=XT CUM/XNUM
C 580 XP CAP=XT CUM/XNUM
          XP CAP=XT CUM/XNUM
          OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
          IF (NUM-NMAX) 610,590,610
C 590 WRITE (6,600) XP CAP
          IF (NUM-NMAX) 610,590,610
C 600 FORMAT (1X,24HTHE RELIABILITY IS ,F8.4)
C 610 XP LCL=XP CAP-XK*SQRT(XPCAP*(1.-XP CAP)/XNUM)
          IF (XP LCL) 620,630,630
C 620 XP LCL=0.

```

```

C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESS 631,661 ADDED FOR THIS PRINT DELETION ONLY
C ADDRESS 630 ALSO MOVED FOR THIS DELETION
C IF (NUM-NMAX) 661,631,661
C31 WRITE (6,640) XPLCL
C30 WRITE (6,640) XPLCL
C40 FORMAT (1X24HTHE LOWER CONF LIMIT IS ,F8.4)
C40 WRITE (6,650) PL
C50 FORMAT (1X24HTHE SPEC REQUIREMENT IS ,F8.4)
C50 WRITE (6,660) RED2
C60 FORMAT (1X17HTHE READINESS IS ,7XF8.4)
C61 AVA=UP4/173
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 669 AND 671 ADDED FOR THIS PRINT DELETION ONLY
C IF (NUM - NMAX) 671,669,671
C69 WRITE (6,670) AVA
C70 FORMAT (1X28HTHE AVERAGE AVAILABILITY IS ,F8.4)
C71 XIAUP=IAUP
C AVAINS=XIAUP/XNUM
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 679 AND 681 ADDED FOR THIS PRINT DELETION ONLY
C IF (NUM-NMAX) 681,679,681
C79 WRITE (6,680) AVAINS
C80 FORMAT (1X28HTHE INSTANT AVAILABILITY IS ,F8.4)
C81 XDOWN=XNUM-XTCUM
C IF (XDOWN) 690,690,700
C90 XMTBA=2.0*SUMX
C90 XLCCL=0.434*SUMX
C90 VAR=(0.5*SUMX)**2
C GO TO 710
C90 XMTBA=SUMX/XDOWN
C90 VAR=(SUMX2/XNUM)-(SUMX/XNUM)**2
C90 CORR=(SUMX*(1/XDOWN-1/XNUM))**2
C90 VAR=VAR+CORR
C90 XLCCL=XMTBA-(1.28*SQR(XVAR))
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 741 ADDED FOR THIS PRINT DELETION ONLY
C IF (NUM-NMAX) 741,710,741
C710 WRITE (6,720) XMTBA
C720 FORMAT (1X41HTHE MEAN TIME BETWEEN MISSION FAILURES IS,F20.1)
C730 WRITE (6,730) XLCCL
C730 FORMAT (1X21HTHE LCL,90, MTBMF IS ,F20.1)
C740 WRITE (6,740) VAR
C740 FORMAT (1X27HTHE MTBMF VARIANCE IS ,F20.1)
C741 XIFF=IFFR
C750 XMTU=2.0*UP4

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```

XMDT=0.0
GO TO 750
760 XMUT=UP4/XIFF 780,770,780
770 XMDT=(TT3-UP4-T3SUM)/XIFF
GO TO 750
780 XMDT=(TT3-UP4-T3SUM)/XIFF
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
IF (NUM - NMAX) 830,790,830
790 WRITE (6,810) XMUT
C
C SULLIVAN ACDS
C
AVGDT = TOTDT/FLOAT(NOPT)
AVMUP = 1 - (AVGDT/FLOAT(NTIME))
WRITE (6,795) AVGDT
WRITE (6,796) AVMUP
795 FORMAT (2X, 'AVERAGE HOURS FLOWN IN DOWN STATUS',F9.1)
796 FORMAT (1X, 'PROBABILITY OF ALL A/C IN AN UP STATUS',F6.4)
C
C SULLIVAN STOPS
C
800 WRITE (6,820) XMDT
810 FORMAT (/1X18THE SYSTEM MUT IS ,F20.1)
820 FORMAT (1X18THE SYSTEM MDT IS ,F20.3)
830 IF (XPCAP-PL) 840,840,920
840 IF (NOPT-NUM) 870,870,850
850 WRITE (6,860)
860 FORMAT (1X14ANOTHER SET OF,3H 50,20HMISSIONS WILL BE RUN,43H TO 0
1BTAIN REQUIRED STATISTICAL CONFIDENCE.)
GO TO 330
870 WRITE (6,880)
880 FORMAT (1X52HSIMULATION COMPLETE-OPTIMUM NUMBER MISSIONS WERE RUN)
IF (PL-EG.1.) GO TO 910
890 WRITE (6,900)
900 FORMAT (1X33HWEAPON SYSTEM FAILS REQUIREMENTS.)
GO TO 1010
920 IF (NMAX-NUM) 930,930,960
930 WRITE (6,940)
940 FORMAT (1X52HSIM COMPLETE-PREDEFINED MAX NUMBER MISSIONS WERE RUN)
950 IF (XPLCL-PL) 890,990,990
960 IF (XPLCL-PL) 850,570,970
970 WRITE (6,980)
980 FORMAT (2X22HSIMULATION COMPLETE - )
IF (PL-EG.1.) GO TO 1010
990 WRITE (6,1000)
1000 FORMAT (1X33HWEAPON SYSTEM MEETS REQUIREMENTS.)
1010 CONTINUE

```

```

1020 IF (JC-1) 1020,1020,1040
1030 READ (5,1030) SPRS,APPL,GMMA,DMNO
1030 FORMAT (4A4)
1040 IF (SPRS.EQ.BLNK) GO TO 1190
1050 IDIFF=0
TAFM=0.0
TACMMH=0.0
WRITE (6,1060)
1060 FORMAT (1H1,4X53HEQUIP FAILURES AND CORRECTIVE MAINTENANCE (CM) SUM
1MARY/8X71HEQUIP. NO. TYPE NO. TOTAL EQUIP. AVG. NO. FAILURES A
2VG. CM MANHOURS/32X8HFAILURES,7X11HPER MISSION,5X11HPER MISSION/)
DO 1090 I=1,NEQ
IF (XMTTR(IEQU(I)).EQ.9999.) GO TO 1090
IF (KEQU(I)) 1090,1090,1070
1070 AFM=KEQU(I)/XNUM
IEQ=IABS(IEQU(I))
ACMMH=AFM*ABS(XMTTR(IEQ))
WRITE (6,1080) I,IEQ,KEQU(I),AFM,ACMMH
1080 FORMAT (10X14,6X14,6X110,6XF10.3,6XF10.3)
IDIFF=ICIFF+KEQU(I)
TAFM=TAFM+AFM
TACMMH=TACMMH+ACMMH
1090 CONTINUE
WRITE (6,1100) IDIFF,TAFM,TACMMH
1100 FORMAT (31X10H-----,6X10H-----,6X10H-----/31X110,6X
1F10.3,6XF10.3)
1110 CONTINUE
WRITE (6,1120)
C1120 FORMAT (1H1,3X41HAVERAGE NUMBER OF SPARES USED PER MISSION)
C1130 WRITE (6,1130)
C1130 FORMAT (/4X6HSPARES,7X4HSHIP,18X6HTENDER,16X4HBASE)
1140 WRITE (6,1140)
1140 FORMAT (8X4HTYPE,4X3(5HSTOCK,3X4HUSED,10X))
DO 1170 J=1,NTYPE
ALDONE=0.0
DO 1150 I=1,3
DONE(I)=IUSED(I,J)/XNUM
ALDONE=ALDONE+DONE(I)
1150 CONTINUE
IF (ALDCNE) 1155,1170,1155
1155 WRITE (6,1160) J,(ISPAE(I,J),DONE(I),I=1,3)
1160 FORMAT (8X14,4X3(15,F7.2,10X))
1170 CONTINUE
1180 CONTINUE
1190 IF (APPL.EQ.BLNK) GO TO 1210
1200 BAPRN=-1.0
C
CALL APPLE

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```

10 DO 20 I=1,3
DO 20 J=1,NTYPE
IUSED(I,J)=0
20 CONTINUE
DO 30 I=1,NEQ
30 ETIME(I)=100000.
40 CONTINUE
C
50 DO 120 ILB=1,NEQ
KEQ=ILB
IF (ETIME(KEQ)+100001.001)55,120,55
55 IF (ETIME(KEQ)+99999.160,60,120)
60 IF (IFLAG(LL)) 120,70,120
C
70 ETIME(KEQ)=STPHAS
IABC=IABS(IEQU(KEQ))
IF (XMTTR(IABC)) 80,80,100
80 XX=VMTTR(IABC,LL)
IF (XXX-9999.) 120,90,120
90 ETIME(KEQ)=-99999.
GO TO 120
100 XX=XMTTR(IABC)
C
110 CALL TTE
C
120 CONTINUE
C
DO 140 ILB=1,NEQ
KEQ=ILB
IEQU(KEQ)=IABS(IEQU(KEQ))
IF (ETIME(KEQ)-100000.) 130,140,130
130 IEQU(KEQ)=-IABS(IEQU(KEQ))
140 CONTINUE
150 CONTINUE
C
KK K2=KKK
K=NLIN(11)
DO 250 I=1,K
DO 250 J=2,8
KEQ=IABS(IEQU(KEQ),I,J))
IF (KEQ-MAXNEQ) 151,151,250
151 IF (KEQ)250,250,155
155 IF (ETIME(KEQ)+100001.001)160,250,160
160 IEQU(KEQ)=IABS(IEQU(KEQ))
IABC=IEQU(KEQ)
IF (XMTTR(IABC)) 170,170,180
170 IF (VMTTR(IABC,LL)-9999.) 180,190,180
180 CONTINUE

```

```

C C C C C
C SULLIVAN CHANGE
C C C C C
C IF (IFLAG(LL)-1) 210,190,210
C IF (ETIME(KEQ)) 200,210,210
C 190 ETIME(KEQ)=ETIME(KEQ)-(ENDPHA-STPHAS)
C 200 IF (ETIME(KEQ)-100000.) 220,240,220
C 210 IF (ABS(ETIME(KEQ))-STPHAS) 240,230,230
C 220 IF (STPHAS) 250,240,250
C 230 IF (ETIME(KEQ)=-STPHAS
C 240 IABC=IABS(IEQU(KEQ))
C XX=XMTBF(IABC)
C C C C C
C 190 IF (ETIME(KEQ) - 100000.) 225,195,225
C 195 IABC = IABS(IEQU(KEQ))
C XX = XMTBF(IABC)
C GO TO 240
C 225 IF (IFLAG(LL) - 1) 250,250,230
C 230 IF (ETIME(KEQ)) 250,250,235
C 235 ETIME(KEQ) = ETIME(KEQ) + (ENDPHA - STPHAS)
C 240 CONTINUE
C C C C C
C SULLIVAN STOP
C CALL TTE
C 250 CONTINUE
C KK2=1
C
C DO 330 ILB=1,NEQ
C KEQ=ILB
C IF(ETIME(KEQ)+100001.001)255,330,255
C 255 IF(IEQU(KEQ))260,260,330
C 260 IEQU(KEQ)=IABS(IEQU(KEQ))
C IABC=IEQU(KEQ)
C IF (XMTTR(IABC)) 270,270,280
C 270 IF (VMTTR(IABC,LL)-9999.) 280,290,280
C 280 CONTINUE
C IF (IFLAG(LL)-1) 310,290,310
C 290 IF (ETIME(KEQ)) 300,320,320
C 300 ETIME(KEQ)=ETIME(KEQ)-(ENDPHA-STPHAS)
C GO TO 330
C
C 310 IF(ETIME(KEQ)) 331,320,320
C 320 IEQU(KEQ)=IABS(IEQU(KEQ))

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GO TO 320
331 IEQU(KEQ)=-IABS(IEQU(KEQ))
330 CONTINUE
C
CALL STATUS
CALL STNDBY
C
CALL STATUS
C
SULLIVAN ADDS
THIS SECTION WILL CALCULATE DTIME IF AIRCRAFT STARTS FLIGHT PHASE
IN A DOWN STATUS.
C
IF (ISW(N).GT.0) GO TO 338
IF (IFLAG(LL).GE.1) GO TO 336
DTIME = DTIME + (ENDPHA - STPHAS)
JNDT = 1
GO TO 337
336 IF (JNCT.EQ.1) GO TO 338
DTIME = CTIME + (STPHAS - UPLAST)
UPLAST = ENDPHA
JNDT = 0
337 JNDT = 1
WRITE (6,478) DTIME, TIME
C
SULLIVAN STOPS
C
338 IF (ISW(N)) 350,350,340
340 IAUPI(JBB)=IAUPI(JBB)+1
350 XIAUPI=IAUPI(JBB)
XAVI=XIAUPI/XKAA
C
TIME=STPHAS
DN TI=0.0
DO 360 KSS=1,N
360 SS TIME(LL,KSS,1)=0.0
C
370 TP=TIME
C
CALL STNDBY
C
SULLIVAN ADDS
C
IF (ISW(N).GT.0) UPLAST = TIME
C
SULLIVAN STOPS
C
380 IF (KS(6)) 390,440,390

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390 WRITE (6,430) TP
DO 410 J=1,NEQ
IF (ETIME(J)-100000.) 400,410,400
400 IEQ=IABS(IEQU(J))
WRITE(6,420) J,IEQ,ETIME(J)
410 CONTINUE
420 FORMAT (1X15,1X15,5XF22.4)
430 FORMAT (1XF12.4)
C 440 CALL EVENT
C
C 445 WRITE (6,445) ETIME(888)
FORMAT (2X,ETIME (888) ',F6.1)
TIME=ABS(ETIME(KEQ))
C
IF (KS(5)) 450,470,450
450 WRITE (6,460) KEQ,ETIME(KEQ),KAA
460 FORMAT (10X5HEQUIP,15,F12.4,5X7HMISSION,110)
470 DELT=TIME-TP
C
CALL STATUS
C
SULLIVAN ACDS
THIS SECTION CALCULATES HOURS FLOWN IN A DOWN STATUS, WHEN AIRCRAFT
GOES TO A DOWN STATUS WHILE AIRBORNE.
C
IF (ISW(N)) 473,473,475
C 473
C 474
C 475
FORMAT (2X,ISW(N) LESS THAN 1')
IF (ISW(N).GT.0) GO TO 480
IF (IFLAG(LL).GE.1) GO TO 480
IF (INDT.EQ.1) GO TO 480
WRITE (6,992) ETIME(KEQ)
FORMAT (2X,ETIME',F8.2)
IF (ETIME(KEQ).GE.ENDPHA) GO TO 480
WRITE (6,993) UPLAST
FORMAT (2X,UPLAST',F8.2)
DTIME = DTIME + (ENDPHA- UPLAST)
NDT = 1
JNDT = 1
WRITE (6,478) DTIME,TIME
C 478
FORMAT (1X,DOWNTIME: ',F8.2, TIME: ',F9.1)
C
C SULLIVAN STOPS
C
480 DO 510 KSS=1,NX
IF (ISW(KSS)) 490,490,500
490 SSTM(LL,KSS,1)=SSTM(LL,KSS,1)+DELT

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500 GO TO 510
510 SS TIME(LL,KSS,1)=0.0
520 IF (ISW(N)) 520,520,530
530 SS TIME(LL,N,1)=SSTIME(LL,N,1)+DELT
540 T3=T3+DELT
550 IF (TIME-ENDPHA) 522,522,521
560 T3=T3+ENOPHA-TP-DELT
570 RDT=RDT+DELT
580 GO TO 550
590 T3=0.0
600 RDT=0.0
610 IF (SSTIME(LL,N,1)) 1140,550,540
620 T1=SSTIME(LL,N,1)
630 SS TIME(LL,N,1)=0.0
640 CONTINUE
650 IF (SSTIME(LL,N,1)) 570,560,570
660 IF (T1) 620,620,580
670 IF (T1) 620,610,620
680 IFF=IFF+1
690 IFR=IFR+1
700 T1=0.0
710 GO TO 620
720 T1=SSTIME(LL,N,1)
730 CONTINUE
740 IF (ICRI) 640,640,660
750 SSC=1
760 ISSA(1)=N
770 IF (RDT-TAD2) 645,645,930
780 ICRI=0
790 IF (SSTIME(LL,N,1)-SSTIME(LL,N,2)) 650,650,960
800 ICRI=0
810 SSC=0
820 DO 655 KSS=1,NX
830 IF (SSTIME(LL,KSS,1)-SSTIME(LL,KSS,2)) 655,655,652
840 SSC=1
850 ISSA(1)=KSS
860 CONTINUE
870 IF (ISSC) 660,660,962
880 CONTINUE
890 IF (TIME-ENDPHA) 670,670,1140
900 IF (ISW(N)) 680,680,730
910 CALL APPLE
920

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730 IF (ETIME(KEQ)) 810,810,740
740 IABC=IABS(IEQU(KEQ))
750 IF ((IFLAG(LL)-1) 750,760,750
760 CALL LRND(ISEED,RN,1,16807,0)
770 IF (RN-REPOL) 770,770,800
780 ETIME(KEQ)=-99999.
790 GO TO 820
800 IF (XMTTR(IABC)) 780,780,790
810 XX=VMTTR(IABC,LL)
820 IF (XX-9999.) 820,760,820
830 XX=XMTTR(IABC)
840 GO TO 820
850 ETIME(KEQ)=-100001.001
860 GO TO 830
870 IABC=IABS(IEQU(KEQ))
880 XX=XMTTR(IABC)
890 IF (IEQU(KEQ)) 811,821,821
900 I EQU(KEQ)=IABS(IEQU(KEQ))
910 ?
920 ETIME(KEQ)=100000.
930 GO TO 830
940 C
950 821 CALL TTE
960 C
970 830 IF (ETIME(KEQ)) 840,1150,870
980 C
990 840 KEQU(KEQ)=KEQU(KEQ)+1
1000 IF (ISW(N)) 850,850,370
1010 850 DNT1=DNT1+DELT
1020 IF (ICRI) 860,370,860
1030 860 REDADI(JBB)=REDADI(JBB)+DELT
1040 GO TO 370
1050 C
1060 870 CONTINUE
1070 IF (ISW(N)) 880,880,370
1080 880 DNT1=DNT1+DELT
1090 IF (ICRI) 890,900,890
1100 890 REDADI(JBB)=REDADI(JBB)+DELT
1110 900 TDOWN=TIME-SSTIME(LL,N,1)
1120 TTEMP=SSTIME(LL,N,1)
1130 IF (KS(13)) 370,370,910
1140 910 CHERE ALSO CHANGE LABEL 910
1150 920 WRITE (6,920) LL,TDOWN,TTEMP,KAA
1160 920 FORMAT (13H DURING PHASE,16,20H SYSTEM WENT DOWN AT ,F14.4,13H DOWN
1170 1TIME IS ,F14.4,3X7HMISSION,16)
1180 910 GO TO 370
1190 C
1200 930 ICRI=5

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TABORT=TIME-(RDT-TAD2)
IF (TABORT-ENDPHA) 940, 645, 645
IF (XTAET(KAA)-100000.) 660, 950, 660
940 IT EMP=1
950 IT EMP2=1
CHERE WRITE(6, 1010) LL, JBB, KAA, TABORT, TITLE(LL, N), TAD2
GO TO 1020
960 ICRI=4
GO TO 564
962 ICRI=2
964 TABORT=TIME-(SSTIME(LL, ISSA(1), 1)-SSTIME(LL, ISSA(1), 2))
970 IF (TABORT-ENDPHA) 990, 980, 980
980 IF (ICRI-2) 650, 985, 650
985 ICRI=0
GO TO 660
C ?
990 IF (XTAET(KAA)-100000.) 660, 1000, 660
1000 IT EMP=1
IT EMP2=1
CHERE DO 1005 I=1, ISSC
C1005 WRITE(6, 1009) LL, JBB, KAA, TABORT, TITLE(LL, ISSA(1))
C1009 I, SSTIME(LL, ISSA(1), 2)
1009 I, FORMAT(1X9HIN PHASE, 12, 1X3HSEQ, 13, 4X7HMISSION, 16, 4X15HABORTED AT
1TIME, F10.4, 10H BECAUSE, A4, 35H EXCEEDED PHASE ALLOWABLE DOWNTIME
2, 2XFI0.3, 5H HRS.)
1010 I, FORMAT(1X9HIN PHASE, 12, 1X3HSEQ, 13, 4X7HMISSION, 16, 4X15HABORTED AT
1TIME, F10.4, 10H BECAUSE, A4, 37H EXCEEDED MISSION ALLOWABLE DOWNT
2IME, 2XFI0.3, 5H HRS.)
1020 XT ABT(KAA)=TABORT
IF (TABORT) 1590, 1590, 1040
1040 DO 1110 I=1, NEQ
IF (ETIME(I)) 1050, 1110, 1110
1050 IF (IEQU(I)) 1080, 1110, 1080
1080 IF (KS(2)) 1110, 1110, 1110
CHERE PREVIOUS LINE WAS 1090, 1110, 1090
C1090 WRITE(6, 1100) I, ETIME(I)
1100 I, FORMAT(17X9HEQUIPMENT, 15, 24H DOWN IT WILL COME UP AT, F16.4)
1110 CONTINUE
C
1120 CALL APPLE
C
IT EMP2=0
1130 GO TO 660
C
1140 CONTINUE
IF FEOP=ISW(N)
IF (ISW(N)) 1160, 1160, 1270
1150 CONTINUE

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1160 TDEOP=ENDPHA-TP
1170 CONTINUE
1180 IF (KS(3)) 1210,1210,1180
1190 IF (TDECP) 1210,1210,1210
CHERE PREVIOUS LINE WAS 1190,1210,1190
C1190 WRITE (6,1200) LL,TDEOP,KAA
1200 FORMAT (1X27HSYSTEM DOWN AT END OF PHASE,16,13H FOR DJRATION,F10.4
1210 CONTINUE
DNT1=DNT1+TDEOP
RDT=RDT+TDEOP-DELT
DELT=TDECP
C
C CALL APPLE
C
CM WRITE (6,1211)
C1211 FORMAT (2X,'LINE 1211 APPLE')
C1270 CONTINUE
IF (ICRI) 1280,1290,1280
1280 RE DAD1(JBB)=REDAD1(JBB)+TDEOP
1290 DNT2=DNT2+DNT1
1300 IF (DNT2) 1310,1330,1310
1310 IF (KS(6)) 1330,1330,1330
CHERE PREVIOUS LINE WAS 1325,1330,1325
C1325 WRITE (6,1320) LL,KAA,DNT2
1320 FORMAT (1X5HPHASE,15,1X29HTOTAL SYS DOWNTIME IN MISSION,15,1X3HWAS
1330 CONTINUE
C
1340 IF (ICRI) 1350,1350,1340
1350 IF (ITEMP) 1360,1360,1350
XCUM=1-ITEMP
IN OABT(JBB)=INOABT(JBB)+1-ITEMP
INMI(JBB)=INMI(JBB)+1
C1360 CONTINUE
XNO=INOABT(JBB)
TNMI=INMI(JBB)
IF (TNMI) 1380,1380,1370
1370 RELY=XNC/TNMI
GO TO 1390
1380 RELY=0.0
1390 RELPY=RELPY*RELY
TT1=ENDPHA-STPHAS
TT2(JBB)=TT2(JBB)+TT1
UP1=TT1-DNT1
UP2(JBB)=UP2(JBB)+UP1
IF (ISW(N)) 1410,1410,1400
1400 IAUP2(JBB)=IAUP2(JBB)+1

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141C XIAUPP=IAUP2(JBB)
XAV=XIALPP/XKAA
IF (KAA-INUM) 1570,1420,1570
CHERE1
C1420 WRITE (6,1430) XAVI
1430 FORMAT (/47X2)HINSTANT AVAILABILITY,5X2X4H IS ,F6.4)
CHERE1
C1440 WRITE (6,1450) LL,JBB,RELY,LL,RELY
1450 FORMAT (9X17HRELIABILITY PHASE,13,1H,,13,5H, IS ,F6.4,3X25HRELIABI
LITY UP TO PHASE ,12,4H IS ,F6.4)
C ?
CHERE 1420 IN BELOW LINE SHOULD BE NEXT TC ABOVE WRITE(6,1430)
142C RELGA(JBB)=RELY
AENDT1=0.0
AENDT2=0.0
DO 1520 I=1,KAA
1460 IF (XTAB(I))-100000.) 1470,1520,1520
1470 IF (XTAB(I))-TIMA(JBB)) 1480,1520,1520
1480 AENDT2=AENDT2+TIMA(JBB)-XTAB(I)
JBB1=JBB-1
IF (JBB1) 1500,1500,1490
1490 IF (TIMA(JBB1))-XTAB(I)) 1500,1500,1510
150C AENDT1=AENDT1+TIMA(JBB)-XTAB(I)
GO TO 1520
1510 AENDT1=AENDT1+TIMA(JBB)-TIMA(JBB1)
1520 CONTINUE
TT3=TT3+TT2(JBB)
UP3=UP3+UP2(JBB)
REDAD2=REDAD2+REDAD1(JBB)
RED1=(UP2(JBB)-AENDT1+REDAD1(JBB))/TT2(JBB)
RED2=(UP3-AENDT2+REDAD2)/TT3
1530 LABEL TRANSFERRED BELOW
CHERE 1530 WRITE (6,1540) RED1,RED2
C1530 WRITE (6,1540) RED1,RED2
1540 FORMAT (9X16HREADINESS ,9X4H IS ,F6.4,3X25HREADINESS
,2X4H IS ,F6.4)
1530 AVA1=UP2(JBB)/TT2(JBB)
AVA2=UP3/TT3
CHERE 1530 WRITE (6,1550) AVA1,AVA2
1550 FORMAT (9X23HAVERAGE AVAILABILITY ,2X4H IS ,F6.4,3X25HAVERAGE AV
AILABILITY ,2X4H IS ,F6.4)
CHERE 1560 WRITE (6,1560) XAV
1560 FORMAT (47X2)HINSTANT AVAILABILITY,5X2X4H IS ,F6.4)
1570 CONTINUE
1580 KKK=1
JBB=JBB+1
TI=SSTIME(LL,N,1)
1590 RETURN
END

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C      7C      KS(1)=1
      80      KS(4)=0
            KS(3)=0
            KS(2)=0
            KS(5)=0
            KS(6)=0
            KS(7)=0
            KS(8)=0
            KS(9)=0
            KS(10)=0
            GO TO 130
      90      KS(1)=1
            KS(6)=0
            KS(10)=0
            GO TO 110
      100     KS(1)=1
            KS(6)=1
            KS(7)=1
            KS(10)=1
            KS(12)=1
      110     KS(2)=1
            KS(3)=1
            KS(4)=1
            KS(5)=1
            KS(7)=0
            KS(8)=1
            KS(9)=1
            GO TO 130
      120     KS(1)=0
            KS(4)=0
            GO TO 80
C      130     NEQ=0
            DO 140 I=1,MAXNEQ
            ET IME(I)=100000.
            IEQU(I)=0
      140     CONTINUE
            DO 155 J=1,6
            DO 150 I=1,MAXTYP
            XM TBF(I)=0.0
            VM TTR(I,J)=0.0
      150     XM TTR(I)=0.0
      155     CONTINUE
C      160     WRITE (6,170)
      170     FORMAT (/11H TYPE NAME,18X4HMTBF,5X4HMTTR,7X2HDC,8X4HADT1,4X4HADT

```

```

12)
180 READ (5,190) I,(DUM(J),J=1,4),X,Y,U,V,W,IDUM
190 FORMAT (14,4A4,F8.0,4F4.0,I4)
C SULLIVAN ACD
C REPTIM(I) = V
C SULLIVAN STOP
IF (I) 200,490,200
200 IF (I-MAXTYP) 220,220,210
210 WRITE (6,440)
GO TO 1000
220 DO 230 J=1,4
230 F(I,J)=IDUM
IF (IUI(I)) 240,250,240
240 READ (5,450) IU,(VDC(IU,ILL),ILL=1,NPH)
250 IF (Y) 260,280
260 READ (5,50) (VMTTR(I,J),J=1,NPH)
270 IF (I) 280,490,280
280 EX(1,I)=V
EX(2,I)=W
IF (KS(1)) 310,310,290
290 WRITE (6,300) I,(F(I,J),J=1,4),X,Y,U,V,W
300 FORMAT (1X14,2X4A4,2XF10.1,F10.2,F10.3,2(F8.1))
310 IF (IUI(I)) 380,380,320
320 IF (KS(1)) 340,340,330
330 WRITE (6,460) (VDC(IU,ILL),ILL=1,NPH)
340 DO 370 ILL=1,NPH
IF (VDC(IU,ILL)) 360,360,350
350 VDC(IU,ILL)=(X/VDC(IU,ILL))*XM
GO TO 370
VDC(IU,ILL)=(X/.001)*XM
360 CONTINUE
370 IF (KS(1)) 410,410,390
380 IF (Y) 400,410,410
390 WRITE (6,470) (VMTTR(I,J),J=1,NPH)
400 IF (XM TBF(I)) 420,430,420
420 WRITE (6,480) I
GO TO 1000
430 IF (U) 435,435,433
433 XM TBF(I)=XM*(X/U)
435 XM TTR(I)=Y*XM1
GO TO 180
(9X39HEQUIP TYPES HAVE EXCEEDED MAX ALLOWABLE)
440 FORMAT (14,19(F4.0))
450 FORMAT (14X16H VARY DUTY CYCLE ,4F10.3)
460 FORMAT (14X16H VARIABLE MTR ,4F10.3)
470 FORMAT (1X4HTYPE,15,1X13HDEFINED TWICE)
480
C

```

```

490 WRITE (6,500)
500 FORMAT (/1X15HTYPE EQUIPMENT)
510 READ (5,10) NTYPE, (LOAD(I),I=1,19)
520 IF (LOAD(1)) 520,650,520
530 DO 620 I=1,19
540 IF (LOAD(I)) 530,620,530
550 IF (LOAD(I)) 530,620,530
560 IF (IBM-500) 560,560,540
570 WRITE (6,550)
580 FORMAT(1X,EQUIPMENT NUMBER GREATER THAN 500 *****)
590 GO TO 1000
600 IF (IBM-NEQ) 580,580,570
610 NEQ=IBM
620 IF (IEQU(IBM)) 590,610,590
630 IF (IEQU(IBM)) 590,610,590
640 WRITE (6,600) IBM
650 GO TO 1000
660 FORMAT (1X9HEQUIPMENT,15,1X34HDEFINED TWICE *****)
670 CONTINUE
680 IEQU(IBM)=NTYPE
690 CONTINUE
700 IF (KS(1)) 640,640,630
710 WRITE (6,10) NTYPE, (LOAD(I),I=1,19)
720 NTY=NTYPE
730 GO TO 510
740
750 OREILLY CHANGE
760 WRITE (6,660)
770 FORMAT (/1X11HSPARES TYPE,6X4HSHIP,4X6HTENDER,6X4HBASE,12X6HFACTOR)
780 DO 670 I=1,3
790 OREILLY CHANGE - END
800 NTYPE=NTY
810 DO 670 J=1,NTYPE
820 IUSED(I,J)=0
830 READ(5,675) IUNLIM, SX, SPR1, SPR2, SPR3, SPR4, SPR5, SPR6, SPR7, SPR8, SPR9
840 SPR10, SPR11, SPR12, SPR13, SPR14
850 SPR10, SPR11, SPR12, SPR13, SPR14
860 IF (SX-999.) 681,676,681
870
880 CALL SPARES
890
900 IF (KS(1)) 740,740,677
910 DO 678 I=1,NTYPE
920 WRITE (6,750) I, (ISPARE(J,I),J=1,3), SX
930 GO TO 740
940 IF (SX) 684,682,684
950 SX=1.0
960 IF (IUNLIM-IBLANK) 690,720,690

```

```

69C WRITE (6,700)
700 FORMAT (IX4I,HALL EQUIPMENT TYPES HAVE UNLIMITED SPARES)
DO 710 I=1,NTYPE
DO 710 J=1,3
710 ISPAE(J,I)=999999
DO 720 I=1,NTYPE
DO 740 J=1,3
720 READ (5,10) (ISPARE(J,I),J=1,3)
BILL=FLCAT(ISPAE(1,I))*SX
IF (INT(BILL)-BILL) 727,725,727
725 ISPAE(1,I)=BILL
GO TO 728
727 ISPAE(1,I)=INT(BILL)+1
728 CONTINUE
IF (KS(1)) 740,740,730
730 WRITE(6,750)I,ISPARE(J,I),J=1,3),SX
740 CONTINUE
750 FORMAT(5X,I4,2X,3I10,13X,F6.2)
760 WRITE(6,770) NPH
770 FORMAT(1H1,3X,28HTHE MISSION WILL BE RUN WITH,I4,7H PHASE ,27HTYPE
1S IN VARIABLE SEQUENCE.)
C
DO 777 I=1,6
DO 776 J=1,10
DO 775 K=1,60
ISB(K,J,I)=0
775 CONTINUE
776 CONTINUE
777 CONTINUE
DO 990 K=1,NPH
READ (5,780) XID,LL,NSS(K),ISS(K,NSS(K)+1),SSTIME(K,NSS(K)+1,2)
ISYS(K)=ISS(K,NSS(K)+1)
FORMAT (A4,3I4,F8.0)
780 NX=NSS(K)
N=NX+1
IF (KS(1)) 820,820,790
790 WRITE (6,810) XID,LL,NSS(K),ISS(K,N),SSTIME(K,N,2)
800 FORMAT (IXA4,3I4,F10.2)
810 FORMAT (/IXA4,3I4,F10.2)
820 TITLE(K,N)=XID
C?
DO 840 IK=1,NX
READ (5,780) TITLE(K,IK),KK,MM,ISS(K,IK),SSTIME(K,IK,2)
IF (KS(1)) 840,840,830
830 WRITE (6,800) TITLE(K,IK),LL,MM,ISS(K,IK),SSTIME(K,IK,2)
840 CONTINUE
C
DO 850 JA=1,MAXIB

```

```

      DO 850 JB=1,8
      IB(K,JA,JB)=0
      NRO(K,JA)=0
850   CONTINUE
      IOR=0
      I=0
860   I=I+1
      READ(5,10) (IVAL(J),J=1,10),IRULE
      IF (IVAL(1).EQ.0) GO TO 990
      IF (IRULE.NE.0) GO TO 930
C
      IF (I.LE.MAXIB) GO TO 880
      WRITE(6,870) MAXIB
870   FORMAT(1H1,10X,29H# OF GROUP CARDS GREATER THAN,14)
      STOP
880   NRO(K,I)=IVAL(1)
C
      DO 890 J=1,8
      IB(K,I,J)=IVAL(J+1)
      CONTINUE
890   IBNUM(K,IB(K,I,1)-500)=1
      NLINE(K)=I
900   IF (KS(1)) 860,860,910
910   WRITE(6,920) NRO(K,I), (IB(K,I,J),J=1,8)
920   FORMAT(1X,13,8I4)
      GO TO 860
930   CONTINUE
      I=I-1
      IOR=IOR+1
C
      IF (IOR.LE.MAXSTO) GO TO 950
      WRITE(6,940) MAXSTO
940   FORMAT(1H1,10X,36H# OF OPERATE RULE CARDS GREATER THAN,14)
      STOP
950   CONTINUE
      DO 960 J=1,10
      ISTB(IOR,J,K)=IVAL(J)
960   CONTINUE
      IF (KS(1)) 860,860,970
970   WRITE(6,980) (ISTB(IOR,J,K),J=1,10)
980   FORMAT(30X,10I4)
      GO TO 860
990   CONTINUE
1000  CONTINUE
      RETURN
      END
C
C

```

```

*****
C C C
SUBROUTINE EVENT
COMMON /ALPHA/DNT2, ENDPHA, ICRI, IFF, IFR, INUM, IOPT, JBB, KEQ, KKK, KZZ
1, KKI, KSI, LL, LL, LAST, NEQ, NPH, NTYPE, NUM, REDAD2, REDAD1(760), RELP, RED2
2, KELPY, KPOL, STPHAS, TP, T1, XCUM, IT3, UP3, IFFECF, T3, TIME, T3SUM
COMMON /TYP/EX(2,200), ISPAE(3,200), IUSED(3,200)
COMMON /NPH/NSS(6), IFLAG(6), TITLE(6,31), SSTRIME(6,31,2), ISS(6,31)
COMMON /N/IEQU(500), KEQU(500), ETIME(1000), XMTBF(200), XMTTR(200)
COMMON /XSPARE/XFLAG, BUDGET, COST(201), RFTIM(31,20), NPET(31), NUAC
C SULLIVAN CHANGE
COMMON /YSPARE/BCM(200), SRTIM(200), EL, ESS, RET, REPTIM(200), NUP(200)
C C C
INTEGER RFKEQ
NEG = 0
R = ABS(ETIME(1))
KEQ = 1
DO 15 I = 2, NEQ
RR = ABS(ETIME(I))
IF (R - RR) 15, 15, 17
17 R = RR
KEQ = I
15 CONTINUE
160 IF (TIME) 160, 210, 160
160 IF (IFLAG(LL) - 1) 200, 210, 210
200 IF (ETIME(KEQ)) 205, 210, 210
C C C
ECK A PART THAT HAS GCNE TO AN UP STATUS (NEG ETIME) DURING A FLIGHT
PHASE, IT CAN'T BE INSTALLED ON THE AIRCRAFT UNTIL THE A/C LANDS ON
DECK (BEGINNING OF REPAIR PHASE)
205 IF (ABS(ETIME(KEQ)) - ENDPHA) 207, 600, 600
207 ETIME(KEQ) = -ENDPHA - 0.1
NEG = NEG + 1
C C C
AFTER ADJUSTING THE UPTIME FOR THE PART ABOVE, RESORT THE TIMES TO
FIND THE NEXT SCHEDULED EVENT.
C C C
IF (NEG - NEQ) 5, 220, 220
C C C
THE FIRST TIME THROUGH THE SUBROUTINE, THERE ARE NO PARTS IN THE
PIPELINE, SO EXIT SUBROUTINE
C C C
210 IF (TIME) 600, 600, 220
C C C
SORT EACH PART TYPE PIPELINE TO FIND EARLIEST TIME

```

```

C 220 UV = RFITIM(1,1)
    RFKEQ = 1
    DO 300 II = 2, NTYPE
        UV1 = RFITIM(II,1)
        IF (UV - JV1) 300,300,250
250     UV = UV1
        RFKEQ = II
300     CONTINUE
C 310 COMPARE FIRST PIPELINE TIME (UV) TO FIRST PART ETIME (R)
    IF (UV - R) 340,340,600
C 320 A REPAIR TIME OCCURS BEFORE THE NEXT EVENT
C 330
340     IF (UV - ENDPHA) 350,350,600
350     IF (ISPAE(1,RFKEQ)) 430,430,420
420     CONTINUE
    IUSED(1,RFKEQ) = IUSED(1,RFKEQ) - 1
430     CONTINUE
C 340 PIPELINE TIME OCCURS FIRST, PLACE RFI PART IN RETAIL STOCK, DECREASE
C 350 STOCK USED COUNT BY 1
C 360 INCREASE THE PART SUBSCRIPT UP FOR EACH PART STARTING WITH THE 2ND
C
    IJK = NCP(RFKEQ)
    DO 450 KK = 1, IJK
        RFITIM(RFKEQ, KK) = RFITIM(RFKEQ, KK + 1)
450     CONTINUE
C 370 SORT THE PIPELINE TO FIND THE NEXT EVENT
    JJ = RFITIM(RFKEQ, 1)
C 380 THERE WAS ONLY ONE PART IN THE PIPELINE, NO NEED TO SORT
    IF (IJK - 1) 550,550,520
520     DO 550 KX = 2, IJK
        JJJ = RFITIM(RFKEQ, KX)
        IF (JJ - JJJ) 550,550,530
530         RFITIM(RFKEQ, 1) = JJJ
        RFITIM(RFKEQ, KX) = JJ
        JJ = JJJ
550     CONTINUE
C 390 DECREASE THE COUNT OF PARTS IN THE PIPELINE
    NOP(RFKEQ) = NOP(RFKEQ) - 1
C 400 GO BACK TO SORT THE PIPELINE TIMES AGAIN, FOLLOWED BY A ANOTHER
C 410 COMPARISON TO SEE IF THE FIRST PIPELINE TIME IS PRIOR TO ETIME
    GO TO 220
600     CONTINUE

```

```

C THESE NEXT 4 LINES CAN BE ACTIVATED IN ORDER TO EXAMINE REPAIR
C TIMES OR THE NUMBER OF PARTS IN THE REPAIR PIPELINE.
C
C170 WRITE (6,170) (RFITIM(I,1),I=1,NTYPE)
C171 FORMAT (2X,RFITIM: ',4F9.1)
C172 WRITE (6,185) (NOP(K),K=1,NTYPE)
C185 FORMAT (2X,NOP ',8I4)
C RETURN
C END
C
C *****
C SUBROUTINE TTE
C COMMON /ALPHA/ DNT2, ENDPHA, ICRI, IFF, IFR, INUM, IOPT, JBB, KEQ, KKK, KZZ,
C 1, K1, KS1, LL, LLAST, NEQ, NPH, NTYPE, NUM, REDAD2, REDAD1(760), RELP, RED2
C 2, RELPY, REPOL, STPHAS, TP, TI, XCUM, TT3, UP3, IFFECF, T3, TIME, T3SUM
C COMMON /N/ IEQU(500), KEQU(500), ETIME(1000), XMTBF(200), XMTTR(200)
C COMMON /EXTRA/ KS(200), ISW(31)
C COMMON /NPH/ NPS(6), IFLAG(6), ITLE(6,31), SSTIME(6,31,2), ISS(6,31)
C COMMON /TYP/ EX(2,200), ISPARE(3,200), IUSED(3,200), IUSED(3,200)
C COMMON /DELTA/ KKK2
C COMMON /XXX/ XXX
C COMMON /VDC/ VDC(50,6), IUI(200), VMTTR(200,6), TAD2
C COMMON /GAMMA/ XMTBA, VAR, RELGA(760), TIMA(760), XXT(1442), ITT, ISEED
C COMMON /XSPARE/ XFLAG, BUDGET, COST(201), RFITIM(31,20), NPET(31), NOAC
C SULLIVAN CHANGE
C COMMON /YSPARE/ BCM(200), SRTIM(200), EL, ESS, RET, REPTIM(200), NOP(200)
C REAL UARRAY(2), EARRAY(2)
C NRP = C
C CALL LRND(ISEED, UARRAY, 2, 1, 0)
C CALL LEXPNI(ISEED, EARRAY, 2, 1, 0)
C
C K REFERS TO PART NUMBER, J REFERS TO PART TYPE
C
C10 K=KEQ
C20 J=IABS(IEQU(K))
C30 IF (ETIME(K)) 136,31,40
C31 IF (IFLAG(LL) - 1) 36,136,35
C
C IN THIS CASE, THE MISSION HAS BEGUN WITH THE A/C ON DECK (REPAIR
C PHASE). FAILURE TIMES WON'T START UNTIL BEGINNING OF FLIGHT PHASE.
C
C35 ETIME(K) = ENDPHA + ABS(XXX)*EARRAY(2)
C GO TO 37)
C

```

```

C IN THIS CASE, THE MISSION HAS BEGUN IN THE FLIGHT PHASE.
C FAILURES CAN BEGIN IMMEDIATELY.
C
36  C ETIME(K) = ABS(XXX)*EARRAY(2) + ETIME(K)
    C GO TO 370
C
C A PART HAS FAILED (ETIME PRIOR TO SUBROUTINE IS POSITIVE)
C
40  C CONTINUE
    C IF (ISPAE(1,J)-IUSED(1,J)) 60,60,50
C THERE ARE STILL SOME SPARE PARTS IN INVENTORY, INCREASE USED COUNT
C
50  C IUSED(1,J)=IUSED(1,J)+1
C NRP IS A MARKER TO SIGNIFY THAT THE FAILED PART WAS REPLACED WITH
C STOCK ON HAND (NRP = 1 MEANS STOCK USED)
C
    C NRP = 1
    C 60 CONTINUE
C INCREMENT PIPELINE COUNTER (THE NUMBER OF PARTS EITHER IN THE REPAIR
C PIPELINE OR IN THE ORDER/SHIP PIPELINE)
C
    C NOP(J) = NOP(J) + 1
C
C THIS NEXT LINE WILL ENSURE THAT THE NEXT ETIME WILL BE NEGATIVE,
C MEANING THAT THE PART IS IN THE FAILURE MODE, AND THE NEXT EVENT
C WILL OCCUR WHEN THE PART IS RESTORED TO AN UP STATUS.
C
    C X = -1.0
C THE FAILED PART WILL EITHER BE REPAIRED OR BCM'ED. DRAW A RANDOM
C BCM RATE (BCMDEC), DISTRIBUTED UNIFORM (0,(2*BCM(J)))
C
    C BCMDEC = UARRAY(1) *2* BCM(J)
C IF A UNIFORM(0,1) RANDOM NUMBER IS LESS THAN THE BCMRATE, BCM PART.
C
    C IF (UARRAY(2) - BCMDEC) 115,115,118
C PART WILL BE BCM'ED, COMPUTE EXPONENTIAL ORDER/SHIP TIME
C
    C 115 ADT = EARRAY(1) * SRTIM(J)
    C GO TO 125
C PART WILL BE REPAIRED, COMPUTE EXPONENTIAL REPAIR TIME
C
    C 118 ADT = EARRAY(1) * REPTIM(J)

```

```

C PIPELINE TIMES ARE ASSIGNED TO PARTS PLACED IN THE REPAIR OR
C ORDER/SHIP PIPELINE, AS SOON AS PHASE ENDS (A/C LANDS).
C
125 RFTIM(J,NOP(J)) = ADT + ENDPHA
C
C SCRT PIPELINE TIMES, PLACE EARLIEST TIME FIRST, FOR EACH TYPE
C
      JJ = RFTIM(J,1)
      IJ = NCP(J)
      IF (IJ.EC.1) GO TO 130
      DO 130 KX = 2, IJ
        JJJ = RFTIM(J,KX)
        IF (JJ - JJJ) 130,130,128
128   RFTIM(J,1) = JJJ
      RFTIM(J,KX) = JJ
      JJ = JJJ
130 CONTINUE
C
C IF THE FAILED PART WAS REPLACE WITH ONE FROM INVENTORY, THERE WILL
C NC DOWNTIME WHILE THE PIPELINE PRODUCES A SPARE PART FOR THE NEXT
C EXPECTED UP TIME. WAITING INVOLVES ONLY PART REPLACEMENT TIME.
C
      IF (NRP) 140,140,137
C
C FCR A PART ENTERING SUBROUTINE WITH NEGATIVE ETIME (ARRIVING IN
C DOWN STATUS), NEXT LINE ENSURES POSITIVE ETIME NEXT EVENT
C
136   X = 1.0
      ETIME(K) = X*(ABS(XXX)*EARRAY(2) + ENDPHA)
      GO TO 370
C
C NO DELAY (ADT) IS INCURRED FOR REPLACING A FAILED PART THAT HAS A
C SPARE AVAILABLE. NEXT EVENT TIME IS COMPUTED.
C
137 ETIME(K) = X*(ABS(XXX)*EARRAY(2) + ENDPHA)
      GO TO 370
C
C NO SPARES WERE AVAILABLE, UPTIME MUST INCLUDE A DELAY TIME.
C
140 ETIME(K) = X*(ABS(XXX)*EARRAY(2) + ENDPHA + ADT)
370 CONTINUE
C WRITE (6,499) XXX
C 499 FORMAT (2X,XXX',F10.4)
      RETURN
C END

```

```

C *****
C
C
C
SUBROUTINE STNDBY
COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOP,T,JBB,KEQ,KKK,KZZ
1,KK1,KSL,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD1(763),REL,P,RED2
2,REL,PY,REPGL,STPHA,S,TP,TI,XCUM,TI3,UP3,IFFEOP,T3,TIME,T3SUM
COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
COMMON /XXX/XXX
COMMON /STAN/ISTB(60,10,6)
COMMON /XSPARE/XFLAG,BUDGET,COST(201),RFITIM(31,20),NPET(31),NUAC
DO 170 I=1,50
IF (ISTE(I,1,LL)) 10,180,10
C
10 INDEX=1
DO 50 J=2,10
KK=ISTB(I,J,LL)
IF (KK) 30,60,20
20 IF (ETIME(KK)) 40,50,50
C
30 KK=IABS(KK)
IF (ETIME(KK)) 40,40,50
40 INDEX=0
GO TO 60
50 CONTINUE
C
60 K=IABS(ISTB(I,1,LL))
ISO=ISTB(I,1,LL)
C
70 IF (ETIME(K)) 170,170,80
80 IF (ETIME(K)-100000) 120,90,120
90 IF (INDEX) 170,110,100
100 IF (ISO) 170,170,150
110 IF (ISC) 150,170,170
120 IF (INCEX) 170,140,130
130 IF (ISC) 160,170,170
140 IF (ISO) 170,170,160
C
150 IABC=IABS(IEQU(K))
XX=X=XMTBF(IABC)
KEQ=K
CALL TTF
GO TO 170
C
160 ETIME(K)=100000.
170 CONTINUE

```

```

180 RETURN
END

```

C C C C C

\*\*\*\*\*

```

SUBROUTINE STATUS
COMMON /ALPHA/DNT2, ENDPHA, ICRI, IFF, IFR, INUM, IOPT, JBB, KEQ, KKK, KZZ,
1, KKI, KSI, LL, LLLAST, NEQ, NPH, NTYPE, NUM, REDAD1(76), RELP, RED2,
2, RELPY, REPOL, STPHA, STP, T1, XCUM, T13, UP3, IFFEGP, T3, TIME, T3SUM
COMMON /BETA/NRO(6,300), IB(6,300,8), NLINE(6)
COMMON /EXTRA/ KS(20), ISW(31)
COMMON /N/IEQU(500), KEQU(500), ETIME(1000), XMTBF(200), XMITR(200)
COMMON /NPH/ NSS(6), IFLAG(6), TITLE(6,31), STIME(6,31,2), ISS(6,31)
COMMON /XSPARE/XFLAG, BUDGET, COST(20), RFTIM(31,20), NPET(31), NUAC
COMMON /YSPARE/BCM(20), SRTIM(200), EL, ESS, RET, REPTIM(200), NOP(200)

```

C

```

KID=0
NL1=NLINE(LL)
DO 130 K=1,NL1
10 KT=IB(LL,K,1)
12 IF(KID-KT)16,18,16
14 ISUM=0
16 IF(NRO(LL,K))130,130,20
20 DO 60 J=2,8
30 KK=IABS(IB(LL,K,J))
40 IF(ETIME(KK)) 60,60,50
50 ISUM=ISUM+1
60 CONTINUE
70 IF(IISUM-NRO(LL,K)) 80,90,90
80 ETIME(KT)=-1.
90 GO TO 100
90 ETIME(KT)=1.
SULLIVAN CHANGE
100 IF(KS(12))125,125,110
110 IF(KS(12))125,125,125
120 WRITEL(6,120)KT,ETIME(KT)
120 FORMAT(1X3HKK=,I5,7H ETIME=,F10.5)
SULLIVAN STOP
125 KID=KT
130 CONTINUE
N=NSS(LL)+1
DO 160 I=1,N
J=ISS(LL,I)

```

C

```

C SULLIVAN CHANGE ISW(I) TO REAL FORMAT
140 ISW(I)=-1.0
GO TO 160
150 ISW(I)=1.0
C SULLIVAN STOP
160 CONTINUE
KZZ=0
RETURN
END

C
C
C *****
SUBROUTINE APPLE
DIMENSION IPRNT(50), ICHLD(50), MKBA(100)
COMMON /ALPHA/DNT2, ENDPHA, ICR1, IFF, IFR, INUM, IOPT, JBB, KEQ, KKK, KZZ
1, KKL, KSL, LL, LLAST, NEQ, NPH, NTYPE, NUM, REDAD2, REDAD1(760), RELP, RED2
2, RELPY, REPOL, STPHA, TP, T1, XCUM, T13, UP3, IFFECF, T3, TIME, T3SUM
COMMON /BETA/NRO(6,300), IB(6,300,8), NLIN(6)
COMMON /N/IEQU(500), KEQU(500), ETIME(1000), XMTBF(200), XMTTR(200)
COMMON /TIGAP/ UP4, XNUM, BAPRIN, AVA, XPCAP, RUNID(19), TYCOUN(500)
+ , COUNTB(500), XTCUM
COMMON /RUNAP/ ITEMP2, DELT, ISSA(31), ISSC
COMMON /NPH/NSS(6), IFLAG(6), TITLE(6,31), SSTIME(6,31,2), ISS(6,31)
COMMON /PACKAP/ IBNUM( 6,500), ISYS( 6), F(200,4)
COMMON /XSPARE/ XFLAG, BUDGET, COST(201), RFITIM(31,20), NPET(31), NOAC

C IF (BAPRIN) 790, 90, 90
90 JCOUNT=0
100 IPTR=0
L=LL
IF (ITEMP2) 240, 105, 107
105 K=IBNUM(L, ISYS(L)-500)
GO TO 108
107 KSS=ISSA(ISSC)
108 K=IBNUM(L, ISS(L, KSS)-500)
110 NN=2
C DO 210 N=NN, 8
IGRP=IE(L, K, N)
IF (IGRP) 240, 212, 140
140 IF (ETIME(IGRP)) 150, 150, 210
150 IF (IGRP-500) 170, 170, 160

```

```

C 170 IF (JCCUNT) 240,200,180
180 DO 190 I=1,JCOUNT
190 IF (MKBA(I)-IGRP) 190,210,190
200 CONTINUE
210 JCCUNT=JCCUNT+1
212 IF (K-1) 220,220,214
214 KI D2=IB(L,K-1,1)
216 K=K-1
220 GO TO 108
C 220 IF (IPTR) 240,260,230
C 230 K=IPRNT(IPTR)
KI D1=IB(L,K,1)
NN=ICHLD(IPTR)
IPTR=IPTR-1
GO TO 120
C 160 IF (N-8) 165,167,240
C 165 IPTR=IPTR+1
IPRNT(IPTR)=K
ICHLD(IPTR)=N+1
167 K=IBNUM(L,IGRP-500)
GO TO 108
C 240 WRITE (6,250)
250 FORMAT (12H APPLE ERROR)
GO TO 300
C 260 IF (ITEMP2) 240,265,262
262 ISSC=ISSC-1
265 IF (ISSC) 240,265,100
FCUNT=FLOAT(JCOUNT)
IF (ITEMP2) 270,270,280
C 270 DO 275 I=1,JCOUNT
275 TY COON(MKBA(I))=TY COON(MKBA(I))+DELT/FCUNT
GO TO 300
C 280 DO 290 I=1,JCOUNT

```

```

290 COUNTB(MKBA(I))=COUNTB(MKBA(I))+1/FCOUNT
300 CONTINUE
    RETURN
C
790 CONTINUE
    WRITE (6,800) (RUNID(I),I=1,19)
800 FORMAT(1H1,3X,19A4//)
810 FORMAT(32X,19HCRITICAL EQUIPMENTS//32X,18HUNAVAILABILITY AND/ 27
1X25HPERCENT OF UNAVAILABILITY//)
820 WRITE (6,820)
820 FORMAT (24X4HNAME,17X7HNUM HRS,11X5HUNAVA,2X7HPERCENT,6X8HEQU TYPE
1,5X7HEQU NUM/)
C
830 IF (AVA-1.) 830,880,830
    TR=TYCCCN(1)
    INDEX=1
    DO 850 I=2,NEQ
    TRR=TYCCCN(I)
    IF (TR-TRR) 840,850,850
840 TR=TRR
850 CONTINUE
    TYCUM=TYCOON(INDEX)/TT3
    TYCUM2=TYCOON(INDEX)/(TT3-UP4)*100.
    IF (TYCCCN(INDEX)) 860,880,860
860 IX=IABS(IEQU(INDEX))
    WRITE (6,870) (F(IX,J),J=1,4),TYCOON(INDEX),TYCUM,TYCUM2,IXX
1,INDEX
870 FORMAT (20X4A4,F20.4,4XF8.4,F8.2,8X14,10X14)
C
    TYCOON(INDEX)=0.0
    GO TO 830
880 WRITE (6,890) (RUNID(I),I=1,19)
890 WRITE (6,910)
910 FORMAT(32X,19HCRITICAL EQUIPMENTS//32X,17HUNRELIABILITY AND/ 27X
127HPERCENT OF MISSION FAILURES//)
920 WRITE (6,920)
920 FORMAT (12X11HDESCRIPTION,8X3HNO.,6X6HUNREL ,3X7HPERCENT,2X13HEQUI
1P EQUIP/28X8HFAILURES,22X10HTYPE NO.)
    IF (XPCAP-1.) 930,1090,930
C
930 INEWA=0
    DO 950 I=1,NEQ
    IF (COUNTB(I)) 950,950,940
940 INEWA=INEWA+1
    MKBA(INEWA)=I
950 CONTINUE

```

```

C
  TOTAL=XNUM-XTCUM
  IF (INEWA-1) 1010,575,952
  INDEX=MKBA(1)
  NN=1
  TR=COUNTB(INDEX)
  DO 970 I=2,INEWA
  IF (TR-COUNTB(MKBA(1))) 960,970,970
  960 INDEX=MKBA(I)
  NN=I
  TR=COUNTB(INDEX)
  970 CONTINUE
  977 UNREL=TR/XNUM
  PERC=TR/TOTAL*100.X)
  IND=IABS(IEQU(INDEX))
  WRITE(6,990) (F(IND,J),J=1,4),TR,UNREL,PERC,IND,INDEX
  990 FORMAT(9X4A4,3XF6.1,5XF6.4,3XF6.2,4X14,3X14)
  MKBA(NN)=MKBA(INEWA)
  INEWA=INEWA-1
  GO TO 955

C
  975 INDEX=MKBA(1)
  TR=COUNTB(INDEX)
  GO TO 977

C
  1010 JNUM=IFIX(XNUM)
  WRITE(6,1020) JNUM
  1020 FORMAT(//9X19HTOTAL NO. MISSIONS=,I4)
  ITCTAL=ITCTAL
  WRITE(6,1030) ITOTAL
  1030 FORMAT(9X27HTOTAL NO. MISSION FAILURES=,I4)
  1090 RETURN
  END

*****
C
C
C
C
C
SUBROUTINE SPARES
COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
1,KKI,KSI,LL,LLLAST,NEQ,NPH,NTVPE,NUM,REDAD2,REDAD1,(76J),RELP,RED2
2,RELPLY,REPOL,STPHAS,TP,T1,XCUM,TI3,UP3,IFFECP,T3,TIME,T3SUM
COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
COMMON /TYP/EX(2,200),ISPAARE(3,200),IUSED(3,200),IUSED(3,200)
COMMON /CSPARE/SPR1,SPR2,SPR3,SPR4,SPR5,SPR6,SPR7,SPR8,SPR9
1,SPR10,SPR11,SPR12,SPR13,SPR14,ITMPOP(200)
C
C
C
C
C
CREILLY AED

```

```

COMMON/XSPARE/XFLAG,BUDGET,COST(201),RFITIM(31,20),NPET(31),NOAC
COMMON /KSPARE/JTIME,TOTSPR
C SULLIVAN CHANGE
COMMON/YSAPARE/BCM(200),SRTIM(200),EL,ESS,RET,REPTIM(200),NOP(200)
WRITE (6,999) XFLAG
999 FORMAT (2X,'XFLAG: ',F4.1)
C
C SULLIVAN CHANGE
C THIS NEXT LINE WILL READ IN ACIM INVENTORY LEVELS (OR ANY OTHER
C ARBITRARY LEVELS CHOSEN)
C
C READ (5,6) (ISAPARE(1,J),J=1,NTYPE)
C IF (XFLAG-1) 5,2,3
C 2 CALL ASAPARE
C 2 CALL MSPARE
C
C WRITE (6,9)
C GO TO 101
C 3 CALL GSPARE
C 3 CALL RIMAIR
C WRITE (6,11)
C GO TO 101
C
C WRITE (6,22)
C GO TO 101
C 5 CUT=SPRI
C 6 FORMAT (35I2)
C 5 CONTINUE
C GO TO 101
C SULLIVAN STOP
C XAVAIL=.9
C XBUDL=.85*BUDGET
C WRITE (6,300)XBUDL ,F8.3)
C 300 FORMAT (/1X,5HBUDL ,F8.3)
C XBUDH=1.05*BUDGET
C WRITE (6,301)XBUDH ,F8.2)
C 301 FORMAT (/1X,5HBUDH ,F8.2)
C HIGH=1.0
C LOW=.0
C
C SULLIVAN CHANGE
C 5 FJRMAT (/1X,31HSPARES BEING COMPUTED USING ASO)
C WRITE (6,303)XAVAIL
C 11 FORMAT (/1X,34HSPARES BEING COMPUTED USING RIMAIR)
C SULLIVAN STOP
C CREILLY STOP
C DO 10 I=1,NTYPE

```

```

ITMPOP(I)=0
10 CONTINUE
DO 20 I=1,NEQ
ITMPOP(IEQU(I))=ITMPOP(IEQU(I))+1
20 CONTINUE
25 DO 90 I=1,NTYPE
EX90DD=((8766./XMTBF(I))/4.)*ITMPOP(I)
WRITE(6,29) I,EX90DD
C 29 FORMAT(/IX,16H EX90DD FOR ITEM ,I4,4H IS ,F8.0)
IF (EX90DD-1.) 60,30,30
C 30 PRBSUM=EXP(-EX90DD)
DUM=PRBSUM
KFACT=1
K=0
40 K=K+1
KFACT=KFACT*K
PRBSUM=PRBSUM+DUM*(EX90DD**K)/KFACT
WRITE(6,303)XAVAIL
C 303 FORMAT(/IX,9H XAVAIL = ,F6.4)
IF (PRBSUM-XAVAIL) 40,50,50
50 ISPAE(1,I)=K
GO TO 90
60 IF (4.*EX90DD-CUT) 80,80,70
C 70 ISPAE(1,I)=1
GO TO 90
80 ISPAE(1,I)=0
90 CONTINUE
XSUM=0.0
DO 95 I=1,NTYPE
XSUM1=ISPAE(1,I)*COST(I)
XSUM=XSUM1+XSUM1
95 CONTINUE
WRITE(6,302)XSUM
C 302 FORMAT(/IX,5H XSUM ,F8.2)
IF (XSUM-XBUDL) 200,97,96
C 96 IF (XSUM-XBUDL) 97,97,210
IF (XSUM-XBUDH) 200,200,205
97 WRITE(6,98)XAVAIL
98 FORMAT(/IX,44H,FSLIP ALLOWS CONSTRAINED BY BUDGET, XAVAIL= ,F8.6)
99 DO 100 I=1,NTYPE
DO 100 J=2,3
ISPAE(J,I)=0
100 CONTINUE
C 100 ORREILLY ACC
WRITE(6,22)
22 FORMAT(/IX,11H SPARES TYPE,6X4HSHIP,4X6HTENDER,6X4HBASE,12X6HFACOR)

```

```

101 RETURN
200 IF (XAVAIL-.9) 97,99,99
C 205 XLOW=XAVAIL
C XAVAIL=(HIGH+XAVAIL)/2.
205 IF (XAVAIL-.1) 208,208,206
206 XAVAIL=XAVAIL-.05
WRITE(6,303)XAVAIL
GO TO 25
208 DO 215 I=1,NTYPE
J=1
ISPARE(J,I)=0
215 CONTINUE
GO TO 57
C 210 HIGH=XAVAIL
C XAVAIL=(XLOW+XAVAIL)/2.
C GO TO 25
C CREILLY STOP
C END
C *****
C SULLIVAN ADDS
C SUBROUTINE ASPARE
C THIS PROGRAM CALCULATES AVCAL SPARES USING ASO POLICY
COMMON/ALPHA/DNT2, ENDPHA, ICRI, IFF, IFR, INUM, IOPT, JBB, KEQ, KKK, KZZ
1,KK1, KSI, LL, LLLAST, NEQ, NPT, NTYPE, NUM, REDAD2, REDAD1(76), RELP, RED2
2,REPLY, REPOL, STPHAS, TP, T1, XCUM, TT3, UP3, CFEEGP, T3, TIME, T3SUM
COMMON/N/IEQJ(500), KEQU(500), ETIME(1000), XMTBF(200), XMTTR(200)
COMMON/XSPARE/XELAG, BUDGET, CUST(201), RFITIM(31,20), NPET(31), NOAC
COMMON/KSPARE/JTIME, TOTSPR, COMB(9999), COMBA(9999), SER(100)
COMMON/TYP/EX(2,200), ISPARE(3,200), IUSED(3,200), IUSED(3,200)
COMMON/YSPARE/BCM(200), SRTIM(200), EL, ESS, RET, REPTIM(200), NOP(200)
REAL TCCST, MRP, V(200)
INTEGER AVCAL, RP, AA
C INITIALIZE VARIABLES
TCOST=0.0
WRITE(6,1)
FORMAT(/1X,46HSPARES WILL BE DETERMINED USING ASOINST POLICY)
1 DO 5 I=1,NTYPE
DO 5 J=1,3
5 ISPARE(J,I)=0
CONTINUE
DO 91 K=1,NTYPE
AA=0

```

```

C
AVCAL = 0
RP = 0
I = 0
QTRDEM = (FLOAT(JTIME)*NPET(K)*NOACJ)/XMTBF(K)
WRITE (6,991) QTRDEM, JTIME, NPET(K), NOAC, XMTBF(K)
991 FORMAT (2X, 'QTRDEM ', F9.4, 2X, 15, 1X, 12, 2X, 12, 2X, F9.4)
BCMR = CTRDEM*BCM(K)
MRP = (CTRDEM*(1.0-BCM(K)))
MRP = MRP*REPTIM(K)/2160.
IF (MRP.LT.0.1) GO TO 40
IF (MRP.LT.20.0) GO TO 10
  RP = 1.2817 * (MRP**0.5) + MRP + 0.5
  GO TO 40
E = EXP (-MRP)
X=E
Y=E
IF (X.GE.0.895) GO TO 20
I=I+1
Y=Y*MRP/FLOAT(I)
X=X+Y
GO TO 15
20 RP=I
40 CONTINUE
IF (RP.EQ.0) GO TO 70
IF (BCMR.LT.1.0) GO TO 50
IF (IFIX(BCMR+0.5).LE.1) AA=1
IF (IFIX(BCMR+0.5).GT.1) AA=IFIX(BCMR+0.5)
  GO TO 60
50 CONTINUE
AA=0
60 CONTINUE
GO TO 80
70 CONTINUE
IF (COST(K).LT.5000.) GO TO 75
IF (BCMR.LT.0.5) GO TO 80
IF (IFIX(BCMR+0.5).LE.1) AA=1
IF (IFIX(BCMR+0.5).GT.1) AA=IFIX(BCMR+0.5)
  GO TO 80
75 CONTINUE
IF (BCMR.LT.0.34) GO TO 80
IF (IFIX(BCMR+0.5).LE.1) AA=1
IF (IFIX(BCMR+0.5).GT.1) AA=IFIX(BCMR+0.5)
80 CONTINUE
AVCAL = RP + AA
TCOST = TCOST + COST(K)*FLOAT(AVCAL)
ISPAE(1,K)=AVCAL
91 CONTINUE

```

```

C
C
C C101
191
END
WRITE(6,101)
FORMAT(/IX,29HALL SPARES HAVE BEEN COMPUTED)
WRITE(6,191) TCOST
FORMAT(2X,10TOTAL COST ASOMAN: ',F12.1)
RETURN
END
*****
SUBROUTINE RIMAIR
THIS PROGRAM UTILIZES RIMAIR OPTIMIZATION TO COMPUTE AVCAL
COMMON/ALPHA/DNT2, ENDPHA, ICRI, IFF, IFR, INUM, IOPT, JBB, KEQ, KKK, KZZZ
1,KK1, KS1, LL, LLAST, NEQ, NPH, NTYPE, NUM, REDAD1(763), RELP, RED22
2, RELPY, REPOL, STPHAS, TP, T1, XCUM, T13, UP3, OFFEOP, T3, TIME, T3SUM
COMMON/N/IEQU(500), KEQU(500), ETIME(1000), XMTBF(200), XMTTR(200)
COMMON/XSPARE/XFLAG, BUDGET, COST(201), RFITIM(31,20), NPET(31), NOAC
COMMON/XSPARE/JTIME, TOTSPR, COMB(9999), COMBA(9999), SER(100)
COMMON/TYP/EX(2,200), ISPARE(3,200), IUSED(3,200), IUSE(3,200)
COMMON/YSPARE/BCM(200), SRTIM(200), EL, ESS, RET, REPTIM(200), NOP(200)
INTEGER OPTMAL
REAL MPP, V(200), EL
INITIALIZE VARIABLES
TCOST=0.
DO 3 I=1, NTYPE
DO 3 J=1, 3
ISPARE(J, I)=0
CONTINUE
ESS=1.0
KK=1, NTYPE
DO 950 KK=1, NTYPE
OSTP = SRTIM(KK)/24.0
OSTK = SRTIM(KK)/24.0
BCMRAT = BCM(KK)
BCMWAR = BCM(KK)
QTRDEM = (FLOAT((JTIME)*NPET(KK)*NOAC))/XMTBF(KK)
BCMP=QTRDEM*BCMRAT
BCMW = QTRDEM * BCMWAR
MRP = REPTIM(K) * QTRDEM * (1. - BCMRAT)/2160.
COSTK=CCST(KK)
WP = MRP + COSTW + RET ) * BCMWAR * QTRDEM/90.
IF (WP .EQ. 0.0) GO TO 5
BEGIN EVALUATION

```

```

C      OLP=((558.61*BCMP)/COSTK)**0.5
C      OLW=((558.61*BCMW)/COSTK)**0.5
C      END = BCMP * (1. - (RET/90.)) - (OSTW/90.)) + (BCMP * OSTP/90.)
C      END MUST BE ZERO OR GREATER
C      IF (END.LT.0.0) END=0.0
C      CALCULATE BASIC PIPELINE
C      GR = WP + END
C      CALL APPROPRIATE SUBROUTINE BASED ON WARTIME PIPELINE
C      IF (WP.GE.5.) GO TO 10
C      CALL POISSON (WP,GR,EL,COSTK,QTRDEM,ESS,OPTMAL,OLP)
C      GO TO 20
C      CALL NCRMAP (OLP,EL,WP,COSTK,QTRDEM,ESS,GR,CPTMAL)
C      CALL AVCAL (GR,OLP,OPTMAL,COSTK,CCOST)
C      TCOST = TCOST + CCOST
C      IF (OPTMAL.EQ.0.) GO TO 5
C      ISPAR(1,KK) = OPTMAL
C      CONTINUE
C      WRITE (6,335) TCOST
C      FORMAT(2X,'TOTAL COST RIMAIR: ',F13.0)
C      RETURN
C      END

```

```

C
C      SUBROUTINE POISSON (WP,GR,EL,COSTK,QTRDEM,ESS,OPTMAL,OLP)
C      INTEGER S,OPTMAL,MAX
C      REAL EL,MN,ESS,WP,GR,QTRDEM,A,PS3,CT,PS,OLP
C      MN = 0.0
C      A = 0.95
C      MAX = 0
C      PS3 = EXP(-GR)
C      CT = PS3
C      IF (CT.GE.A) GO TO 7
C      MAX = MAX + 1
C      PS3 = PS3*GR/FLOAT(MAX)
C      CT = CT + PS3
C      GO TO 5
C      CONTINUE
C      MAX = MAX + OLP - 1 + 0.5
C      TRUNCATE WARTIME PIPELINE TO INTEGER VALUE
C      S = WP
C      CALCULATE POISSON DISTRIBUTION OF MEAN WARTIME PIPELINE
C      PS = EXP (-WP)
C      CALCULATE POISSON DISTRIBUTION OF BASIC PIPELINE
C      PS2 = EXP (-GR)
C      ASSIGN CS POISSON OF GR
C      CS = PS2
C      CALCULATE MINIMUM STOCK

```

```

C      IF (QTRDEM.NE.0.0) MN=(EL*COSTK)/(QTRDEM*ESS)
C      OPTIMIZATION LOOP
C      IF (S.EC.0) GO TO 15
C      DO 10 I=1,S
C      PS = (PS*WP)/FLOAT(I)
C      CS=CS+PS2
C      10 COMPARE WARTIME PIPELINE POISSON VALUE WITH MINIMUM STOCK,
C      IF LOWER, BRANCH
C      15 IF (PS.LT.MN) GO TO 40
C      20 IF (CS.GE.A) GO TO 30
C      IF (PS.LT.MN) GO TO 40
C      S = S + 1
C      CALCULATE NEW POISSON VALUES AND CS
C      PS=(PS*WP)/FLOAT(S)
C      PS2=(PS2*GR)/FLOAT(S)
C      CS=CS+PS2
C      GC TO 20
C      30 IF (PS.LT.MN) GO TO 40
C      IF (S.GE.MAX) GO TO 40
C      S = S + 1
C      PS = PS*WP/FLOAT(S)
C      GC TO 30
C      40 CONTINUE = S
C      OPTIMAL
C      RETURN
C      END
C      NORMAL APPROXIMATION TO POISSON
C      SUBROUTINE NORMAP (OLP,EL,WP,COSTK,QTRDEM,ESS,GR,OPTMAL)
C      INTEGER OPTMAL,LMN,NNP
C      REAL ESS,PI,OLP,OLW,WP,COST(200),QTRDEM,GR
C      PI=3.14159
C      CALCULATE APPROX OF MIN STOCK USING NORMAL APP
C      AMN=(EL*COSTK*(2*PI*WP)**0.5)/(QTRDEM*ESS)
C      COMPARE APPROX TO ONE, BRANCH IF LESS OR EQUAL
C      IF (AMN.LE.1) GO TO 10
C      SET OPTMAL EQUAL TO ZERO, RETURN TO MAIN
C      OPTMAL = 0
C      RETURN
C      CALCULATE LMN AND NNP (ROUNDUP)
C      10 LMN=WP + 1 + ((-2)*WP*ALOG(AMN))**0.5
C      NNP=2.33*(GR**0.5) + GR + OLP
C      IF (NNP.LT.LMN) GO TO 20
C      SET OPTMAL EQUAL TO LMN, RETURN TO MAIN
C      OPTMAL = LMN
C      RETURN

```

```

C 20 SET OPTMAL EQUAL TO NNP, RETURN TO MAIN
   OPTMAL = NNP
   RETURN
   END
C
C   COMPUTE AVCAL
C
C   SUBROUTINE AVCAL (GR,OLP,OPTMAL,COSTK,CCOST)
C   INTEGER OPTMAL,MIN,IACAL
C   REAL A,GR,OLP,OLW,COST(200),CCOST
C   A=0.5
C   COMPARE GROSS REMOVALS TO CONSTANT, IF LOW, BRANCH
C   IF (GR.LT.A) GO TO 10
C   COMPARE OPERATING LEVEL TO ONE, SET EQUAL TO ONE IF LOW
C   IF (OLP.LT.1.) OLP=1.
C 10 MIN=OLP+GR+0.5
C   COMPARE OPTMAL TO MIN, BRANCH IF EQUAL OR GREATER
C   IF (OPTMAL.GE.MIN) GO TO 20
C   SET IACAL EQUAL TO MIN
C   IACAL = MIN
C   GO TO 30
C 20 SET IACAL EQUAL TO OPTMAL
C   IACAL = OPTMAL
C 30 CALCULATE COST AND RETURN TO MAIN
C   CCOST=FLOAT(IACAL)*COSTK
C   OPTMAL=IACAL
C   RETURN
   END

```

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