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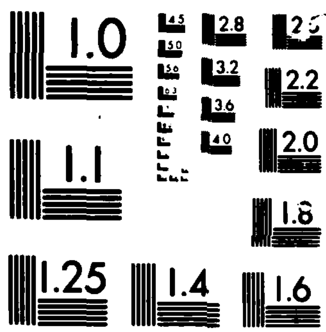

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AFIT/GOR/ENS/85D-6

A SIMULATION MODEL OF THE T-46A AIRCRAFT FOR AVAILABILITY AND SORTIE PROJECTIONS

THESIS

Roger A. Foley
Captain, USAF

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AFIT/GOR/ENS/85D-6

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Regression analysis techniques were used to estimate the functional relationship between the independent variables and the response variables. After initial screening, only two factors were included as the independent variables. These were mean time between failures (MTBF) and mean time to repair (MTTR). A central composite design was used to gather the data needed to perform the regression.

The results of the regression analysis indicated that for both aircraft availability and sortie generation rate, a second order regression equation in terms of only the MTBF factor provided the best fit. As was expected, an increase in MTBF, meaning the aircraft is more reliable, results in an increase in both aircraft availability and sortie generation rate. Estimates and confidence intervals for aircraft availability and sortie generation rate were determined.

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A SIMULATION MODEL OF THE T-46A AIRCRAFT FOR AVAILABILITY AND SORTIE PROJECTIONS

THESIS

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

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Roger A. Foley　　　　Douglas S Hager

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List of Symbols

1. AA - Aircraft Availability
2. AFIT - Air Force Institute of Technology
3. AFOTEC - Air Force Operational Test and Evaluation Center
4. ANOVA - Analysis of Variance
5. ASD - Aeronautical System Division
6. ATC - Air Training Command
7. LCOM - Logistics Composite Modeling
8. MTBF - Mean Time Between Failure
9. MTTR - Mean Time To Repair
10. SLAM - Simulation Language for Alternative Modeling
11. SGR - Sortie Generation Rate
12. UPT - Undergraduate Pilot Training
13. WUC - Work Unit Code

ABSTRACT

This study simulated the operation of the T-46A trainer aircraft in the Undergraduate Pilot Training (UPT) environment in order to estimate aircraft availability and sortie generation rate. The simulation model is based on current T-37 aircraft UPT operations and uses estimates of the reliability and maintainability of the T-46A.

Regression analysis techniques were used to estimate the functional relationship between the independent variables and the response variables. After initial screening, only two factors were included as the independent variables. These were mean time between failures (MTBF) and mean time to repair (MTTR). A central composite design was used to gather the data needed to perform the regression.

The results of the regression analysis indicated that for both aircraft availability and sortie generation rate, a second order regression equation in terms of only the MTBF factor provided the best fit. As was expected, an increase in MTBF, meaning the aircraft is more reliable, results in an increase in both aircraft availability and sortie generation rate. Estimates and confidence intervals for aircraft availability and sortie generation rate were determined.

A SIMULATION MODEL OF THE T-46A AIRCRAFT FOR AVAILABILITY AND SORTIE PROJECTIONS

I. Introduction

Background

One of Air Training Command's (ATC's) primary functions is to provide flight training to undergraduate aircrew candidates. Currently, ATC uses the Cessna T-37B aircraft as the primary trainer to perform this function. Unfortunately, "[t]he T-37 is a 1950's technology trainer that is becoming increasingly more costly to operate due to high fuel consumption, price escalation of fuel and parts, availability of parts, and increases in manpower costs" (4:1). In addition, the T-37 does not have a pressurized cockpit which limits the airspace in which the T-37 is able to perform its training maneuvers. Finally, the number of T-37's available is less than the number projected to be needed in future years.

Because of these deficiencies, the Air Force has made the decision to buy a new primary trainer for flight training. Fairchild Republic has been given the contract to produce this new primary trainer called the T-46A. The objectives of the T-46A are to overcome the "...operational deficiencies of the T-37B, to realize operational and support cost savings through the use of modern airframe and engine technology, and to provide ATC an adequate number of airframes to meet flying hour requirements beyond FY 87" (4:3).

Fairchild Republic will deliver the first two production aircraft to the Air Force in April 1986 (7:109). The Air Force Operational Test and Evaluation Center (AFOTEC) will use these two aircraft to perform initial operational test and evaluation. However, before these planes are delivered, the Aircraft Logistics Analysis Branch in AFOTEC (AFOTEC/LG4A) is interested in obtaining a simulation model which will estimate certain performance characteristics of the T-46A. Specifically, AFOTEC is interested in predicting aircraft availability and the sortie generation rate for the T-46A aircraft. Aircraft availability is the percent of time that an aircraft is capable of performing all of its assigned missions. The sortie generation rate is the average number of sorties (flights) an aircraft is capable of performing in a given time frame. The time frame for this study will be one day. The sortie generation rate is a function of the total number of aircraft at a location, aircraft availability, mission length, and flight line operations.

Statement of the Problem

The problem this study considers is determining the expected aircraft availability and sortie generation rate for the T-46A aircraft. This will be accomplished by simulating the scheduled and unscheduled maintenance of the T-46A aircraft as well as the flight line operations at a typical Undergraduate Pilot Training (UPT) base.

Scheduled maintenance is maintenance that is performed on all aircraft after a specified amount of flight hours have been accumulated. An example of scheduled maintenance is the removal and thorough inspection of the engines after every 300 hours of flight time. Unscheduled maintenance is maintenance that is required whenever a component or subsystem, such as a radio, fails on the aircraft.

The flight line operations include preflight and postflight inspections, on-aircraft maintenance, engine test facilities, engine repair shops, and other off-aircraft maintenance activities. This study will be limited to preflight and postflight inspections and on-aircraft maintenance. Because of this limitation, this study will not attempt to determine manpower requirements at the UPT base.

The model will be based upon estimated reliability and maintainability data in order to predict the expected performance of the T-46A aircraft prior to actual operational testing. As operational testing is begun in April 1986, the test data that is collected will be used to update the model and reevaluate the performance characteristics to determine whether the T-46A is achieving the desired levels of performance.

Research Question

What levels of aircraft availability and sortie generation rate can be achieved with the T-46A trainer in an UPT environment?

Objectives

The overall objective of this research is to develop a valid simulation model of a UPT wing equipped with T-46A aircraft in order to determine the expected aircraft availability and sortie generation rates.

In order to fulfill this objective, several subobjectives need to be accomplished. These subobjectives are:

1. Collect data on break rates and repair times for major subsystems of the T-46A aircraft.

2. Model the flying operation and maintenance of the T-46A aircraft in the UPT environment.

3. Develop confidence intervals and prediction equations for model estimates of aircraft availability and sortie generation rates.

General Technique

The general technique that will be used in this research is simulation. Simulation is chosen over an analytic technique because of the probabilistic nature of modeling aircraft flying operations. The overall reliability and maintainability of an aircraft is dependent on many random processes. These random processes often interact with each other which makes the problem of determining the availability and sortie generation rate very difficult to solve analytically. Simplifying assumptions can be made to make the problem analytically tractable, however, these numerous assumptions may cast doubt on the validity of the results. A simulation, on the other hand, can model the interactions between random processes and provide valid results.

The simulation will be accomplished using SLAM (Simulation Language for Alternative Modeling). SLAM is chosen for several reasons. First, the sponsor for this research (AFOTEC) has requested that SLAM be used. AFOTEC will be using this simulation model during operational testing and they are familiar with the SLAM language. In addition, SLAM is a very flexible simulation language yet it is also very easy to use. Finally, a SLAM model, being FORTRAN based, is easily transported between different computers. Thus, AFOTEC will be able to easily adapt the model to their computer.

Methodology

As just discussed, simulation is the general technique chosen for providing answers to the research question. However, the actual methodology required to arrive at those answers involves accomplishing the subobjectives that were mentioned earlier: collecting data, modeling the T-46A in the UPT environment, and developing confidence intervals for the model output.

Collecting data is the initial phase of this research.

Data must be collected which estimates the break rates and repair times of major subsystems of the T-46A aircraft. Since the T-46A is a new aircraft, past performance data for the subsystems are not available. However, some of the subsystems are similar to subsystems currently being used on other Air Force aircraft. In these instances, the data from the currently used subsystems can be substituted for the T-46A subsystems. The reliability for the subsystems where comparability data does not exist has to be estimated. Knowledgeable personnel from the contractor and ATC maintenance can provide realistic estimates for these subsystems.

After collecting the data, the next phase is to model the T-46A aircraft in the UPT environment. However, before a model can be built, the modeler must understand the real life system. Therefore, the first priority is gathering information on the T-37 operations in the current UPT environment. Once the current system is understood, the next step is to attempt to model the UPT environment as accurately as possible. While developing the model, the T-37 operations should be modified to reflect anticipated changes in the flight operations for the T-46A. An important step in this phase is the verification and validation of the model as it is built.

Once the final model has been verified and validated, the last phase of the research is to develop confidence intervals for aircraft availability and sortie generation rate. This can be accomplished by using regression analysis techniques which estimate the effects of independent variables on the response variables. Performing the regression analysis requires that several tasks be accomplished. The first task is to identify factors in the model which could influence the main performance characteristics, aircraft availability and sortie generation rate. The second task is to design an experiment to collect output data from the model. The next task is to perform a regression analysis on the data to estimate the parameters of the functional relationship suggested by the data. Finally, the last task is to perform analysis on the factors so that confidence intervals can be constructed around the model estimates of aircraft availability and sortie generation rate.

Scope

The scope of this study has been limited in three areas. First, this analysis will use only one scenario. This scenario represents the current UPT operations modified to reflect expected changes for the T-46A. Second, the analysis is limited to on-aircraft maintenance only. Finally, the analysis is limited to UPT operations of only the T-46A. The analysis will not include any T-38 considerations.

Overview

The remainder of this thesis consists of four chapters. Chapter II gives a verbal description of the model, detailing the UPT environment and the major assumptions used in building the model.

Chapter III analyzes the factors and outlines the experimental design. In addition, the steps required to ensure valid simulation output are discussed.

Chapter IV provides the results of the experimental design and the analysis of those results.

The final chapter, Chapter V, presents the confidence intervals for the main performance characteristics, aircraft availability and sortie generation rate, as well as discussing the conclusions reached during the course of this research.

II. Model Description

A full description of the model of the T-46A in the UPT environment requires that a description of the aircraft and the UPT environment be presented first. Because the simulation language used has an important impact on the development of the model, a brief description of SLAM will also be presented before the description of the model. These will be followed by an overview of the model and then a more detailed narrative description of the model. The assumptions inherent in the model will be presented next. Finally, the chapter will conclude with a description of the steps taken to verify and validate the model.

T-46A Description

The T-46A is a twin engine aircraft with side by side seating. In its role as the primary phase trainer for UPT, the T-46A, like the T-37B, must be capable of performing several different training missions. The cockpit of the T-46A will be pressurized and contain more modern avionics. These and other characteristics will improve the flight training capabilities of the T-46A as compared to the T-37B (2:3; 4:1). The availability of the T-46A will depend heavily on the reliability of its system components. This study will analyze the T-46A by classifying the aircraft into 74 subsystems. These subsystems are listed in Table B.1 of Appendix B.

The T-46A and the UPT System

The T-46A is projected to be assigned to six ATC training bases. They are Columbus AFB MS, Laughlin AFB TX, Reese AFB TX, Vance AFB OK, Williams AFB AZ, and Mather AFB CA for Undergraduate Navigator Training (4:8). Laughlin AFB will be the first base to receive the T-46A for UPT. Flight operations are essentially identical at each UPT base. These operations are described next.

The flight operations of the T-46A in UPT can be described under two broad headings, flying and maintenance. There are two categories of maintenance, scheduled maintenance, which are preventative actions, and unscheduled maintenance, which are corrective actions. These will be discussed later. The daily flying use of the T-46A includes four activities. They are scheduling which aircraft will fly, preparing the scheduled aircraft for that days flying, the flights themselves, and after each flight, a short inspection and servicing of the aircraft. These four activities are discussed in more detail next.

Scheduling aircraft to fly on a particular day is accomplished during the previous night. Not all aircraft will be flown each day. Some will not be available to fly because of maintenance requirements. Moreover, in general, there are more aircraft available than are needed to fly a days training schedule. Aside from insuring that there are enough aircraft available to fly the days missions, the main objective of determining which aircraft to use is to provide an even flow of aircraft into the phase inspection. A phase inspection is required for an aircraft after it has been flown a specific number of hours. Therefore, this goal translates to keeping the number of flying hours all aircraft have been flown since their last phase inspection uniformly distributed from zero to the number of flying hours at which a phase inspection is required (14). The scheduling procedure also identifies a few aircraft to be used as spares in case the primary aircraft are unable to fly during the day. After the scheduling procedure has determined which aircraft will be flown they are prepared for that days missions.

The T-46A will receive one major inspection every 24 hours in preparation for flying. The inspection will be done in place of the two inspections, one before the days flying and one after, that are currently being done for the T-37B (13). This daily inspection, hereafter called the preflight inspection, is accomplished during the early morning. The preflight inspection is done by crew chiefs beginning duty at midnight for just that purpose. These crew chiefs will also do minor maintenance on the aircraft if needed.

Once the aircraft have been prepared, they may fly several times. Most flights are performed during daylight. These flights begin 15 minutes before sunrise and must be finished by 15 minutes after sunset. If required for training, night flights are also performed. All flights are scheduled with a minimum of three minutes between takeoffs. Each aircraft on the schedule may be flown four, five, or six times. The number of flights an individual aircraft flies depends on that days flying schedule. The flying schedule includes such factors as the amount of daylight hours and the need for any night time flying training. After a flight, each aircraft is serviced. The servicing includes refueling and a short walk-around inspection, called the thruflight inspection. In addition to these flying activities, the T-46A also undergoes maintenance actions. These actions will be described next.

Maintenance actions required by the T-46A fall into two categories, scheduled and unscheduled. Scheduled maintenance is preventative maintenance and is to be done to keep the aircraft in a ready-to-fly status. This maintenance includes the preflight and thruflight inspections, corrosion prevention, and phase inspections, among other scheduled maintenance actions. Scheduled maintenance is required based on the number of hours the aircraft has been flown. Table B.3 of Appendix B contains a list of scheduled maintenance actions and the flying hour intervals between them as proposed by Fairchild Republic. Scheduled maintenance is performed mainly during the normal dayshift.

Unscheduled maintenance is corrective maintenance done to return an aircraft to a ready-to-fly status after a part has failed or has been reported as malfunctioning. Unscheduled maintenance is performed when needed but the majority of it is performed during the swing shift, from 1600 to midnight (14). These maintenance actions are performed by technicians assigned by specialties to twenty different work centers. Table B.2 of Appendix B contains a list of the work centers currently used in the ATC maintenance policy.

In summary, there are two major activities in the operation of the T-46A in its role as the primary trainer aircraft in UPT. They are flying activities and maintenance activities. The flying activities include determining which aircraft will fly on a particular day, preparing them for flight, the flying itself, and post flight servicing. The maintenance activities include scheduled and unscheduled maintenance. Before describing the model of this system, a background description of SLAM is necessary to understand how this model was developed.

SLAM Background

SLAM is a special purpose language which is used for simulation modeling. It is based on the FORTRAN language. SLAM provides two orientations, or a combination of both, to modeling. They are event-scheduling and process-interaction (6:99). Each orientation has its advantages and disadvantages. The process-interaction orientation is easier to use but may not describe all the processes that can occur. The event-scheduling orientation allows modeling to the level of complexity desired but at a cost of an increased modeling effort (12:323). Fortunately, SLAM allows both orientations to be used simultaneously.

The process-interaction orientation of SLAM uses networking concepts to model a system. There are nodes and branches which represent parts of the system such as decision points, queues, and activities. Entities, such as aircraft in this case, then flow through the network.

The event-scheduling orientation of SLAM uses the concept that changes to the system can be modeled as happening at specific instances. These changes, called events, are coded in FORTRAN subroutines by the modeler. These events can be as complex as needed to model the system. SLAM automatically controls time advancement and sequencing of events. SLAM also provides subprograms that can be used for common event activities such as event scheduling, random sampling, and statistics collection (12:73).

The SLAM model developed for the F-46A uses both the process-interaction and event-scheduling orientations. Use of both orientations allows for entities in the network model to initiate events and for events to change the flow of entities in the network (12:74). An overview of the model is provided before a more detailed narrative description of the model is presented.

Model Overview

Earlier, the UPT system was described as consisting of two major activities, flying activities and maintenance activities. The purpose of the model overview is to present the model structure and show how the flying and maintenance activities are incorporated into this structure. The description of the model structure will include an explanation of why the repair network is not a SLAM network and a description of how the aircraft are modeled. In addition to the model structure, the overview will present information about the data for the model. This will include the number of aircraft chosen, manpower resource levels used, and the data sources for the model.

Model Structure. The T-46A model is a combined network and discrete-event simulation model. It consists of two parts, a SLAM network portion and a FORTRAN portion. The SLAM portion consists of three major network segments and four supporting network modules. The three major network segments are the sortie generation, failure, and phase inspection segments. The sortie generation segment includes all four actions described as flying activities. The failure segment covers unscheduled maintenance while the phase inspection segment provides for scheduled maintenance. These three major network segments are interconnected. The sortie generation segment includes branches to the other two major segments at the appropriate times. Figure 1 shows the relationship of the major model segments.

The interconnection of the major network segments is in

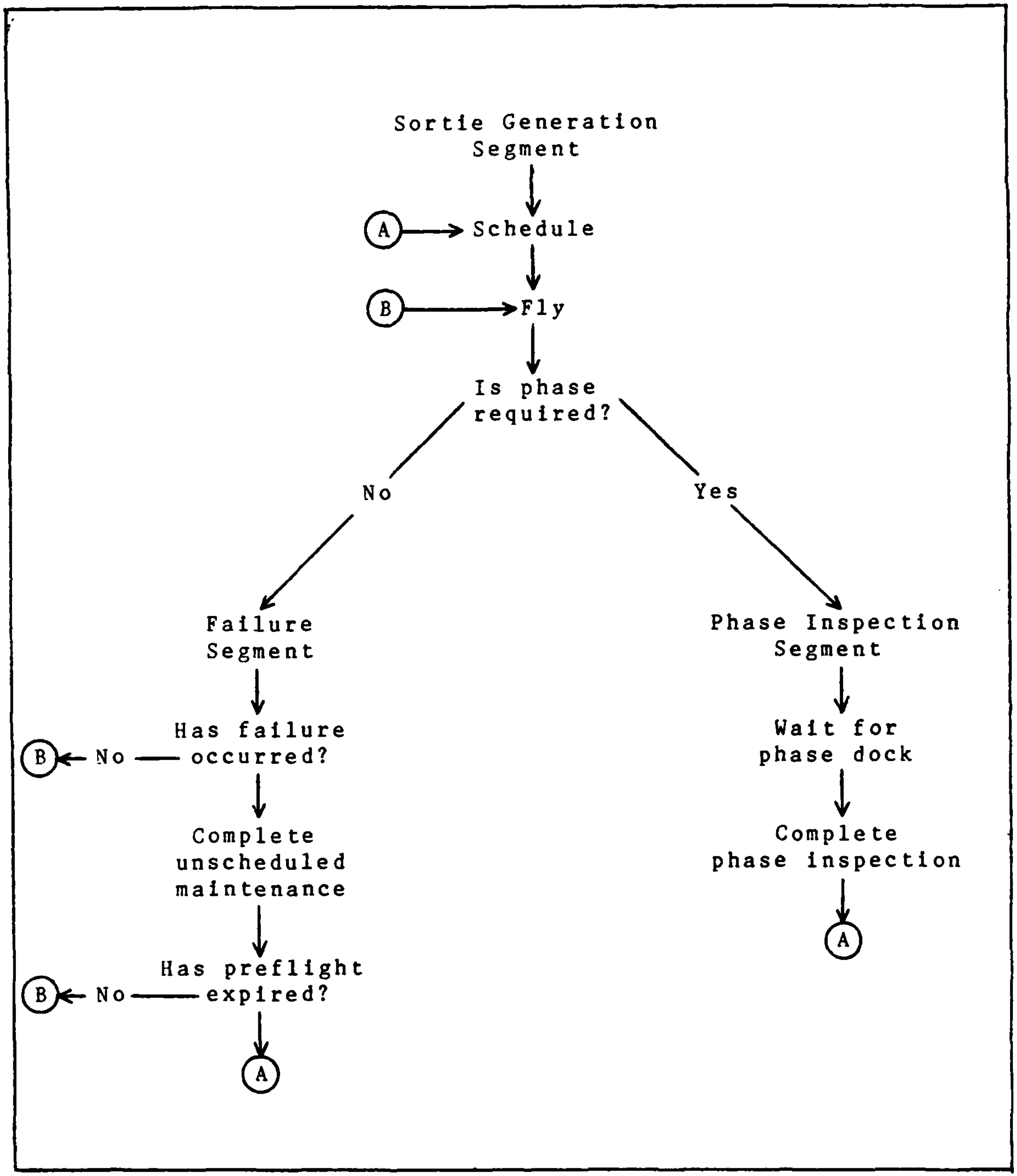


Figure 1. Major Model Network Segments and Interrelationships

contrast to the four supporting network modules. Each of these is an independent network. However, the four support modules control the flow of activities in the three major network segments. These modules limit flying to daylight only, change crew sizes at shift changes, create three minute intervals between takeoffs, and reset counters used for statistics.

The remaining portion of the model is the FORTRAN program. The FORTRAN program consists of two major parts, an allocation subroutine and an event subroutine. The allocation subroutine allocates repair crew resources to fix aircraft with failures. The event subroutine controls the discrete-event orientation of the model. One part of the event subroutine is the repair network.

The repair network for unscheduled maintenance is based on the ATC Logistics Composite Modeling (LCOM) model network. However, because of a SLAM limitation of 500 nodes, as implemented on the AFIT VAX 11/785 computer, the LCOM unscheduled maintenance network cannot be converted to a SLAM network. Thus, the network is contained in a FORTRAN subroutine and is somewhat hidden from view. The form of this network will be discussed in more detail in the narrative description of the model. There are two additional reasons for choosing a FORTRAN network. The first is that entering or changing data for the FORTRAN network is easier than for a SLAM network. The second and more important reason is that FORTRAN allows easier modification of the repair network. For example, consider a change in the work unit code (WUC) level at which the aircraft is modeled. The WUC is an indication of the amount of detail at which the aircraft is analyzed. The number of digits in the WUC corresponds to the level of aggregation. For example, a 5-digit WUC represents a specific part whereas a 3-digit WUC represents a subsystem such as the nose landing gear. For an increase in the number of WUC digits, the FORTRAN network requires only a change in the global variable defining the number of WUCs used. SLAM, on the other hand, requires that a new network segment be built for each new WUC. The level of detail chosen for this model is presented next.

In determining the overall availability of the T-46A the aircraft was modeled at the 3-digit WUC level. There are 74 3-digit WUCs modeled. Table B.1 of Appendix B contains a list of the WUCs and the mean time between failures (MTBF) for each. The failures of these subsystems are generated using a probability per flight rather than a failure clock.

So far, the overview has presented the structure of the model. The remainder of the overview will present information about the data used in the model.

Data Input. Since Laughlin AFB is scheduled to receive the T-46A first, the number of aircraft and manpower levels from that base will be used as representative levels. Laughlin currently has 82 T-37B aircraft assigned to it for

UPT. This is the number of T-46A aircraft used in modeling this UPT system. The manpower levels of repair technicians can be found in Table B.2 of Appendix B. It is presented there by work center and shift.

There are three major sources of data for this model. Information concerning the T-46A in the UPT system came from interviews conducted with MAJ Schad (14), Quality Assurance at Laughlin AFB, and MAJ Purcell (13), T-46A System Program Office at Wright-Patterson AFB, OH. The ATC LCOM Final Report (3) and model (5) provided numerous data on manpower levels, the UPT system, and the unscheduled maintenance network. An early version of the Aeronautical System Division (ASD) T-46A LCOM model (1) supplemented the ATC LCOM model on the last item. Finally, a Fairchild Republic document (8) provided estimates of the MTTR (mean time to repair) and MTBF of the subsystems of the T-46A. This report also provided information about scheduled maintenance. The data can be found in Appendix B.

Narrative Description

The FORTRAN portion of the model will be described first because the FORTRAN code defines events that are used in the SLAM network. The SLAM and FORTRAN codes are contained in Appendix A.

The FORTRAN model consists of five parts, the main program which initiates the simulation, an initialization subroutine, an event subroutine, an allocation subroutine, and an output subroutine. Only the event and allocation subroutines will be described here.

There are nine events that are accessed through the event subroutine. They are named DAYSHIFT, SWINGSHIFT, MIDSHIFT, SCHEDULE, TOPREFLIGHT, TAKEOFF, FAIL, FREECREWS, and DETCREWS. Three of the events model the change in the number of repair personnel at shift changes. These are the events DAYSHIFT, SWINGSHIFT, and MIDSHIFT. Event SCHEDULE determines which aircraft will be flown the next day. This event also causes event TOPREFLIGHT to occur. This is the event which actually allows the aircraft chosen by SCHEDULE to be queued for a preflight. The event TAKEOFF allows one aircraft which is ready to fly to begin the flight sequence. Event FAIL determines if any of the aircrafts subsystems have failed. This is done by converting the MTBF of each subsystem to a probability of failure for one flight. Then a random number from zero up to one is drawn and checked to see if it falls in the failure range for that subsystem. All of the aircraft systems are checked for a failure. The event FREECREWS releases crews which have been used to repair an aircraft. The final event is DETCREWS which is the unscheduled repair network. Event DETCREWS determines which crew will repair a failure. The size of the repair crew is also determined. If an aircraft has more than one failure, the crews needed to repair all failures are determined at this time. Event DETCREWS models the repair network in a way similar to LCOM. The ATC LCOM model of the T-37B provided the basic form for this model's repair network. However, the T-46A has a subsystem structure which is slightly different than the T-37B. Therefore, an early version of the ASD LCOM model of the T-46A was used to supplement the ATC LCOM model. This T-46A repair network model includes repair activities that have one or two actions. The term action is used here to represent the steps necessary to complete an LCOM repair task. In LCOM, tasks are coded into several categories such as minor maintenance ("M") or cannot duplicate ("H"). However, for the tasks taken from the ATC network model, the "M" tasks consolidate minor maintenance and cannot duplicate tasks. The "R" tasks denote remove and replace tasks (3:1-1 to 1-2).

Most of the repair activities in this model have only one maintenance action and that action may be performed by one of a few specific repair crews. A few maintenance activities have two actions. The first action is one that must be done first by a specific crew but the other may be performed by one of several crews. An example of a maintenance activity with two actions is repairing a main landing gear. The aircraft must first be put on jacks before the actual repair activity takes place. In this model those actions which must be done prior to the actual repair activity are called required maintenance actions. Required maintenance actions are always done by the one type of repair crew. All other maintenance actions are called possible maintenance actions because one of several different types of crews, possibly with different sizes, may complete the repair activity. The repair network is contained in Table B.4 of Appendix B. The other major portion of the FORTRAN program is the allocation subroutine.

The allocation subroutine seizes the repair crew needed to fix an aircraft when the repair crew is available. If an aircraft has more than one failure, the availability of all necessary repair crews are checked. If there is more than one aircraft waiting for repair crews, all of the aircraft are checked to see if crews are available to fix them. A more detailed description of the allocation subroutine can be found in Appendix A.

Figure 2 shows the sortie generation network in detail. First, 82 aircraft are created and assigned an initial number of flight hours. The initial flight hours are distributed uniformly from 0 to 300. Three hundred hours is the interval Fairchild Republic recommends between phase inspections (8:4-10). The aircraft then wait to be scheduled to fly the next days missions. Approximately 40 aircraft are normally used on one day (14). However, in this model all aircraft are allowed to fly in order to determine what sortie generation rate the T-46A can achieve. The aircraft which have been chosen to fly are then given a preflight inspection. The aircraft next wait for daylight and a

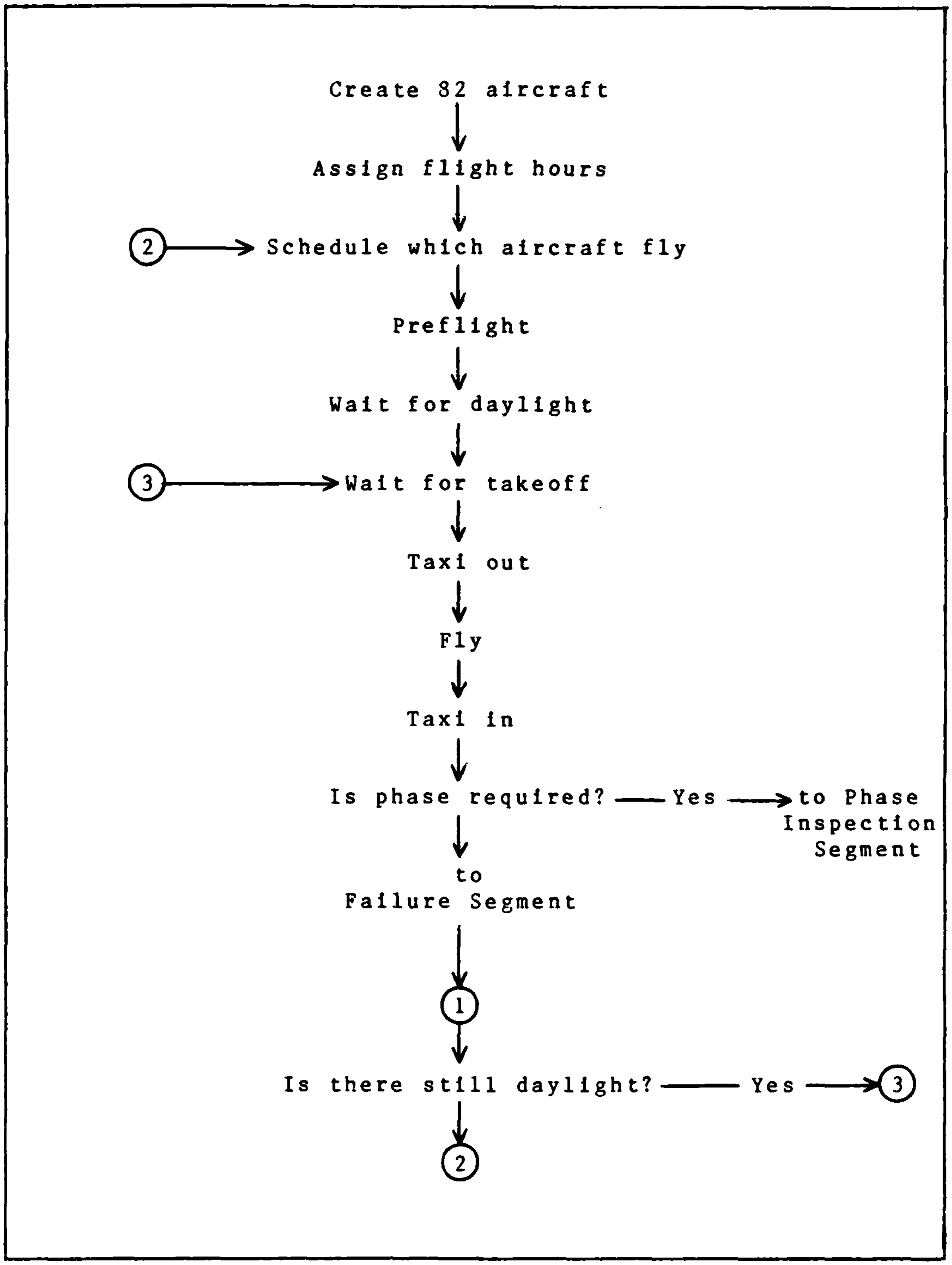


Figure 2. Sortie Generation Network Segment

takeoff slot. The length of the flight is randomly set based on a normal distribution with a mean of 1.3 hours and a variance of 10% (3:5-3). Following the flight, the aircraft is sent to the phase inspection network if the aircraft has accumulated more than 300 hours. When a phase inspection is not required the aircraft is then sent to the failure network. The aircraft may return from the failure network to two different places in the sortie generation network. If more than twenty-four hours have passed since its last preflight, the aircraft is sent to be scheduled for the next day. When a preflight is not required, the aircraft is sent back to a decision node called CONT in the sortie generation network. From here the aircraft is sent to wait for a takeoff slot if it is still daylight. If it is not, the aircraft is sent to be scheduled for the next day. At the end of the day, all aircraft that are waiting for takeoff are also sent to be scheduled for the next day.

When a phase inspection is required, the aircraft first waits for a phase dock to become available. There are four phase docks in this model. Maintenance manhours for all scheduled maintenance actions are accumulated in this network with the exception of those hours spent on preflight and thruflight inspections. These maintenance manhours are collected as they occur in the sortie generation network. Following completion of the phase inspection the flying hours for that aircraft are reset to zero and the aircraft is sent to be scheduled for the next days missions.

Figure 3 contains a diagram of the failure network. First, each aircraft is checked to determine if a failure has occurred. If there are no failures the aircraft is sent back

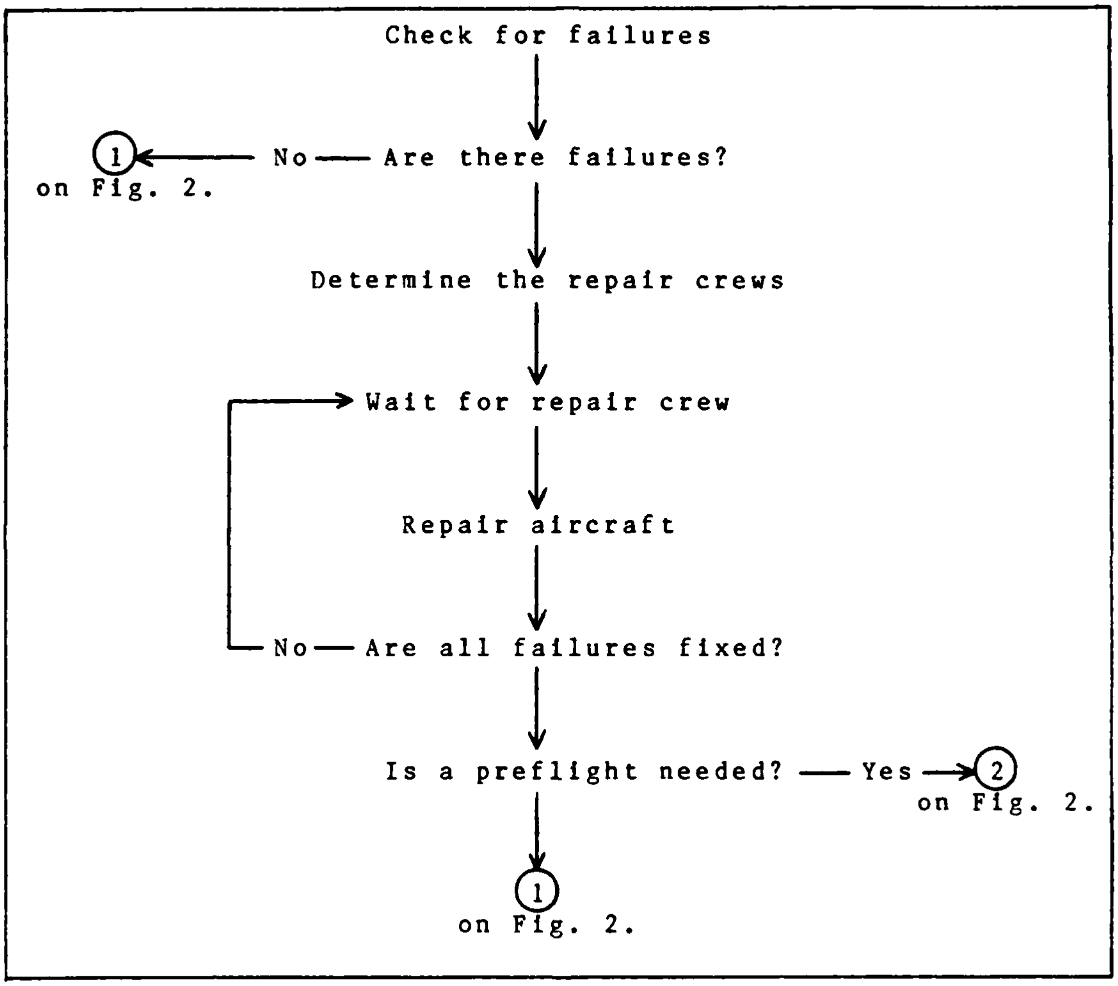


Figure 3. Failure Network Segment

to the sortie generation network. When there are failures, the crews needed to repair the failures are determined. The aircraft then waits for these crews to become available to perform the unscheduled maintenance. After all failures have been fixed, the aircraft is returned to the sortie generation network. The aircraft may return to that network in two different places. If the aircraft has had a preflight within the last 24 hours it is returned where it can be flown if there is still daylight. When an aircraft needs a preflight it is sent to be scheduled for the next day.

This T-46A model has been developed to a degree sufficient to test the effects of various factors on the availability of the T-46A and its sortie generation rate. There are, however, assumptions inherent in the model that effect the prediction of availability and sortie generation rate. These are discussed next.

Model Assumptions

The assumptions inherent in this model fall into two categories. Assumptions created by leaving something out of the model and assumptions made in determining the working details of the model. In the former category, this model does not address spare parts or weather. The inclusion of spare parts is beyond the scope of this study. Resupply and cannibalization of spares are complex issues which may warrant further study but they are not considered here. A crude approximation of the effect of spare parts on availability can be made by subtracting the historic percentage of aircraft not mission capable due to supply. This reduction in the number of aircraft available is anticipated to have no effect on the T-46A sortie generation rate. Weather was not modeled because the intent of this study is to determine what the sortie generation rate of the T-46A will be if allowed to fly under the ATC three minute stratified takeoff concept. ATC considers the impact weather will have on the UPT system when determining the flying training programs for each base. Thus, there is more interest on what the aircraft can do when not constrained by the weather.

There are eight assumptions made in determining the logic of the model. They are:

1. A repair crew works until finished with a repair.
2. Most scheduled maintenance manhours are counted in the phase inspection network.
3. Scheduling of aircraft takes place at midnight.
4. An aircraft is checked for failures after each flight.
5. Multiple failures are repaired sequentially.
6. Multiple failures are repaired from lowest WUC to highest.
7. Aircraft waiting for a particular crew are repaired in random order.
8. Aircraft are given preflight inspections in order of flight hours.

The first assumption made in the logic of the model is that once a repair is started the repair crew will work until it is finished with the repair. This assumption may have an impact when the crew's shift is scheduled to end during the repair. The impact is felt only when the shift change results in a decrease of repair personnel on duty for that specialty code. In this case, the decision to keep the crew working would normally be made by the supervisor. The decision would be based on the need for that particular aircraft and other considerations. However, for repairs that last just a little past a shift change the impact of this assumption is negligible.

A second assumption involves how the manhours for scheduled maintenance are counted. Scheduled maintenance includes those actions listed in Table B.3 and also the preflight and thruflight inspections. The maintenance manhours for the preflight and thruflight inspections are counted as these actions occur in the sortie generation network. There is only one network for the remaining scheduled maintenance, the phase inspection network. The manhours for all maintenance listed in Table B.3 are counted during this network. This is done by calculating a per-300-hour equivalent for all of the maintenance in Table B.3. This sum, which is 97.798, is then counted each time an aircraft enters phase. It may be more realistic to accumulate more of the maintenance manhours as each scheduled maintenance action should occur.

When the scheduling activity takes place is another assumption. This is a concern because the preflight inspections can begin only after the scheduling is complete. In the model, scheduling is done at midnight every night. This allows the midnight shift crew chiefs eight hours to preflight aircraft. In the real world scheduling may be finished before midnight thus allowing more time to preflight aircraft. However, eight hours for the midnight shift plus the additional time in the morning before the first aircraft returns from flying should allow all aircraft to be preflighted before the crew chiefs are also needed for repair activities.

The premise that an aircraft is checked for failures after each flight is a fourth assumption. This does not happen when the aircraft is required to have a phase inspection. In this case the aircraft is sent to the inspection in lieu of being checked for failures. Not checking for failures after every flight may have an impact on the model because the failures are being generated based on a probability of failure per flight. However, the impact is expected to be small. If the impact is large, it will be seen in a chi-square statistic computed to test the validity of the failure generator.

Another model assumption concerning failures is that they are always repaired sequentially. Some maintenance activities such as those involving repair of the fuel system are not allowed to be done concurrently with any other repair. Other combinations of repairs may be impractical. Since data on which repairs are allowed concurrently is not available, the model performs repairs sequentially. Further, during unscheduled maintenance, sequential repairs happen more frequently than concurrent repairs.

The remaining three assumptions in the logic of the model deal with the order in which aircraft entities are moved within the SLAM network. This concern about the order arises twice in the allocation subroutine. The first of these probably has little or no effect. It is the order in which multiple failures to an aircraft are repaired. The model checks for crew availability in the order of the lowest numbered failure to the highest. Because of the way failures are determined, the failures for an aircraft are ordered from lowest WUC to highest. The first failure to have crews available for the repair is fixed.

The second concern may have more of an impact. This concern results from switching the order of the aircraft waiting for repair crews when there is more than one aircraft waiting. The switching is done to insure that when a crew becomes available to repair a waiting aircraft that the repair begins at that time. The switching allows for the possibility that when two aircraft are waiting for the same crew, the aircraft that has been waiting the least time may be repaired first. This may be done in actual practice and, in any event, should not effect such statistics as the average waiting time. However, it will effect the longest waiting time.

The order in which the aircraft are placed in the queue for preflights is the final model assumption. In the model aircraft are placed in this queue during the scheduling event. This event orders the aircraft by the number of flight hours and then places them in the preflight queue by that ranking. The reason for the concern here is that aircraft which are preflighted first and thus, fly first, have a higher probability of flying more missions in a given day than aircraft that are inspected later. Whether ascending or descending order is used to rank the aircraft can have a significant impact. If aircraft are placed into the queue in ascending order, the distribution of flight hours becomes less uniform as the aircraft with less hours fly more times per day than those with more hours. This eventually causes many aircraft to reach phase inspection at nearly the same time. This model places the aircraft in the queue from highest to lowest number of flight hours allowing the distribution of flight hours to remain more uniform. This ordering concern may not be as much of a problem if the utilization rate of the T-46A is constrained or less than all aircraft are allowed to fly.

Verification and Validation of the Model

Verification is the process of determining the model works as intended while validation is the process of determining the model accurately portrays the real system being modeled (12:10). This model was verified through the use of two techniques, trace listings and summary reports.

Trace listings showing how the aircraft entities moved through the SLAM networks and the FORTRAN subroutines were generated. The trace listings revealed that the aircraft moved through the SLAM network as intended. The following are examples of network flows that were observed. Aircraft were given a preflight, flew several times, stopped flying at night, and then began this cycle again. Phase inspections were completed at the appropriate times. Aircraft were checked for failures and routed correctly based on whether a failure had occurred. In addition, aircraft with multiple failures were sent through the repair cycle until all failures were fixed. The trace listings also showed that the actions in the discrete events were occurring properly. Examples of these are the following. Failure and crew determinations occurred correctly for the random numbers drawn. Crews were allocated correctly based on the number needed and the number available. If there were more than one aircraft waiting for crews, all aircraft were checked when a crew became available. Shift changes occurred correctly at the appropriate times. Also, the trace listings showed that housekeeping details, such as which planes have what failures and which crews were being waited for, were kept correctly.

The SLAM summary reports were examined for indications of problems such as unexpected queue lengths and destruction or creation of aircraft entities. In particular, the queues for the thruflight inspection and phase docks were examined.

The queue for the thruflight always remained at a reasonable length. However, at first, the queue length for the phase docks was excessive because of the way the aircraft were ordered during the scheduling event. When the ordering of the aircraft was switched to those with the highest number of flight hours received preflights first, the queue length for the phase docks was negligible.

The SLAM summary reports were used to show that entities at branches in the network did not get lost nor were any extra entities created. For example, the number of aircraft leaving the two exit points of the failure network equaled the number entering this network. Each branch node was tested to make sure that the number of entities leaving the node was equal to the number entering the node.

One additional step was taken to verify the model. A chi-square statistic was computed to test whether the failures were being distributed across all WUCs correctly. The chi-square statistic for a test run of 48,000 hours was 90.922. The critical value for a = 0.01 and 73 degrees of freedom is 104.01 (9:437). Therefore, the hypothesis that the failure generator works correctly cannot be rejected. This chi-square statistic was also computed for all of the experimental runs. The value of the statistic ranged from 60.775 to 89.395 for these runs.

Validation of the model is a more difficult task. Ideally, a model can be validated by using historic inputs and then comparing the model outputs to the historic outputs. Since the T-46A is a new aircraft there is no historic data that can be used. Therefore, our validation efforts were aimed at considering the reasonableness of the model outputs to the given inputs. The observed output values were determined to be near the expected values for such measures as the total number of failures and MTTR. In addition, changes in the output measures occurred in ways expected as the inputs were varied. For example, the availability of the aircraft decreased when the failure rate was increased.

III. Methodology

The purpose of this chapter is to select factors to be considered in an experimental design and then to select the most appropriate experimental design. In addition, the steps taken to ensure valid simulation output for the experimental design are discussed.

Factor Selection

A critical step in deciding which experimental design to use is determining which factors need to be examined. Initially, four factors were considered: phase inspections, manpower, mean time between failures (MTBF), and mean time to repair (MTTR).

In looking at the effects of phase inspections, increasing the frequency of phase in the model would only decrease the aircraft availability because the aircraft is tied up in phase more often. This decrease in availability is in contrast to the real world in which an increase in availability is possible if the increased frequency of phase makes the aircraft more reliable. Because this relationship could not be quantified it was decided not to include phase inspection as a factor.

There are two reasons manpower was not used as a factor in this analysis. The first reason is the structure of the manpower data. The manpower data, as previously mentioned, was obtained from the current LCOM model for the T-37 operations at Laughlin AFB. In some cases however, the data represented personnel for both the T-37 as well as the T-38 operations. In these cases, it was not possible to identify the number of people who worked on the T-38. In addition, there are many ways to apportion manpower to provide a constant availability or sortie generation rate. Because there is no unique solution and also no clear guidance on how to reduce manpower, the Laughlin manpower data could no be reduced to reflect only T-46A maintenance. Therefore, this data would tend to overstate the T-46A manpower.

The second reason is the intent of this analysis. While it may be possible to reduce the given levels of manpower in the model, this model was not designed to estimate what the actual manpower requirements should be.

For these reasons, it was determined that varying manpower would not provide a basis for meaningful analysis and therefore should not be included as a factor. However, it would be of interest to determine the maximum aircraft availability and sortie generation rate that could be achieved if manpower is not constrained at all.

One of the current issues in the Air Force is the acquisition of systems that are reliable and easily maintained. As was stated in the Introduction, one of the objectives for the T-46A is operational and support cost savings through the use of modern technology. This translates directly to the reliability and maintainability of an aircraft. Therefore, it was decided that the experimental design should focus on the reliability and maintainability parameters (MTBF and MTTR) of the T-46A and their effects on aircraft availability and sortie generation rate.

The Design

Regression analysis was the approach chosen to investigate the effects of the two independent variables, MTBF and MTTR, on the response variables. Regression analysis combines an experimental design with mathematical methods and statistical inferences which allows the experimenter to empirically analyze the system of interest.

Since the relationship between the response and independent variables is unknown, the first step is to hypothesize a relationship between them. In many cases, polynomial models are used as the approximating function (10:399).

The next step is to collect the data based on an experimental design. The method of least squares is then applied to the data to estimate the parameters of the functional relationship. This regression equation can then be tested. If it is found to be an adequate approximation of the true functional relationship, the experimenter can be confident that working with the fitted model is representative of working with the real system.

For the purposes of this study, it was hypothesized that the functional relationship between the response variables, aircraft availability and sortie generation rate, and the independent variables, MTBF and MTTR, was a second order polynomial.

The experimental design chosen was a second order rotatable central composite design. This design requires five levels for each factor. For two factors the design consists of a 2^2 factorial (coded to ± 1 notation); augmented by 4 axial points ($\pm a$,0),and (0,$\pm a$),

$$\text{where } a = (2^k)^{1/4} = (2^2)^{1/4} = 1.414;$$

plus n center points. By choosing n to be 8, the central composite design sign is made orthogonal (10:462). Thus, this design requires 4 runs for the factorial, plus 4 runs for the axial points, plus 8 runs at the center point for a total of 16 runs. Appendix C contains a layout of the design.

Table I presents the five levels of the factors selected for the design. Looking at the factorial portion of the design, a change of 50% in both directions results in a range that provides a wide variation for determining the effects MTBF and MTTR could have on the response variables. However, for the MTTR data, it was felt that the low level could not be reduced as much because repair work requires some minimum amount of time. Therefore, only a 10% reduction of the Fairchild Republic data was selected as the low level of MTTR. This still results in a range that provides

Table I

Levels of Factors*

		MTBF	MTTR
Factorial points			
High	+1	150%	150%
Low	-1	50%	90%
Axial points			
High	+1.414	170.71%	162.43%
Low	-1.414	29.29%	77.57%
Center points			
Center	0	100%	120%

* As a percentage of the Fairchild Republic data

sufficient variation for evaluating the effects of MTTR. Because this is a central composite design, the center point for the levels of MTTR had to be recomputed. The center point turns out to be 120% of the Fairchild Republic data.

The sixteen runs are then performed at the prescribed levels of the factors. After collecting the data from the sixteen runs, regression analysis can be used to determine the parameters of the second order equation representing the data. From this equation, it is possible to draw response surfaces which describe the effects of the independent variables on the response variables.

Ensuring Valid Simulation Output

Having decided which factors to analyze and the design which would provide the required information, a number of questions remained to be answered before the experimental design could be performed. There were five particular questions of interest.

1. How long of a warm-up period is required to avoid initialization bias?
2. How much time is required for a batch mean observation?
3. Is the data autocorrelated?
4. How many batch mean observations are required?
5. What is the required length of the simulation?

Warm-up Period. In determining how long of a warm-up period was required, two criteria were used. The first criteria for the warm-up period was to determine when, over time, initialization bias no longer appeared to be a factor. An initial run was made for 7200 hours (300 days). The plots of aircraft availability and sortie generation rate versus time were observed to determine when the values reached a steady-state. By 2160 hours the values of both aircraft availability and sortie generation rate had leveled off indicating that any initialization bias was no longer a factor. Thus, the suggested warm-up period was 2160 hours.

The second criteria dealt with phase inspections. Since as part of the simulation initialization all aircraft were given flight hours evenly distributed from 0 to 300 hours, it was felt that the warm-up period should allow for all aircraft to have gone through the phase inspection once. For aircraft flying an average of 1.3 hours per sortie and an average of 2.9 sorties per day, it would require approximately 80 days or 1920 hours for all aircraft to go through phase inspection once. However, since the first criteria suggested a longer warm-up period, it was concluded that 2160 hours would provide a valid warm-up period.

Time For a Batch Mean Observation. In answering the second question about the length of time required for a batch mean observation, the batch mean observations were collected by first clearing the statistical arrays after the warm-up period and then clearing the statistical arrays again after every set amount of time (e.g. every 3 days). The batch mean statistics were computed by taking the average of the statistics over the time that they were collected. Determining the optimum amount of time required for these observations involved an iterative process that was based on a number of factors: whether autocorrelation was present, the calculated number of batch mean observations required, and the computer time which would be needed based on the computed number of batch mean observations required. The discussion on autocorrelation and calculating the number of observations required will be deferred at this time as they are covered in more detail in questions 3 and 4 respectively.

However, separate runs were made which cleared the statistics after every 2, 3, 5, 10, and 20 days. Twenty batch mean observations were collected for the 2 and 3 day periods, and fifteen batch mean observations were collected for the 5, 10, and 20 day periods. Based on tradeoffs in the above factors (autocorrelation, number of observations, and computer time), it was determined that the batch mean statistics collected over 10 days (240 hours) would provide the accuracy desired as well as keeping the length of the simulation at a manageable level.

Autocorrelation. Detecting autocorrelation is important since, as part of the analysis of the simulation, a regression model is used. If autocorrelation is present and the Ordinary Least Squares (OLS) estimators are used, a number of problems occur.

1. If serial correlation is allowed for, the estimators will be inefficient, causing the confidence intervals to be unnecessarily wide and the tests of significance to be less powerful.

2. If autocorrelation is ignored and the classical OLS formulas are used, the usual t and F tests of significance are no longer valid and if used would give misleading conclusions about the significance of the estimated regression coefficients.

3. The OLS estimators become sensitive to sampling fluctuations and may not give an accurate picture of the true population values (9:226).

Two tests were used to detect autocorrelation, the Durbin-Watson d test, and a runs test. The Durbin-Watson d test is based on the ratio of the sum of the squared differences in successive residuals to the Residual Sum of Squares (9:235). As a rule of thumb, if d, the test statistic, is found to be 2, it can be assumed that there is no first-order autocorrelation, either positive or negative. The closer d is to 0, the greater the evidence of positive serial correlation. The closer d is to 4, the greater the evidence of negative serial correlation (9:237).

The BMDP 9R program was used to calculate the Durbin-Watson statistic. The d that was computed was compared against critical upper and lower d values to determine whether autocorrelation existed. The critical values are based on the sample size and number of explanatory variables.

Using the BMDP 9R program on observations obtained with a batch size of 10 days, the computed Durbin-Watson statistic for aircraft availability was 1.7349. The critical values at the 99% level of confidence with $n=15$ and $k'=2$ are $d_{lower} = 0.70$ and $d_{upper} = 1.25$ (9:439). Since the computed value is greater than d_{upper} but still less than 2, we conclude there is no positive serial correlation. The computed Durbin-Watson statistic for the sortie generation rate, for the same run, was 2.4780. The critical values are the same as above. Since the computed value is less than 2.75 ($4 - d_{upper} = 4 - 1.25 = 2.75$) but is greater than 2, we conclude that there is no negative serial correlation.

The second test used to detect autocorrelation was a runs test. Looking at the residuals for the same 15 batch mean observations, for aircraft availability there were 8 runs with 8 +'s and 7 -'s. The critical values for N1 = 8 and N2 = 7 is $\leq$ 4 or $\geq$ 13 (9:440-441). Since 8 is between these values we conclude that there is no serial correlation. Looking at the residuals for sortie generation rate, there are 10 runs with 8 +'s and 7 -'s. The critical values are the same as above, therefore, we again conclude that there is no serial correlation for sortie generation rate. Thus, we are relatively confident that by using the 10-day interval to determine a batch mean, autocorrelation is not present.

<u>Number of Batch Mean Observations Required.</u> It is possible to obtain a value of an output variable such that it estimates the true population value within some accuracy criterion with a high degree of probability. This is done by determining, based on initial sample values, the number of observations that will provide the desired accuracy. The number of batch mean observations required is determined by the following formula (6:427):

$$N \geq \left[\frac{(t_{a/2,N-1})(s)}{e}\right]^2 \qquad (1)$$

where

N	is the number of observations required,
$t_{a/2,N-1}$	is the t-statistic for confidence level a/2 and N-1 degrees of freedom,
s	is the standard deviation of the sample, and
e	is the half-width of the confidence interval.

A confidence level of 95% (a=0.05) and half width of ±0.005 for both aircraft availability and sortie generation rate were used. The half width for aircraft availability yields an estimate to within 1%. The half width for sortie generation rate results in a rate to the nearest 0.01. These half widths were considered reasonable for this study and were used to determine the number of observations required.

Table II contains the calculations for aircraft availability and sortie generation rate using the 10-day batch size and 15 batch means.

Table II

Calculations for Number of Observations

Aircraft Availability	Sortie Generation Rate
$n = 15, \quad a = 0.05$	$n = 15, \quad a = 0.05$
$t_{0.025,14} = 2.145$	$t_{0.025,14} = 2.145$
$\overline{x} = 0.91302$	$\overline{x} = 2.92833$
$S = 0.00329$	$S = 0.00740$
$e = 0.005$	$e = 0.005$
$N = \left[\frac{(2.145)(0.00329)}{(0.005)}\right]^2$	$N = \left[\frac{(2.145)(0.00740)}{(0.005)}\right]^2$
$N = 2^*$	$N = 11^*$
* Rounded up to the nearest integer	

The computation of N for sortie generation rate indicates that for the standard deviation that exists in the sample, only 11 batch mean observations are needed. This is the governing factor for the number of observations. Using the 10-day period with 11 observations requires that the simulation be run for 2640 (240 x 11) hours.

Simulation Length. The length of the simulation is determined by the amount of warm-up time required plus the amount of time required for data collection. For this study the warm-up period was determined to be 2160 hours and the amount of time required for data collection was determined to be 2640 hours. Therefore, the total length of the simulation should be 4800 hours (2160 + 2640) or 200 days.

IV. Results

The last chapter presented the design chosen to investigate the effects of MTTR and MTBF on aircraft availability and sortie generation rate. In addition, a number of questions relevant to running the simulation were discussed. This chapter discusses the results of the analysis performed on the model.

As was discussed, a rotatable central composite design was chosen to obtain data points for the regression analysis. This design required 16 runs to be performed. The coded levels of the factors as well as the results for each run are detailed in Appendix C.

The BMDP 9R stepwise regression program was run on both the aircraft availability and sortie generation rate data using a second order equation of the form:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_{12}X_1X_2 + B_{11}X_1^2 + B_{22}X_2^2 \quad (2)$$

where X_1 and X_2 are MTTR and MTBF respectively.

The 'Best' subset of the five variables was determined using the Mallows' C_p criterion. The Mallows' C_p criterion attempts to identify the subset of variables that has the smallest total mean squared error. When the C_p value for this subset is also near p (the number of parameters in the model), the bias of the regression model is small (11:426-427).

Aircraft Availability Results

When the ANOVA (Analysis of Variance) for aircraft availability based on a 2^2 factorial was performed, both factors, MTTR and MTBF, as well as their interaction term were significant. The ANOVA results are presented in Table III.

Table III

ANOVA Table for Aircraft Availability

Source	SS	df	MS	F
MTTR	0.0188701	1	0.0188701	409.01*
MTBF	0.0705441	1	0.0705441	1529.03*
Interaction	0.0068650	1	0.0068650	148.80*
Error	0.0018455	40	0.0000461	
Total	0.1030216	43		

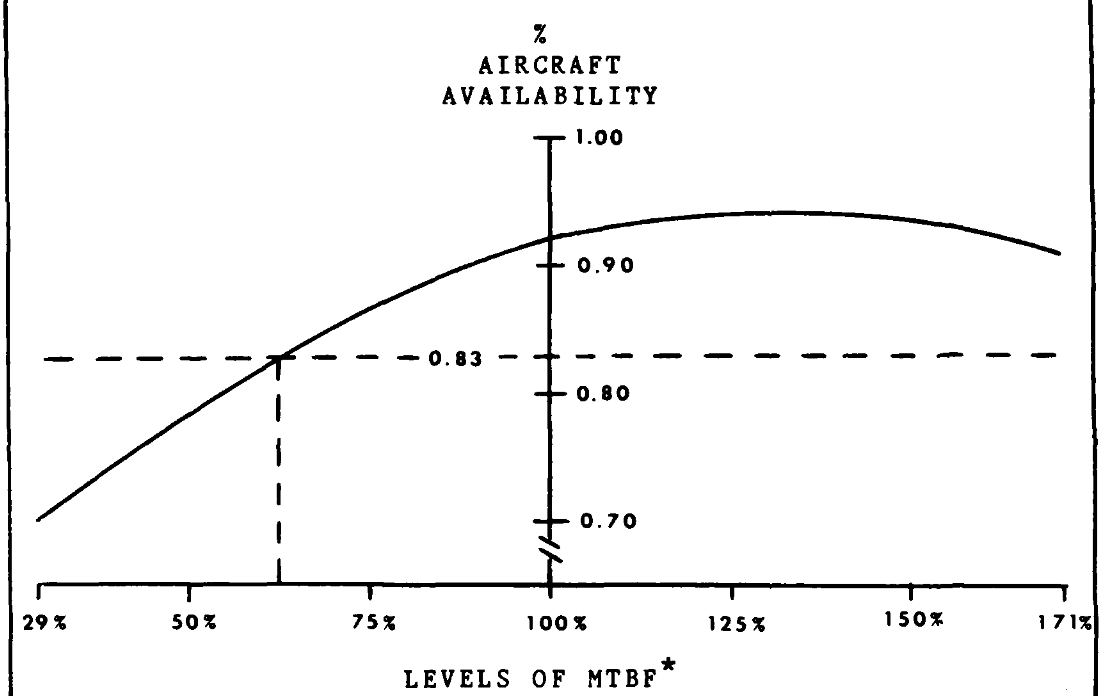
* Significant at a = 1% level

However, in running BMDP 9R on the 16 data points obtained from the central composite design, the 'Best' subset was only in terms of the MTBF variable (the intercept, MTBF, and MTBF squared). For this subset, Mallows' C_p was 2.92 for the three parameters in the model (p = 3). This would indicate that there is little bias in the model. The regression indicated that aircraft availability can be explained by the following equation (See Table D.1 of Appendix D):

$$AA = 0.917869 + 0.0730662(X_2) - 0.054796(X_2{}^2) \qquad (3)$$

where AA is aircraft availability, and
X_2 is the coded level of MTBF.

This equation explains approximately 81% of the variation in aircraft availability. Figure 4 provides a graphical representation of this equation. As might be expected, when MTBF increases (i.e. when there is more time between failures) the availability increases.



* As a percentage of the Fairchild Republic data

Figure 4. Aircraft Availability for Various Levels of MTBF

Of particular interest on this graph is the level of MTBF which results in 83% aircraft availability. This level is the minimum contract requirement for availability (4:5). The levels of MTBF that result in less than 83% availability can be determined from Figure 4. An availability of 83% corresponds to a decrease in the MTBF level of approximately 38%.

Sortie Generation Rate Results

The ANOVA for SGR based on the 2^2 factorial, indicated that both factors, MTTR and MTBF, were significant at the 95% level but that the interaction term was not significant. The ANOVA results are contained Table IV.

Table IV

ANOVA Table for Sortie Generation Rate

Source	SS	df	MS	F
MTTR	0.000596459	1	0.000596459	8.57*
MTBF	0.000349455	1	0.000349455	5.02*
Interaction	0.000160366	1	0.000160366	2.31
Error	0.002782899	40	0.000069572	
Total	0.003889179	43		

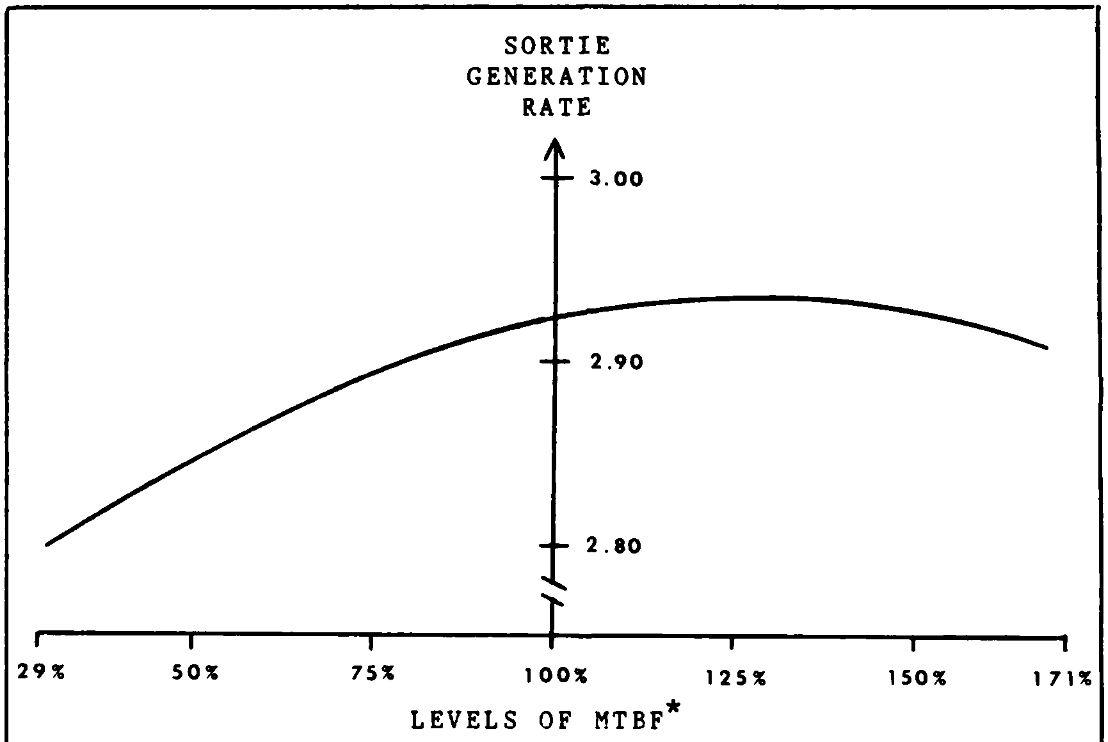
* Significant at a = 5% level

However, after running BMDP 9R on the data, the 'Best' subset was again only in terms of the MTBF variable (the intercept, MTBF, and MTBF squared). For this subset, Mallows' C_p was 1.04 for the three parameters indicating that there was slightly more bias in this model than there was for aircraft availability. The regression indicated that sortie generation rate can be explained by the following equation (see Table D.2 of Appendix D):

$$SGR = 2.92553 + 0.0383215(X_2) - 0.0349404(X_2^2) \quad (4)$$

where SGR is the sortie generation rate, and
X_2 is the coded level of MTBF.

This equation explains approximately 51% of the variation in the sortie generation rate. Figure 5 provides a graphical representation of this equation. Again, as might be



* As a percentage of the Fairchild Republic data

Figure 5. Sortie Generation Rate for Various Levels of MTBF

expected, there is a slight increase in the sortie generation rate when the MTBF is increased (i.e. when there is more time between failures).

Of particular interest on this graph is the fact the predicted sortie generation rate never decreases to 2.2. The T-46A will be flown at an average rate of 60 hours per month per aircraft (4:6). This utilization rate is equivalent to a 2.2 sortie generation rate.

The main reason the regression equation (4) explains only 51% of the variation is due to the manner in which flight line operations are modeled. The simulation is set up to allow all 82 aircraft to fly with the major restriction on the sortie rate being the stratified takeoff (i.e. allowing only one aircraft to takeoff every three minutes). Due to this limitation there is almost always an aircraft waiting to takeoff, even when the rate at which aircraft fail is increased. Because the system is not stressed, the sortie generation rate tends toward the maximum allowable rate per day. If only a portion of the aircraft were allowed to fly all the sorties for a given day, the MTBF would possibly account for a higher percent of the variation in the resultant sortie generation rate equation.

As was mentioned, the regression equation for both aircraft availability and sortie generation rate did not include a MTTR factor. This is not to imply that MTTR is not a significant factor. The ANOVA indicated that it was. However, in performing the regression analysis, once MTBF entered the equation, MTTR was unable to explain any of the remaining variance. Even when MTTR is forced into the equation, the coefficients for MTTR are statistically not different from zero. Therefore, MTTR did not show up in either best fit equation because it was unable to substantially contribute to the explanation of the remaining variation once MTBF entered the equation.

V. Conclusions and Recommendations

Conclusions

Based on the verification and validation efforts for this model, our conclusion is that this is a valid model for predicting the availability and sortie generation rate of the T-46A. Due to the manner in which this model has been constructed, it is a flexible model that can be easily adapted to different aircraft.

From the analysis outlined in Chapter IV the research questions posed in Chapter I can now be answered.

1) What is the availability of the T-46A in the UPT system? The average aircraft availability predicted by the model is 0.921. This estimate uses Fairchild Republic predicted failure rates as opposed to allocated rates. A 95% confidence interval for this prediction is [0.917, 0.923].

2) What sortie generation rate can be achieved by the T-46A? The average sortie generation rate predicted by the model is 2.926. This again is using the Fairchild Republic predicted failure rates. A 95% confidence interval for the sortie generation rate prediction is [2.923, 2.932].

The estimated value of the sortie generation rate is the maximum that can occur under the stratified takeoff restrictions. Only in the most pessimistic case does the sortie generation rate show a modest drop. When the failure rate is increased by more than 70%, the sortie generation rate drops to 2.715. However, this rate is still much above the projected utilization rate of 60 hours per month per aircraft.

In contrast to the sortie generation rate, the estimates of aircraft availability did not meet contract requirements at all levels of the experiment. Analysis shows that if the failure rates increase by 38% over the contractors estimate, the T-46A will be unable to achieve an average availability of 83%.

In summary, the factor that has the most influence on both availability and sortie generation rate is the mean time between failures. Although analysis of variance shows mean time to repair to be a significant factor, it does not enter into either regression equation used to predict availability or sortie generation rate.

Recommendations

There are three areas that suggest further effort. The first area is scheduled maintenance and how it is accounted for in the model. The second area is manpower and how to adjust levels to reflect only T-46A work and not T-38 work, training, and other utilization factors. The final area is the inclusion of spares and off-aircraft maintenance in the model.

Scheduled maintenance is accounted for in this model by delaying the aircraft once every 300 flying hours for phase inspection. All maintenance manhours associated with scheduled maintenance actions, including those not at 300 hour intervals, are accumulated when the aircraft enters the phase inspection network. Accounting for these actions as they are scheduled to occur would give a more accurate representation of the UPT system. A flying hour counter for each scheduled maintenance action would be necessary. This would require fifteen counters in addition to the one currently used to send an aircraft to phase.

Another recommendation involves manpower. We were unable to accurately breakdown the manpower levels given in the ATC LCOM Final Report. The levels contained there reflect not only the on-aircraft maintenance but also off-aircraft and T-38 maintenance, and factors for training, leave, sick days, etc. The manpower normally used for these other activities is used for on-aircraft maintenance in our model of the T-46A. Thus, the manpower levels were not constraining factors as expected. That manpower is not at a constraining level may be seen by comparing the estimate of availability given above (0.921) to an estimate obtained with an unlimited manpower level. Using a level of 10,000 personnel for each specialty code, the estimate for availability is 0.922 with a 95% confidence interval of [0.920, 0.924]. This estimate is not significantly different from the previous estimate. Further research into determining appropriate manpower levels is recommended.

The final recommendation deals with spares and off-aircraft maintenance. This effort at modeling the T-46A was directed at only on-aircraft maintenance. In other words, the model assumes that spares are always available and that off-aircraft maintenance is independent from on-aircraft maintenance. The effects of spares levels and off-aircraft maintenance may be of interest. The model could be expanded to include these considerations.

Appendix A

T-46A Model

This appendix contains the SLAM and FORTRAN codes of the T-46A model developed in this study. The first section lists the SLAM code. The second section is an explanation of the allocation subroutine contained in the FORTRAN code. The final section lists the FORTRAN code.

SLAM Code

```
GEN,FOLEY HAGER,T46 MODEL,10/10/85,1,N,N;
;
;          ATTRIBUTES USED
;             1-- STORES TNOW TO COLLECT DOWN TIME
;             2-- TAIL NUMBER
;             3-- NUMBER OF FLYING HOURS
;             4-- STORES NUMBER OF FAILURES
;             5-- STORES REPAIR TIME
;             6-- STORES REPAIR CREW CODE
;             7-- STORES NUMBER OF REPAIR PERSONS USED
;             8-- STORES LENGTH OF PREFLIGHT AND THRUFLIGHT
;             9-- STORES WUC OF FAILURE WHEN THERE IS A RMA
;            10-- STORES WHICH RMA IS BEING WORKED ON
;            11-- STORES WHICH FAILURE NUMBER THE FAILURE IS
;            12-- STORES TIME OF LAST PREFLIGHT
;
;
;          FILES/QUEUES USED
;             1-- AIRCRAFT WAIT FOR F431 TO PERFORM PREFLIGHT INSPECTION
;             2-- AIRCRAFT WAIT FOR DAYLIGHT
;             3--
;             4--
;             5-- AIRCRAFT WITH FAILURES WAIT FOR REPAIR CREWS
;             6-- AIRCRAFT WAIT FOR PHASE DOCKS
;             7-- AIRCRAFT WAIT FOR STRATIFIED TAKE OFFS
;             8-- AIRCRAFT PLACED IN THIS QUEUE TO BEGIN FLIGHT SEQUENCE
;             9-- AIRCRAFT WAIT FOR F431 TO PERFORM POSTFLIGHT SERVICING
;            10-- AIRCRAFT WAIT FOR SCHEDULING TO OCCUR
;            11--
;            12-- TAKE OFF CREATION ENTITY WAITS HERE FOR DAYLIGHT
;            13-- SLAM CALENDER OF EVENTS
```

```
;
LIMITS,12,12,200;

INTLC,XX(1)=0;              NUMBER OF AIRCRAFT FULLY MISSION CAPABLE
INTLC,XX(2)=0;              TOTAL MAINTENANCE MANHOURS
INTLC,XX(3)=0;              TOTAL NUMBER OF FLIGHTS
INTLC,XX(4)=0;              SORTIE GENERATION RATE
INTLC,XX(5)=0;              COUNTER TO INITIALIZE FLT HOURS
INTLC,XX(6)=0;              SORTIE DURATION
INTLC,XX(7)=0;              MMH/S
INTLC,XX(8)=0;              TOTAL DOWNTIME
INTLC,XX(9)=0;              DOWN TIME PER SORTIE
INTLC,XX(10)=0;             ACCUMULATE REPAIR HOURS TO COMPUTE MTTR
INTLC,XX(11)=0;             COUNTS NUMBER OF SWITCHES IN ALLOC SUBROUTINE
INTLC,XX(12)=0;             AVERAGE DOWN TIME
INTLC,XX(13)=0;             AVG NUMBER OF AIRCRAFT FULLY MISSION CAPABLE
INTLC,XX(14)=0;             NUMBER OF FLIGHTS SINCE LAST STATS COLLECTION
INTLC,XX(99)=0;             TOTAL NUMBER OF AIRCRAFT

TIMST,XX(1),FMC AIRCRAFT;
TIMST,XX(4),SORTIE RATE;
TIMST,XX(13),AVERAGE AC AVL; XX(13) IS SET = TTAVG(1) [XX(1)] IN EVENT 3

RECORD,TNOW,TIME,0,T,240,240;  SAMPLING EVERY 240 HOURS IF THIS CHANGES
VAR,XX(13),A,AVG AVAIL ACFT;     MUST CHANGE DIVISOR IN NODE SGR
VAR,XX(4),S,SORTIE RATE;

PRIORITY/5,LIFO;

;             TIME UNIT IS ONE HOUR
NETWORK;

;          IDENTIFY RESOURCE CONSTRAINTS

;                 CREW RESOURCES

      RESOURCE/R431(0),5;      T-37 REPAIR AND RECLAMATION
      RESOURCE/F431(0),1,5,9;  T-37 FLM
      RESOURCE/P431(0),5;      T-37 INSPECTION

      RESOURCE/S4270(0),5;     MACHINE
      RESOURCE/S4274(0),5;     METALS PROCESSING
      RESOURCE/S4275(0),5;     STRUCTURAL REPAIR
      RESOURCE/S4271(0),5;     CORROSION CONTROL

      RESOURCE/S426(0),5;      T-37    JET ENGINE SHOP
      RESOURCE/A426(0),5;      T-37/38 ACCESSORY REPAIR
      RESOURCE/T426(0),5;      T-37/38 TEST CELL
      RESOURCE/F426(0),5;      T-37    FLIGHT LINE SUPPORT UNIT

      RESOURCE/W431(0),5;      T-37/38 WHEEL AND TIRE
```

```
     RESOURCE/S4233(0),5;      T-37/38 FUEL SYSTEMS
     RESOURCE/S4230(0),5;      T-37/38 ELECTRICAL SYSTEMS
     RESOURCE/S4234(0),5;      T-37/38 PNEUDRAULICS SYSTEMS
     RESOURCE/S4231(0),5;      T-37/38 ENVIRONMENTAL SYSTEMS
     RESOURCE/S4232(0),5;      T-37/38 EGRESS SYSTEMS

     RESOURCE/S3280(0),5;      T-37/38 RADIO AND RADAR REPAIR
     RESOURCE/S3281(0),5;      T-37/38 RADIO AND RADAR REPAIR

     RESOURCE/S325(0),5;       T-37/38 AUTO FLIGHT CONTROL

;               OTHER RESOURCES

     RESOURCE/DOCK(4),6;

     GATE/DAY,CLOSED,2,12;
     GATE/STRAT,CLOSED,7;
     GATE/SCHEDULE,CLOSED,10;

;                       ********** MAIN NETWORK **********

     CREATE,0,,1,82;            GENERATE 82 AIRCRAFT
     ASSIGN,XX(1)=XX(1)+1;
     ASSIGN,ATRIB(2)=XX(1);     ASSIGN TAIL NUMBERS
     ASSIGN,XX(99)=XX(99)+1;    COUNT AIRCRAFT
     ASSIGN,ATRIB(3)=XX(5);
     ASSIGN,XX(5)=XX(5)+3.7;    INITIALIZE FLT HOURS

;*********************************************************************
;*                                                                   *
;*  MODEL SEGMENT I  ************ SORTIE GENERATION *****************  *
;*                                                                   *
;*********************************************************************

SCH   AWAIT(10),SCHEDULE;
APRE  AWAIT(1),F431;                                 WAIT FOR CREW CHIEF
SPFL  ASSIGN,ATRIB(8) = RLOGN(1.414219,.551545,4);  SET PREFLIGHT LENGTH
AMH1  ASSIGN,XX(2) = XX(2) + ATRIB(8);               ACCUMULATE MMH
      ACT,ATRIB(8);                                  PERFORM PREFLIGHT
FPRF  FREE,F431;                                     RELEASE CREW CHIEF
      ASSIGN,ATRIB(12) = TNOW;                       STORE PREFLIGHT TIME
AWDAY AWAIT(2),DAY;                                  WAIT FOR DAYLIGHT
SRTTO AWAIT(7),STRAT;
TFLY  QUEUE(8);
      ACT(82)/1,.2;                                  TAXI FOR LAUNCH
SLEN  ASSIGN,XX(6)=RNORM(1.3,.13,5),
             ATRIB(3)=ATRIB(3)+XX(6);                SET SORTIE LENGTH
      ACT/2,XX(6);                                   FLY MISSION
SSTS  ASSIGN,ATRIB(1)=TNOW,
             XX(14) = XX(14) + 1,
             XX(3)=XX(3)+1;                          COUNT SORTIES
      ACT,.2;                                        AFTER FLIGHT TAXI
```

```
PSTFL AWAIT(9),F431;                                   AWAIT CREW CHIEF
STFL  ASSIGN,ATRIB(8) = RLOGN(.435,.16965,6);          SET THRUFLIGHT LENGTH
AM2   ASSIGN,XX(2) = XX(2) + 1.326*ATRIB(8);           ACCUMULATE MMH
      ACT,ATRIB(8);                                    PERFORM THRUFLIGHT
FPSTF FREE,F431;
MMHPS ASSIGN,XX(7)=XX(2)/XX(3);                  SET MMH/SORTIE
DNTM  ASSIGN,XX(9) = XX(8)/XX(3);                SET DOWNTIME PER SORTIE
SGR   ASSIGN,XX(4)=XX(14)/XX(99)/10;            SET SORTIE GENERATION RATE
F?PHZ GOON,1;
        ACT,,ATRIB(3).GE.300.0,PHAZ;             IS PHASE INSPECTION DUE?
        ACT,,,FAIL;                                IF NOT, CHECK FOR FAILURE
CONT  GOON,1;
        ACT,,NNGAT(DAY).EQ.0,SRTT;               FLY AGAIN IF STILL DAY
        ACT,,,SCH;                                 OR, SCHEDULE FOR NEXT DAY

;***********************************************************************
;*                                                                     *
;*   MODEL SEGMENT II           **** CHECK FOR FAILURES ***            *
;*                                                                     *
;***********************************************************************

FAIL  EVENT,1;
F?REP GOON,1;
        ACT,,ATRIB(4).EQ.0.0,CONT;                 BACK TO FLY IF NO REPAIRS
        ACT;
DETC  EVENT,4;          DETERMINE WHICH CREW IS NEEDED TO REPAIR FAILURE
F1STS ASSIGN,XX(1)=XX(1)-1,ATRIB(1)=TNOW;
REP   AWAIT(5),ALLOC(2);                           WAIT FOR REPAIR CREWS
MTTR  ASSIGN,XX(10)=XX(10)+ATRIB(5);               COLLECT STATS ON MTTR
AMH3  ASSIGN,XX(2)=XX(2)+ATRIB(5)*ATRIB(7);        ACCUMULATE MMH
      ACT,ATRIB(5);                                REPAIR ACTIVITY
RELCR EVENT,2;                                     RELEASE REPAIR CREWS
MLTR? GOON,1;
        ACT,,ATRIB(4).GT.0.0,REP;
        ACT;
F2STS ASSIGN,XX(1)=XX(1)+1,
             XX(12)=TNOW-ATRIB(1),
             XX(8)=XX(8)+XX(12);                   COLLECT DOWNTIME STATS
      GOON,1;                                      BACK TO CONT IF PREFLIGHT
        ACT,,TNOW-ATRIB(12).LT.24.0,CONT;                 IS NOT NEEDED
        ACT,,,SCH;                                   TO SCHEDULE IF ONE IS

;***********************************************************************
;*                                                                     *
;*    MODEL SEGMENT III      ******  PHASE INSPECTION  ******          *
;*                                                                     *
;***********************************************************************

PHAZ  AWAIT(6),DOCK;
P1STS ASSIGN,XX(1)=XX(1)-1;
AMH4  ASSIGN,XX(2)=XX(2)+97.79845;               ACCUMULATE ALL SCHEDULED MMH
RSCL  ASSIGN,ATRIB(3)=0;                         RESET PHASE CLOCK
```

```
      ACT/2,72;                                   3-DAY PHASE DURATION
FDOCK FREE,DOCK;
P2STS ASSIGN,XX(1)=XX(1)+1;
      ACT,,,SCH;                                  TO SCHEDULE

;*********************************************************************
;*                                                                   *
;*     MODEL SEGMENT IV      ****** DAY/NIGHT ******                 *
;*                                                                   *
;*********************************************************************
      CREATE;
      ACT,1;
      EVENT,3;
      ACT,7;
SRISE OPEN,DAY;
      ACT,12;                       12 HRS OF DAYLIGHT
CSCH  CLOSE,SCHEDULE;               CLOSE GATE TO COLLECT AIRCRAFT
NIGHT CLOSE,DAY;                    NIGHT
      ACT,4;
SCHPL EVENT,3;                      SCHEDULE WHICH PLANES FLY THE NEXT DAY
      ACT,8,,SRISE;
;*********************************************************************
;*                                                                   *
;*     MODEL SEGMENT V       ****** WORK SHIFTS ******               *
;*                                                                   *
;*********************************************************************
      CREATE,,8;
DSHF  EVENT,6;                            DAY SHIFT COMES ON DUTY
      ACT,8;
SSHF  EVENT,7;                            SWING SHIFT COMES ON DUTY
      ACT,8;
NSHF  EVENT,8;                            NIGHT SHIFT COMES ON DUTY
      ACT,8,,DSHF;
;*********************************************************************
;*                                                                   *
;*     MODEL SEGMENT VI     ****** CREATE STRATIFIED TAKE OFFS ****** *
;*                                                                   *
;*********************************************************************
      CREATE;
TOAD  AWAIT(12),DAY;
TO    EVENT,5;                          ALLOW ONE PLANE TO TAKE OFF
      ACT,.05,,TOAD;                    DELAY NEXT TAKE OFF FOR 3 MINUTES
;*********************************************************************
;*                                                                   *
;*     MODEL SEGMENT VII       ****** CLEAR STATS ******             *
;*                                                                   *
;*********************************************************************
      CREATE,,6.0;
CLER  ASSIGN,XX(14) = 0;
      ACT,240,,CLER;

      ENDNETWORK;
```

```
INIT,0,4800;
MONTR,CLEAR,0.001,240.0;
FIN;
```

Explanation of Alloc Subroutine

The allocation subroutine is used to allocate crew resources for the repair of aircraft failures. In order to understand the structure of this subroutine a description of how SLAM calls this subroutine must be given first. SLAM calls the allocation subroutine when either of two events happen. The first event is the arrival of an entity at an await node tied to the allocation subroutine. The second event is a change in the quantities of any of the resources used by the allocation subroutine. It is also important to note that SLAM only checks one entity when the allocation subroutine is called. Which entity is checked depends on the queue discipline for that file.

In the model, aircraft can arrive at the node allocating crew resources from two locations. The first location is the SLAM node labeled FISTS. In this case it has just been determined that the aircraft has a failure. The second location is the SLAM node MLTR?. Here the aircraft has more maintenance actions to be accomplished. This could be the result of the aircraft having multiple failures or the maintenance action just completed is a required maintenance action.

Thus, aircraft can arrive at the allocation node in one of two states. There is either no work in progress (a state called NOWIP) or the aircraft has just finished a required maintenance action (state RMAWIP). When the allocation subroutine is called a check is made to determine which state the aircraft is in. Based on the state, a call is made to either the NOWIP or RMAWIP subroutine. Figure A.1 shows a flow chart of the allocation subroutine. Both the NOWIP and RMAWIP subroutines provide the allocation subroutine with the crew code and size and the repair time for the failure selected to be fixed. If there are no crews available to fix a failure, the crew size is zero and the crew code and repair time are meaningless. Next, the allocation subroutine checks to see if a crew is available. If a crew is available, the subroutine seizes the appropriate number of the crew available to fix the failure. When there are no crews available, the allocation subroutine checks to see if there are more aircraft waiting for repairs that need to be checked. If there are, the order of the aircraft in the file are switched to allow another aircraft to be checked.

Subroutines NOWIP, RMAWIP and the subroutines called by them (except REDUCE) are presented only as flowcharts in Figures A.2 through A.5.

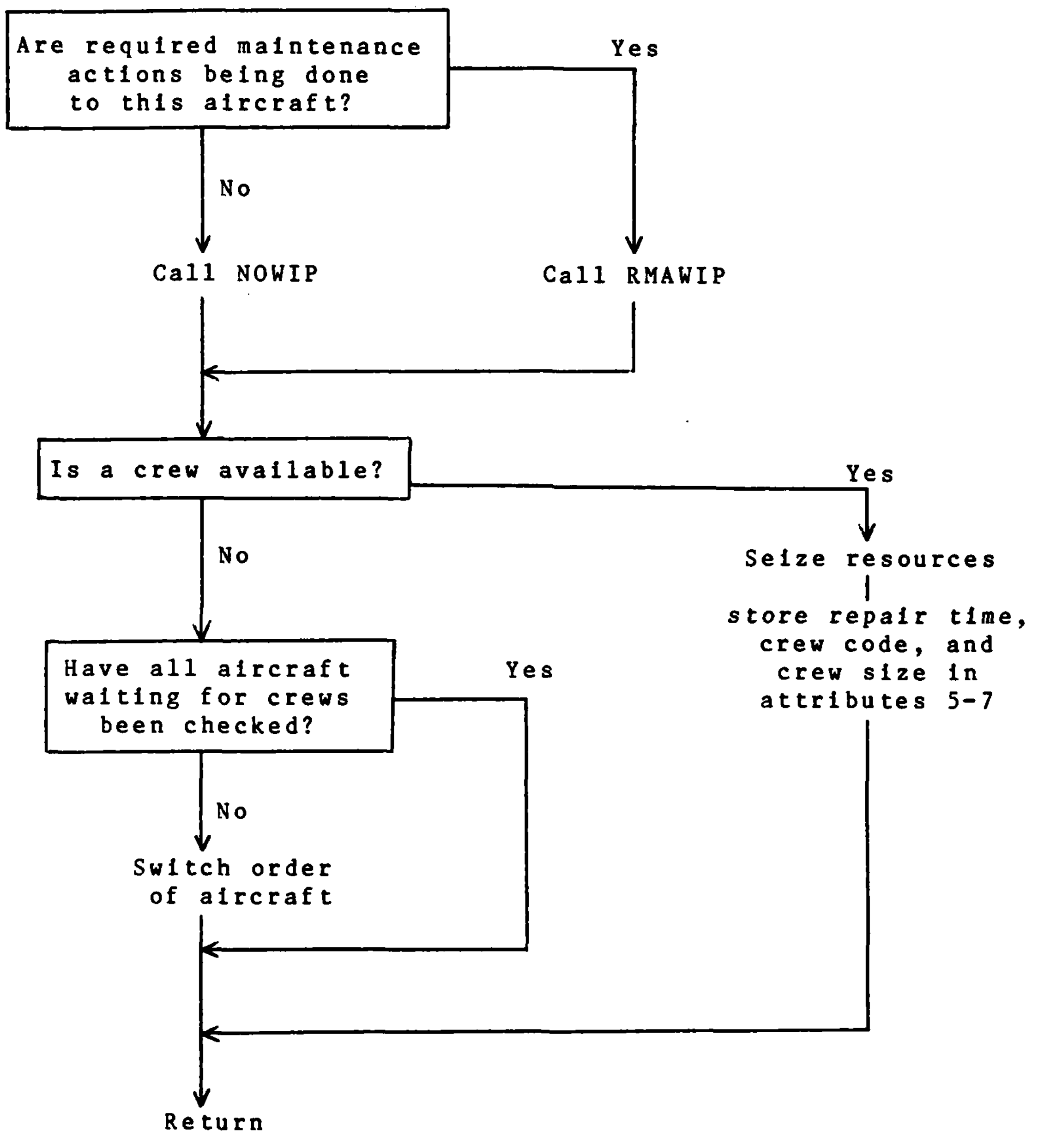


Figure A.1 Subroutine Alloc(2)

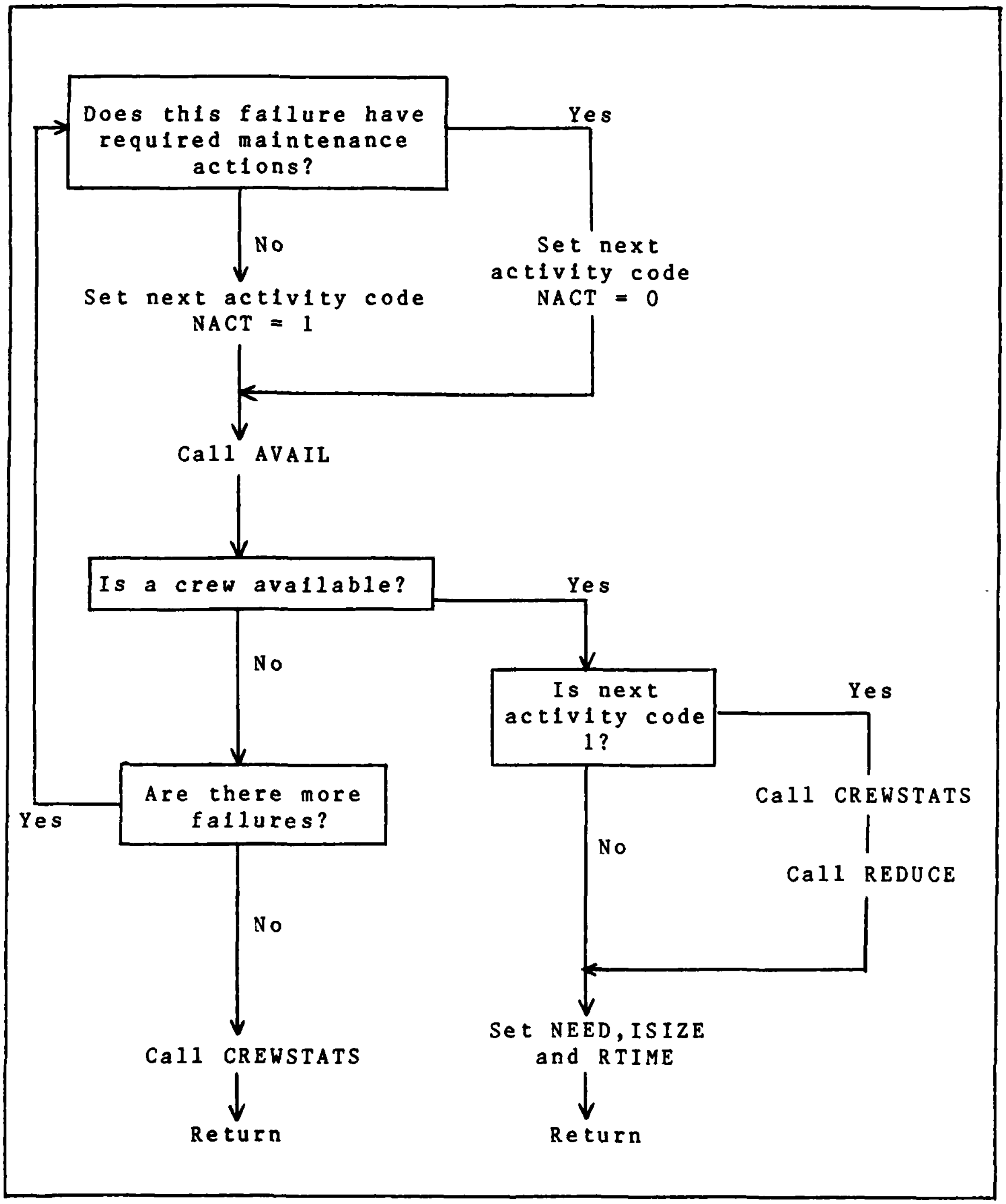


Figure A.2 Subroutine NOWIP(NEED,ISIZE,RTIME)

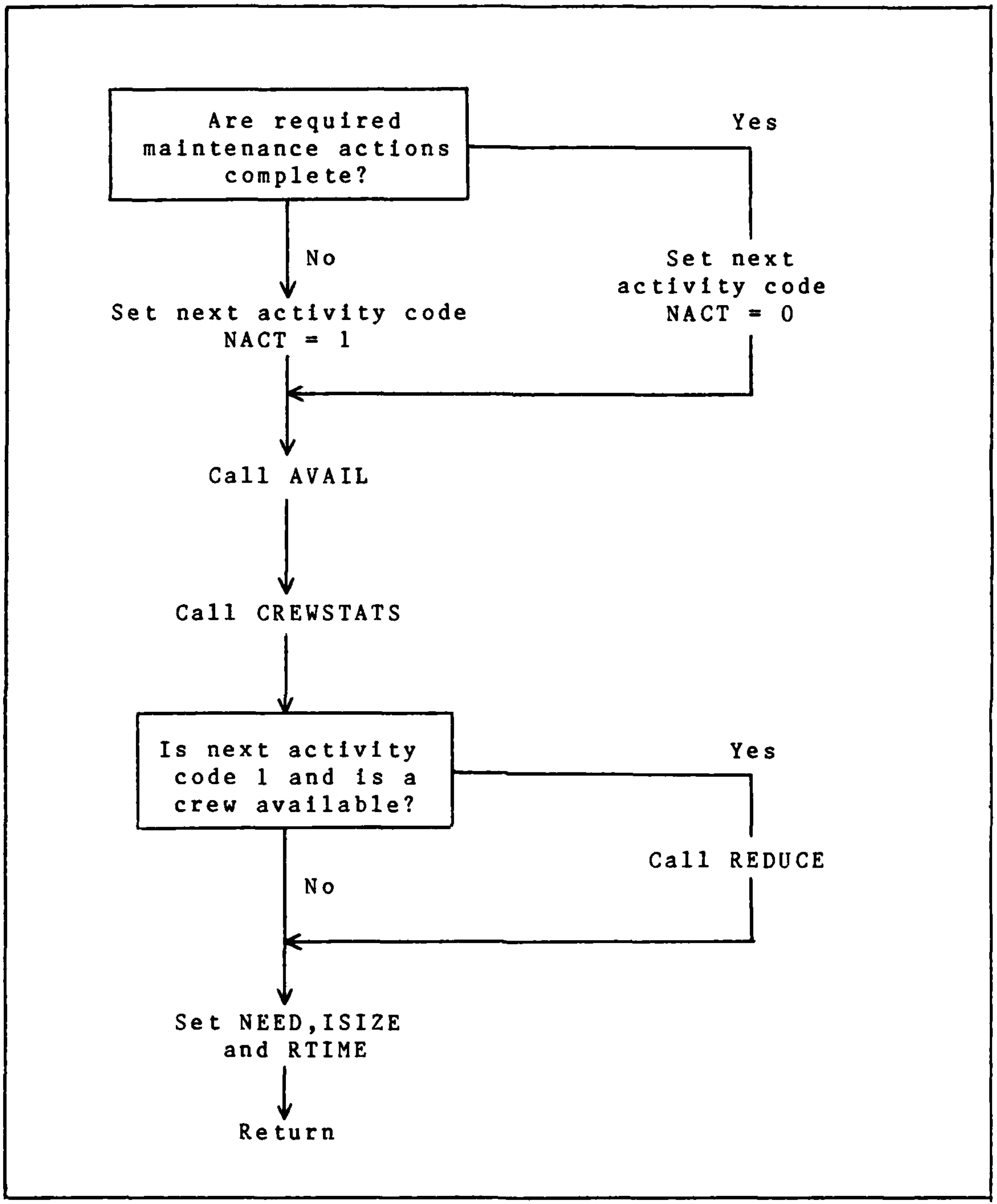


Figure A.3 Subroutine RMAWIP(NEED,ISIZE,RTIME)

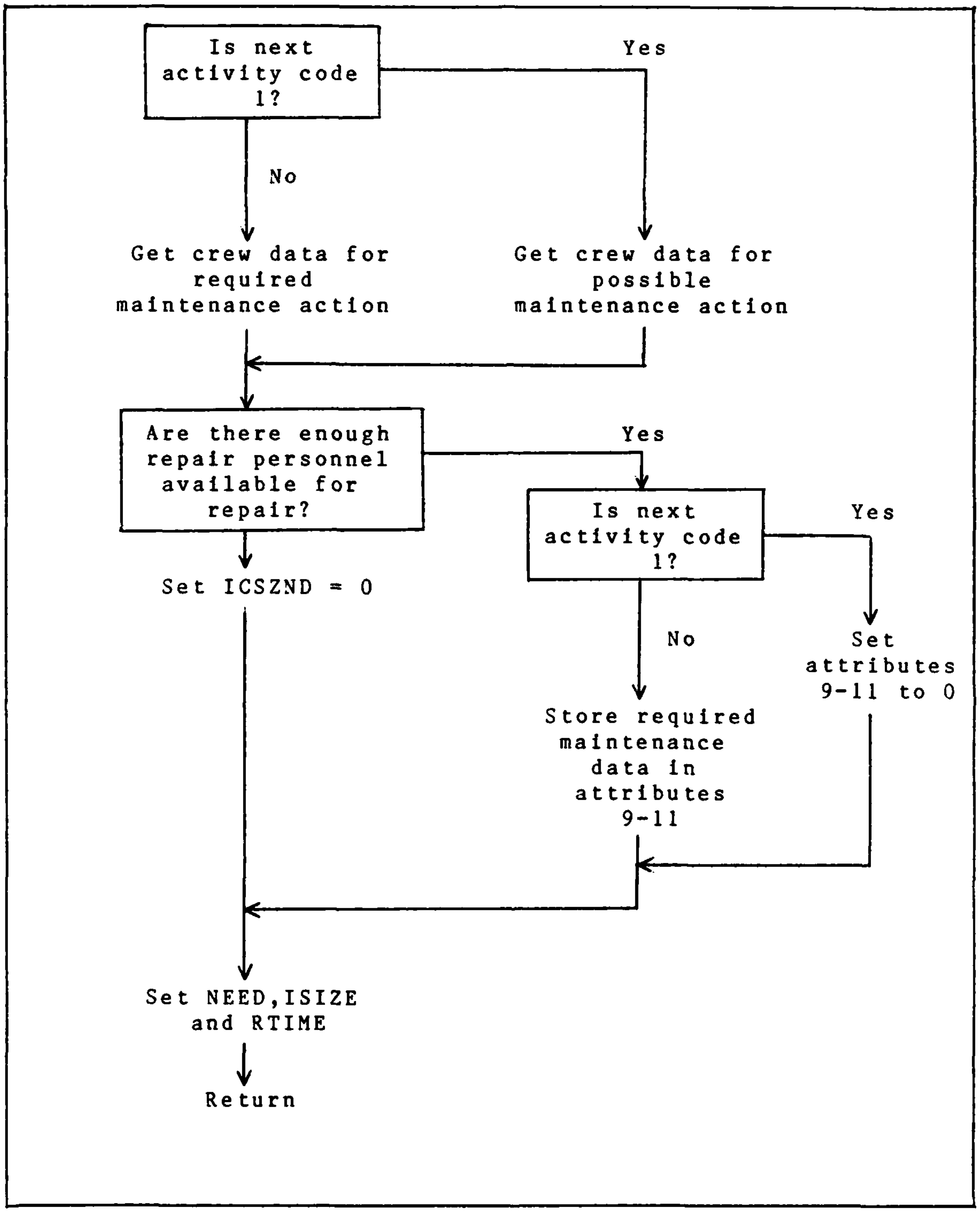


Figure A.4 Subroutine AVAIL(NPLANE,NACT,IFLNUM,MA,NEXTRA,NEED,ISIZE,NEED)

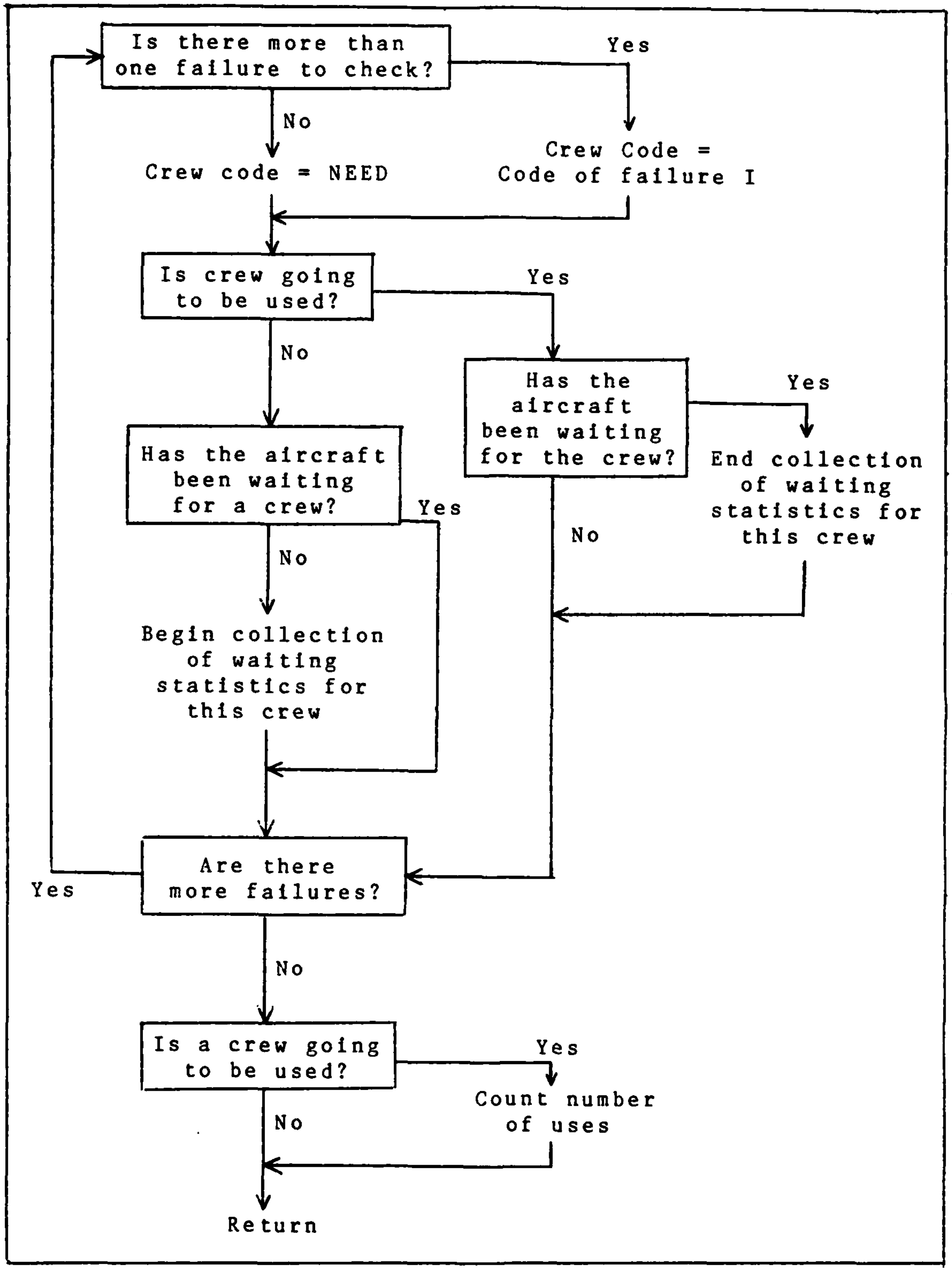


Figure A.5 Subroutine CREWSTATS(NPLANE,NCHECK,NEED,ISIZE)

FORTRAN Code

```
C***********************************************************************
C                                                                      *
C                              MAIN PROGRAM                            *
C                                                                      *
C***********************************************************************
C THIS PROGRAM DEFINES ALL GLOBAL VARIABLES
C THE NAME OF THE USER VARIABLES ARE EXPLAINED BENEATH EACH COMMON
C DECLARATION.  ALL NAMES ARE IMPLICITLY TYPED.
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ ITOTFL,NCREWS,NWUC
C ITOTFL -- COUNTS TOTAL NUMBER OF FAILURES
C NCREWS -- NUMBER OF DIFFERENT SPECIALISTS MODELED
C NWUC   -- NUMBER OF DIFFERENT WUCS MODELED
      COMMON/UCOM2/ ISHFTS(20,3)
C ISHFTS -- CONTAINS THE CHANGE IN MANPOWER FROM ONE SHIFT TO THE NEXT
      COMMON/UCOM3/ NFMAT(74),NPMA(74),NRMA(74)
C NFMAT  -- COUNTS FAILURES BY WUC
C NPMA   -- NUMBER OF POSSIBLE MAINTENANCE ACTIONS BY WUC
C NRMA   -- NUMBER OF REQUIRED MAINTENANCE ACTIONS BY WUC
      COMMON/UCOM4/ NCCRA(74,2),NCSRA(74,2)
C NCCRA  -- CREW CODES FOR REQUIRED MAINTENANCE ACTIONS BY WUC
C NCSRA  -- CREW SIZES FOR REQUIRED MAINTENANCE ACTIONS BY WUC
      COMMON/UCOM5/ RMTBF(74)
C RMTBF  -- MEAN TIME BETWEEN FAILURES BY WUC
      COMMON/UCOM6/ RSTATS(4,20)
C RSTATS -- STATISTICS ON CREW USE FOR UNSCHEDULED MAINTENANCE
      COMMON/UCOM7/ WAITING(82)
C WAITING -- INDICATES WHETHER AN AIRCRAFT IS WAITING FOR A REPAIR CREW
      COMMON/UCOM8/ RTRA(74,2)
C RTRA   -- REPAIR TIME FOR A REQUIRED MAINTENANCE ACTION BY WUC
      COMMON/UCOM9/ SORTAR(82,2)
C SORTAR -- ARRAY USED TO ORDER AIRCRAFT IN EVENT 3
      COMMON/UCOM10/ NCRWRQ(74,13),NCRWSZ(74,13)
C NCRWRQ -- CREW CODES FOR POSSIBLE MAINTENANCE ACTIONS BY WUC
C NCRWSZ -- CREW SIZES FOR POSSIBLE MAINTENANCE ACTIONS BY WUC
      COMMON/UCOM11/ CRWPRB(74,13),REPTIM(74,13)
C CRWPRB -- PROBABILITY THAT A CREW WILL BE USED TO REPAIR A POSSIBLE
C           MAINTENANCE ACTION
C REPTIM -- REPAIR TIME FOR A POSSIBLE MAINTENANCE ACTION BY WUC
```

```
      COMMON/UCOM12/ IDTCC(82,74),IDTCS(82,74),IFAIL(82,74)
C IDTCC  -- CREW CODES OF CREWS DETERMINED TO REPAIR CURRENT FAILURES
C           TO AN AIRCRAFT
C IDTCS  -- CREW SIZES OF THE CREWS NEEDED TO REPAIR CURRENT FAILURES
C           TO AN AIRCRAFT
C IFAIL  -- LIST OF CURRENT FAILURES TO AN AIRCRAFT
      COMMON/UCOM13/ DTRT(82,74)
C DTRT   -- REPAIR TIMES FOR CURRENT FAILURES TO AN AIRCRAFT
C ARRAYS ARE DIMENSIONED AS FOLLOWS
C (74)     - THERE ARE 74 WUCS
C (74,2)   - 74 WUCS BY NUMBER OF REQUIRED MAINTENANCE ACTIONS (THE MODEL
C            ONLY USES ONE RMA BUT CAN BE EXPANDED TO MORE THAN ONE.)
C (74,13) - 74 WUCS BY MAXIMUM OF 13 POSSIBLE MAINTENANCE ACTIONS
C (20,3)   - THERE ARE 20 TYPES OF SPECIALISTS AND 3 SHIFTS
C (4,20)   - 4 TYPES OF STATISTICS BY 20 SPECIALISTS
C     STATISTICS
C     1 - NUMBER OF AIRCRAFT CURRENTLY WAITING FOR EACH SPECIALIST
C     2 - TOTAL NUMBER OF WAITS FOR EACH SPECIALIST
C     3 - AVERAGE AMOUNT OF TIME AIRCRAFT WAIT FOR EACH SPECIALIST
C     4 - TOTAL NUMBER OF USES (IN UNSCHEDULED MAINTENANCE ONLY) FOR
C         EACH SPECIALIST
C (82,2)   - THERE ARE 82 AIRCRAFT BY 2 ATTRIBUTES USED WHEN SORTING
C (82,74) - 82 AIRCRAFT BY 74 POSSIBLE FAILURES
      NCRDR = 5
      NPRNT = 6
      NTAPE = 7
      NNSET = 10000
      NWUC = 74
      NCREWS = 20
      CALL SLAM
      STOP
      END

C*********************************************************************
C                                                                    *
C                          SUBROUTINE INTLC                          *
C                                                                    *
C*********************************************************************
C THIS SUBROUTINE READS DATA INTO THE ISHIFTS,NRMA,NPMA,RMTBF,RTRA,
C NCSRA,NCCRA,CRWPRB,REPTIM,NCRWSZ, AND NCRWRQ ARRAYS.  IT MODIFIES THE
C DATA FOR ISHIFTS AND CRWPRB TO THE FORM NEEDED IN THE MODEL.  IT ALSO
C CREATES THE INITIAL AMOUNT OF CREW RESOURCES IN THE SLAM NETWORK.
      SUBROUTINE INTLC
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
```

```
      COMMON/UCOM1/ ITOTFL,NCREWS,NWUC
      COMMON/UCOM2/ ISHFTS(20,3)
      COMMON/UCOM3/ NFMAT(74),NPMA(74),NRMA(74)
      COMMON/UCOM4/ NCCRA(74,2),NCSRA(74,2)
      COMMON/UCOM5/ RMTBF(74)
      COMMON/UCOM8/ RTRA(74,2)
      COMMON/UCOM10/ NCRWRQ(74,13),NCRWSZ(74,13)
      COMMON/UCOM11/ CRWPRB(74,13),REPTIM(74,13)

      DOUBLE PRECISION DCPACC

      OPEN(UNIT=NTAPE,FILE='MAINT.DAT',STATUS = 'OLD')
      REWIND(UNIT=NTAPE)

      DO 100 I = 1,NWUC
          READ(NTAPE,10) RMTBF(I),NRMA(I),NPMA(I)
          READ(NTAPE,10)

          DO 150 J=1,NRMA(I)
              READ(NTAPE,15) RTRA(I,J),NCSRA(I,J),NCCRA(I,J)
150        CONTINUE
          IF (NRMA(I).GT.0) READ(NTAPE,15)

          DCPACC = 0.0
          DO 200 J = 1,NPMA(I)
              READ(NTAPE,20) CRWPRB(I,J),REPTIM(I,J),
     +        NCRWSZ(I,J),NCRWRQ(I,J)
              DCPACC = DCPACC + CRWPRB(I,J)
              CRWPRB(I,J) = DCPACC
200        CONTINUE
          CRWPRB(I,NPMA(I)) = 1.0

          READ(NTAPE,10,END=300)
100    CONTINUE

300   CLOSE(UNIT=NTAPE)

      OPEN(UNIT=NTAPE,FILE='CREW.DAT',STATUS = 'OLD')
      REWIND(UNIT=NTAPE)

      DO 400 I = 1,NCREWS
          READ(NTAPE,30,END=401) (ISHFTS(I,J),J=1,3)
400   CONTINUE

401   CLOSE(UNIT=NTAPE)

      DO 500 I = 1,NCREWS
          CALL ALTER(I,ISHFTS(I,1))
500   CONTINUE
```

```
      DO 600 I = 1,NCREWS
          IMID = ISHFTS(I,1) - ISHFTS(I,3)
          IDAY = ISHFTS(I,2) - ISHFTS(I,1)
          ISWING = ISHFTS(I,3) - ISHFTS(I,2)
          ISHFTS(I,1) = IMID
          ISHFTS(I,2) = IDAY
          ISHFTS(I,3) = ISWING
600   CONTINUE

10    FORMAT(4X,F11.4,I4,I4)
15    FORMAT(17X,F10.6,6X,I2,I3)
20    FORMAT(11X,F6.3,F10.6,6X,I2,I3)
30    FORMAT(5X,I2,I3,I3)
      RETURN
      END
C*************************************************************************
C                                                                        *
C                            SUBROUTINE EVENT                            *
C                                                                        *
C*************************************************************************
      SUBROUTINE EVENT (J)

      GO TO (1,2,3,4,5,6,7,8,9), J

1     CALL FAIL
      RETURN

2     CALL FREECREWS
      RETURN

3     CALL SCHEDULE
      RETURN

4     CALL DETCREWS
      RETURN

5     CALL TAKEOFF
      RETURN

6     CALL DAYSHIFT
      RETURN

7     CALL SWINGSHIFT
      RETURN

8     CALL MIDSHIFT
      RETURN

9     CALL TOPREFLIGHT
      RETURN

      END
```

```
C*********************************************************************
C                                                                    *
C                         SUBROUTINE  FAIL                           *
C                                                                    *
C*********************************************************************
C THIS SUBROUTINE DETERMINES WHETHER A FAILURE HAS OCCURRED TO ANY OF
C THE AIRCRAFT SUBSYSTEMS BASED ON A PROBABILITY OF FAILURE PER FLIGHT.
C 0.5 IS ADDED TO THE PROBABILITY TO USE THE MIDDLE OF THE DISTRIBUTION
C GENERATING RANDOM NUMBERS. THIS IS DONE TO INCREASE THE ACCURACY OF
C THE FAILURE GENERATOR.  DOUBLE PRECISION IS ALSO USED FOR THIS REASON.
C THIS SUBROUTINE ALSO COUNTS THE NUMBER OF FAILURES FOR THIS AIRCRAFT
C (NFAIL), TOTAL NUMBER OF FAILURES (ITOTFL) AND BY WUC (NFMAT).
      SUBROUTINE FAIL
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),OSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ ITOTFL,NCREWS,NWUC
      COMMON/UCOM3/ NFMAT(74),NPMA(74),NRMA(74)
      COMMON/UCOM5/ RMTBF(74)
      COMMON/UCOM12/ IDTCC(82,74),IDTCS(82,74),IFAIL(82,74)

      DOUBLE PRECISION RNDNM,FLPCNT

      NPLANE = ATRIB(2)
      NFAIL = 0

      DO 5 I = 1,NWUC
          RNDNM = DRAND(9)
          FLPCNT=1.3D+00/RMTBF(I)+0.5D+00
          IF ((RNDNM.LT.0.5).OR.(RNDNM.GT.FLPCNT)) GO TO 5
          NFAIL = NFAIL + 1
          NFMAT(I) = NFMAT(I) + 1
          IFAIL(NPLANE,NFAIL) = I
          ITOTFL = ITOTFL +1
5     CONTINUE

      ATRIB(4) = NFAIL

      RETURN
      END
```

```
C*********************************************************************
C                                                                    *
C                      SUBROUTINE  FREECREWS                         *
C                                                                    *
C*********************************************************************
C THIS SUBROUTINE FREES THE RESOURCES THAT HAVE BEEN USED FOR A REPAIR
      SUBROUTINE FREECREWS
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      J = ATRIB(6)
      K = ATRIB(7)

      CALL FREE(J,K)

      ATRIB(5)=0.0
      ATRIB(6)=0.0
      ATRIB(7)=0.0

      RETURN
      END

C*********************************************************************
C                                                                    *
C                      SUBROUTINE SCHEDULE                           *
C                                                                    *
C*********************************************************************
C THIS SUBROUTINE SUBROUTINE DOES 2 DIFFERENT ACTIONS. FIRST, IT SETS
C XX(13) EQUAL TO THE AVERAGE VALUE OF FMC AIRCRAFT AS COLLECTED BY
C XX(1) IN THE SLAM NETWORK.  SECOND, THIS SUBROUTINE REMOVES ALL
C AIRCRAFT IN A FILE WAITING FOR TAKEOFF AND PLACES THEM INTO THE FILE
C FOR SCHEDULING.  IT THEN STORES IN ARRAY SORTAR THE ORDER (BY NUMBER
C OF FLIGHT HOURS) OF THE AIRCRAFT IN THE SCHEDULING FILE.  FINALLY,
C THIS SUBROUTINE CALLS THE EVENT TOPREFLIGHT.
      SUBROUTINE SCHEDULE
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM9/ SORTAR(82,2)

      XX(13) = TTAVG(1)
```

```
      INDEX = 0
      DO 10 I= 1,NNQ(7)
          CALL RMOVE(1,7,ATRIB)
          INDEX = INDEX + 1
          SORTAR(INDEX,1)=ATRIB(2)
          SORTAR(INDEX,2)=ATRIB(3)
          CALL FILEM(10,ATRIB)
10    CONTINUE

      DO 20 I= 1,NNQ(3)
          CALL RMOVE(1,3,ATRIB)
          INDEX = INDEX + 1
          SORTAR(INDEX,1)=ATRIB(2)
          SORTAR(INDEX,2)=ATRIB(3)
          CALL FILEM(10,ATRIB)
20    CONTINUE

      DO 30 I= 1,NNQ(10)
          CALL COPY(I,10,ATRIB)
          INDEX = INDEX + 1
          SORTAR(INDEX,1)=ATRIB(2)
          SORTAR(INDEX,2)=ATRIB(3)
30    CONTINUE


40    SWITCH = 0.0
      DO 50 I=2,INDEX
          IM1=I-1
          IF (SORTAR(IM1,2).GT.SORTAR(I,2)) THEN
              T1=SORTAR(IM1,1)
              T2=SORTAR(IM1,2)
              SORTAR(IM1,1)=SORTAR(I,1)
              SORTAR(IM1,2)=SORTAR(I,2)
              SORTAR(I,1)=T1
              SORTAR(I,2)=T2
            SWITCH = 1.0
            ENDIF
50    CONTINUE
      IF (SWITCH.GT.0.0) GO TO 40

      CALL SCHDL(9,0,ATRIB)

      RETURN
      END
```

```
C                    ********************************************
C                    *                                          *
C                    *          SUBROUTINE TO PRE FLIGHT        *
C                    *                                          *
C                    ********************************************
C THIS SUBROUTINE MOVES AIRCRAFT FROM THE SCHEDULING FILE TO THE
C QUEUE FOR PREFLIGHTS.  THE AIRCRAFT ARE MOVED IN ORDER OF FLIGHT
C HOURS, THE HIGHEST IS MOVED FIRST.
C CURRENTLY, ALL AIRCRAFT ARE ALLOWED TO FLY, THUS ALL OF THE AIRCRAFT
C ARE MOVED AND THE CALL OPEN(3) STATEMENT IS USED TO OPEN THE
C SCHEDULING GATE.  IF ALL AIRCRAFT ARE NOT ALLOWED TO FLY THE CODE TO
C SELECT THE APPROPRIATE AIRCRAFT SHOULD BE INSERTED AND THE CALL OPEN
C STATEMENT REMOVED.
      SUBROUTINE TOPREFLIGHT
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM9/ SORTAR(82,2)

      DO 60 I = NNQ(10),1,-1
          NRANK = NFIND(1,10,2,0,SORTAR(I,1),.1)
          IF (NRANK.GT.0) THEN
              CALL RMOVE(NRANK,10,ATRIB)
              CALL FILEM(1,ATRIB)
           ENDIF
60    CONTINUE

      CALL OPEN(3)

      RETURN
      END
C***********************************************************************
C                                                                      *
C                              SUBROUTINE DETCREWS                     *
C                                                                      *
C***********************************************************************
C THIS SUBROUTINE DETERMINES WHICH OF SEVERAL POSSIBLE REPAIR CREWS WILL
C REPAIR A FAILURE.
      SUBROUTINE DETCREWS
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ ITOTFL,NCREWS,NWUC
      COMMON/UCOM3/ NFMAT(74),NPMA(74),NRMA(74)
      COMMON/UCOM10/ NCRWRQ(74,13),NCRWSZ(74,13)
      COMMON/UCOM11/ CRWPRB(74,13),REPTIM(74,13)
      COMMON/UCOM12/ IDTCC(82,74),IDTCS(82,74),IFAIL(82,74)
      COMMON/UCOM13/ DTRT(82,74)
```

```
      NPLANE = ATRIB(2)
      NFAIL = ATRIB(4)

      DO 10 I = 1, NFAIL
          RNDNM = DRAND(9)
          DO 20 J = 1,NPMA(IFAIL(NPLANE,I))
              JM1 = J-1
              IF ((RNDNM.LE.CRWPRB(IFAIL(NPLANE,I),J)).AND.
     +          (RNDNM.GT.CRWPRB(IFAIL(NPLANE,I),JM1))) THEN
                  IDTCC(NPLANE,I) = NCRWRQ(IFAIL(NPLANE,I),J)
                  IDTCS(NPLANE,I) = NCRWSZ(IFAIL(NPLANE,I),J)
                  DTRT(NPLANE,I) = REPTIM(IFAIL(NPLANE,I),J)
                ENDIF
20        CONTINUE
10    CONTINUE

      RETURN
      END
C***********************************************************************
C                                                                      *
C                              SUBROUTINE TAKEOFF                      *
C                                                                      *
C***********************************************************************
C THIS SUBROUTINE MOVES ONE AIRCRAFT TO A FILE WHERE THE AIRCRAFT CAN
C BEGIN THE FLIGHT SEQUENCE.
      SUBROUTINE TAKEOFF
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      IF (NNQ(7).GT.0) THEN
          CALL RMOVE(1,7,ATRIB)
          CALL FILEM(8,ATRIB)
        ENDIF

      RETURN
      END
C***********************************************************************
C                                                                      *
C                              SUBROUTINE DAYSHIFT                     *
C                                                                      *
C***********************************************************************
C THIS EVENT ALTERS THE CREW RESOURCES FROM THE MIDNIGHT SHIFT TO THE
C DAY SHIFT LEVELS.
      SUBROUTINE DAYSHIFT
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ ITOTFL,NCREWS,NWUC
      COMMON/UCOM2/ ISHFTS(20,3)
```

```
      DO 100 I = 1,NCREWS
          CALL ALTER(I,ISHFTS(I,2))
100   CONTINUE

      RETURN
      END
C***********************************************************************
C                                                                      *
C                          SUBROUTINE SWINGSHIFT                       *
C                                                                      *
C***********************************************************************
C THIS EVENT ALTERS THE CREW RESOURCES FROM THE DAY SHIFT TO THE SWING
C SHIFT LEVELS.
      SUBROUTINE SWINGSHIFT
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ ITOTFL,NCREWS,NWUC
      COMMON/UCOM2/ ISHFTS(20,3)

      DO 100 I = 1,NCREWS
          CALL ALTER(I,ISHFTS(I,3))
100   CONTINUE

      RETURN
      END
C***********************************************************************
C                                                                      *
C                          SUBROUTINE MIDSHIFT                         *
C                                                                      *
C***********************************************************************
C THIS EVENT ALTERS THE CREW RESOURCES FROM THE SWING SHIFT TO THE
C MIDNIGHT SHIFT LEVELS.
      SUBROUTINE MIDSHIFT
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ ITOTFL,NCREWS,NWUC
      COMMON/UCOM2/ ISHFTS(20,3)

      DO 100 I = 1,NCREWS
          CALL ALTER(I,ISHFTS(I,1))
100   CONTINUE

      RETURN
      END
```

```
C*****************************************************************
C                                                                *
C                      SUBROUTINE ALLOC                          *
C                                                                *
C*****************************************************************
C THIS SUBROUTINE SEIZES CREW RESOURCES (WHEN AVAILABLE) TO FIX AIRCRAFT
C IF NO RESOURCES ARE AVAILABLE AND THERE ARE MORE AIRCRAFT WAITING FOR
C CREWS, THE AIRCRAFT LAST IN THE QUEUE IS REMOVED AND REPLACED IN THE
C QUEUE TO BE CHECKED FOR CREW AVAILABILITY.  THIS OCCURS UNTIL ALL
C AIRCRAFT HAVE BEEN CHECKED.
      SUBROUTINE ALLOC(I,IFLAG)
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      IFLAG = 0

      IF (ATRIB(10).GT.0.0) THEN
          CALL RMAWIP(NEED,ISIZE,RTIME)
        ELSE
          CALL NOWIP(NEED,ISIZE,RTIME)
       ENDIF

      XX(11) = XX(11) + 1.0

      IF (ISIZE.EQ.0) THEN
          IF (XX(11).GE.NNQ(5)) THEN
              XX(11) = 0.0
            ELSE
              CALL RMOVE(NNQ(5),5,ATRIB)
              CALL FILEM(5,ATRIB)
           ENDIF
        ELSE
          CALL SEIZE(NEED,ISIZE)
          ATRIB(5)=RTIME
          ATRIB(6)=NEED
          ATRIB(7)=ISIZE
          IFLAG = 1
       ENDIF

      RETURN
      END
```

```
C                    ****************************************
C                    *                                      *
C                    *           SUBROUTINE NOWIP           *
C                    *                                      *
C                    ****************************************
C WHEN CREWS ARE AVAILABLE THIS SUBROUTINE PROVIDES ALLOC WITH THE CREW,
C ITS SIZE, AND THE REPAIR TIME NEEDED TO FIX A FAILURE.
C WHEN CREWS ARE NOT AVAILABLE THE SIZE VARIABLE IS A ZERO.
C THIS SUBROUTINE GETS THIS INFORMATION FROM AVAIL.
C IF THIS REPAIR ACTION WILL FINISH FIXING A FAILURE THIS SUBROUTINE
C CAUSES THE ARRAYS THAT STORE FAILURE DATA TO BE REDUCED.
      SUBROUTINE NOWIP(NEED,ISIZE,RTIME)
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM3/ NFMAT(74),NPMA(74),NRMA(74)
      COMMON/UCOM12/ IDTCC(82,74),IDTCS(82,74),IFAIL(82,74)

      NEED = 0
      ISIZE = 0
      RTIME = 0.0

      NPLANE = ATRIB(2)
      NFAIL = ATRIB(4)

      DO 10 I = 1, NFAIL
          MA = IFAIL(NPLANE,I)
          IF (NRMA(MA).GT.0) THEN
              NACT = 0
              NEXTRA = 1
            ELSE
              NACT = 1
              NEXTRA = 0
           ENDIF


         CALL AVAIL(NPLANE,NACT,I,MA,NEXTRA,ICC,ICSZND,REPLEN)
         IF (ICSZND.GT.0) GOTO 30

10     CONTINUE

      CALL CREWSTATS(NPLANE,NFAIL,ICC,0)

      RETURN

30    CALL CREWSTATS(NPLANE,NFAIL,ICC,ICSZND)
```

```
      IF (NACT.EQ.1) CALL REDUCE(I)

      NEED = ICC
      ISIZE = ICSZND
      RTIME = REPLEN

      RETURN
      END

C                    ****************************************
C                    *                                      *
C                    *           SUBROUTINE RMAWIP          *
C                    *                                      *
C                    ****************************************
C WHEN CREWS ARE AVAILABLE THIS SUBROUTINE PROVIDES ALLOC WITH THE CREW,
C ITS SIZE, AND THE REPAIR TIME NEEDED TO FIX A FAILURE.
C WHEN CREWS ARE NOT AVAILABLE THE SIZE VARIABLE IS A ZERO.
C THIS SUBROUTINE GETS THIS INFORMATION FROM AVAIL.
C IF THIS REPAIR ACTION WILL FINISH FIXING A FAILURE THIS SUBROUTINE
C CAUSES THE ARRAYS THAT STORE FAILURE DATA TO BE REDUCED.
      SUBROUTINE RMAWIP(NEED,ISIZE,RTIME)
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM3/ NFMAT(74),NPMA(74),NRMA(74)

      NEED = 0
      ISIZE = 0
      RTIME = 0

      NPLANE = ATRIB(2)
      MA = ATRIB(9)
      IFLNUM = ATRIB(11)
      NEXTRA = ATRIB(10) + 1

      IF (NEXTRA.GT.NRMA(MA)) THEN
          NACT = 1
        ELSE
          NACT = 0
       ENDIF

      CALL AVAIL(NPLANE,NACT,IFLNUM,MA,NEXTRA,ICC,ICSZND,REPLEN)

      CALL CREWSTATS(NPLANE,1,ICC,ICSZND)
```

```
      IF ((NACT.EQ.1).AND.(ICSZND.GT.0)) CALL REDUCE(IFLNUM)

      NEED = ICC
      ISIZE = ICSZND
      RTIME = REPLEN

      RETURN
      END
C                  ****************************************
C                  *                                      *
C                  *            SUBROUTINE AVAIL          *
C                  *                                      *
C                  ****************************************
C THIS SUBROUTINE PROVIDES NOWIP AND RMAWIP WITH THE CREW CODE, ITS SIZE
C AND REPAIR TIME NEEDED TO FIX A FAILURE.  IF NOT ENOUGH CREWS ARE
C AVAILABLE THE CREW SIZE IS SET TO ZERO.
      SUBROUTINE AVAIL(NPLANE,NACT,IFLNUM,MA,NEXTRA,NEED,ISIZE,RTIME)
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM4/ NCCRA(74,2),NCSRA(74,2)
      COMMON/UCOM8/ RTRA(74,2)
      COMMON/UCOM12/ IDTCC(82,74),IDTCS(82,74),IFAIL(82,74)
      COMMON/UCOM13/ DTRT(82,74)

      IF (NACT.GT.0) THEN
          ICC = IDTCC(NPLANE,IFLNUM)
          IAVAIL = NNRSC(ICC)
          ICSZND = IDTCS(NPLANE,IFLNUM)
          REPLEN =  DTRT(NPLANE,IFLNUM)
        ELSE
          ICC = NCCRA(MA,NEXTRA)
          IAVAIL = NNRSC(ICC)
          ICSZND = NCSRA(MA,NEXTRA)
          REPLEN = RTRA(MA,NEXTRA)
       ENDIF

      IF ((IAVAIL.LT.ICSZND).OR.(IAVAIL.EQ.0)) THEN
          ICSZND = 0
        ELSE
          IF (NACT.EQ.1) THEN
              ATRIB(9) = 0.0
              ATRIB(10) = 0.0
              ATRIB(11) = 0.0
            ELSE
              ATRIB(9) = MA
              ATRIB(10) = NEXTRA
              ATRIB(11) = IFLNUM
           ENDIF
       ENDIF
```

```
      NEED = ICC
      ISIZE = ICSZND
      RTIME = REPLEN

      RETURN
      END
C                    ****************************************
C                    *                                      *
C                    *         SUBROUTINE CREWSTATS         *
C                    *                                      *
C                    ****************************************
C THIS SUBROUTINE COLLECTS STATISTICS ON HOW MANY TIMES CREWS ARE USED
C FOR UNSCHEDULED REPAIRS.  IT ALSO COLLECTS HOW MANY TIMES CREWS WERE
C NEEDED BUT NOT AVAILABLE AND THE AVERAGE WAITING TIME FOR THESE CREWS
      SUBROUTINE CREWSTATS(NPLANE,NCHECK,NEED,ISIZE)
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM3/ NFMAT(74),NPMA(74),NRMA(74)
      COMMON/UCOM4/ NCCRA(74,2),NCSRA(74,2)
      COMMON/UCOM6/ RSTATS(4,20)
      COMMON/UCOM7/ WAITING(82)
      COMMON/UCOM12/ IDTCC(82,74),IDTCS(82,74),IFAIL(82,74)

      DO 100 I = 1,NCHECK
          IF (NCHECK.EQ.1) THEN
              ICC = NEED
            ELSE
              MA = IFAIL(NPLANE,I)
              IF (NRMA(MA).GT.0) THEN
                  ICC = NCCRA(MA,1)
                ELSE
                  ICC = IDTCC(NPLANE,I)
               ENDIF
           ENDIF

          IF (ISIZE.GT.0) THEN
              IF (WAITING(NPLANE).GT.0.0) THEN
                  RSTATS(1,ICC) = RSTATS(1,ICC) - 1
                  RSTATS(3,ICC) = RSTATS(3,ICC) - TNOW
               ENDIF
            ELSE
              IF (WAITING(NPLANE).EQ.0.0) THEN
                  RSTATS(1,ICC) = RSTATS(1,ICC) + 1.0
                  RSTATS(2,ICC) = RSTATS(2,ICC) + 1.0
                  RSTATS(3,ICC) = RSTATS(3,ICC) + TNOW
               ENDIF
           ENDIF
100     CONTINUE
```

```
      IF (ISIZE.GT.0) THEN
          WAITING(NPLANE) = 0.0
          RSTATS(4,NEED) = RSTATS(4,NEED) + 1.0
        ELSE
          WAITING(NPLANE) = 1.0
       ENDIF

      RETURN
      END

C                     ************************************
C                     *                                  *
C                     *        SUBROUTINE REDUCE         *
C                     *                                  *
C                     ************************************
C THIS SUBROUTINE REDUCES THE ARRAYS THAT STORE WHICH AIRCRAFT HAVE
C WHAT FAILURES, WHO, HOW MANY, AND HOW LONG IT TAKES TO FIX THEM.
C IT ALSO DECREMENTS THE ATTRIBUTE WHICH STORES HOW MANY FAILURES
C THE AIRCRAFT HAS.
      SUBROUTINE REDUCE(INDEX)
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM12/ IDTCC(82,74),IDTCS(82,74),IFAIL(82,74)
      COMMON/UCOM13/ DTRT(82,74)

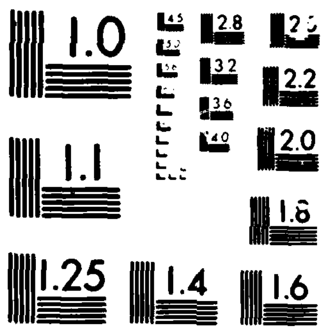
      NPLANE = ATRIB(2)
      NFAIL = ATRIB(4)
      IF (INDEX.LT.NFAIL) THEN
          INDXP1 = INDEX + 1
          DO 100 I = INDXP1,NFAIL
              IM1 = I - 1
              IFAIL(NPLANE,IM1) = IFAIL(NPLANE,I)
              IDTCC(NPLANE,IM1) = IDTCC(NPLANE,I)
              IDTCS(NPLANE,IM1) = IDTCS(NPLANE,I)
               DTRT(NPLANE,IM1) =  DTRT(NPLANE,I)
100           CONTINUE
       ENDIF
      IFAIL(NPLANE,NFAIL) = 0
      IDTCC(NPLANE,NFAIL) = 0
      IDTCS(NPLANE,NFAIL) = 0
       DTRT(NPLANE,NFAIL) = 0.0

      ATRIB(4) = NFAIL - 1

      RETURN
      END
```

AD-A167 121 A SIMULATION MODEL OF THE T-46A AIRCRAFT FOR AVAILABILITY AND SORTIE PROJECTIONS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH R A FOLEY ET AL. 2/2

UNCLASSIFIED DEC 85 AFIT/GOR/ENS/85D-6 F/G 5/9 NL



MICROCOPY CHART

```
C*************************************************************************
C                                                                        *
C                           SUBROUTINE OTPUT                             *
C                                                                        *
C*************************************************************************
C THIS SUBROUTINE PRINTS OUT USER DEFINED OUTPUT
      SUBROUTINE OTPUT
      DIMENSION NSET(10000)
      COMMON QSET(10000)
      EQUIVALENCE (NSET(1),QSET(1))
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/ ITOTFL,NCREWS,NWUC
      COMMON/UCOM3/ NFMAT(74),NPMA(74),NRMA(74)
      COMMON/UCOM4/ NCCRA(74,2),NCSRA(74,2)
      COMMON/UCOM5/ RMTBF(74)
      COMMON/UCOM6/ RSTATS(4,20)
      COMMON/UCOM8/ RTRA(74,2)
      COMMON/UCOM9/ SORTAR(82,2)
      COMMON/UCOM10/ NCRWRQ(74,13),NCRWSZ(74,13)
      COMMON/UCOM11/ CRWPRB(74,13),REPTIM(74,13)
      COMMON/UCOM12/ IDTCC(82,74),IDTCS(82,74),IFAIL(82,74)
      COMMON/UCOM13/ DTRT(82,74)

      CHARACTER*5 CREW(20)
      DATA CREW/'R431 ','F431 ','P431 ','S4270','S4274','S4275','S4271',
     +'S426 ','A426 ','T426 ','F426 ','W431 ','S4233','S4230','S4234',
     +'S4231','S4232','S3280','S3281','S325 '/

      DIMENSION EXPT(74)
      DOUBLE PRECISION FLPCNT

      WRITE(NPRNT,100)
100   FORMAT(1X,'OBSERVED FAILURES BY WUC')
      WRITE(NPRNT,101) (NFMAT(I),I=1,NWUC)
101   FORMAT(10(3X,I5))

      CHISQ = 0.0
      SUMFLS = 0.0
      DO 10 I = 1,NWUC
          FLPCNT=1.3D+00/RMTBF(I)
          EXPT(I) = XX(3) * FLPCNT
          SUMFLS = SUMFLS + EXPT(I)
          CHISQ = CHISQ + ((NFMAT(I)-EXPT(I))**2)/EXPT(I)
10    CONTINUE

      WRITE(NPRNT,101)
      WRITE(NPRNT,120)
120   FORMAT(1X,'EXPECTED NUMBER OF FAILURES BY WUC')
      WRITE(NPRNT,121) (EXPT(I),I=1,NWUC)
121   FORMAT(10(F7.3,1X))
      WRITE(NPRNT,101)
```

```
      WRITE(NPRNT,130) CHISQ
130   FORMAT(1X,'CHI-SQUARE STATISTIC FOR FAILURE GENERATOR:',F9.3)
      WRITE(NPRNT,101)
      WRITE(NPRNT,140) XX(3)
140   FORMAT(1X,'TOTAL NUMBER OF FLIGHTS IS',F10.1)
      WRITE(NPRNT,150) ITOTFL
150   FORMAT(1X,'OBSERVED NUMBER OF FAILURES',I6)
      WRITE(NPRNT,160) SUMFLS
160   FORMAT(1X,'EXPECTED NUMBER OF FAILURES',F8.2)

      DO 20 I=1,NWUC
          EXPT(I) = 0.0
          NFMAT(I) = 0
20     CONTINUE

      DO   40 I = 1,NCREWS
          IF (RSTATS(1,I).EQ.0.0) GO TO 40
          NCW = RSTATS(1,I)
          DO 30 J=1,NCW
              RSTATS(3,I) = RSTATS(3,I) - TNOW
30         CONTINUE
40    CONTINUE

      DO   50 I = 1,NCREWS
          IF (RSTATS(2,I).EQ.0.0) GO TO 50
          RSTATS(3,I) = -RSTATS(3,I)/RSTATS(2,I)
50     CONTINUE
      WRITE(NPRNT,170)
170   FORMAT(1X,'CREWS')
      WRITE(NPRNT,180) (CREW(I),I=1,NCREWS)
180   FORMAT(10(3X,A5))
      WRITE(NPRNT,190)
190   FORMAT(1X,'RESOURCE STATS: NUMBER OF TIMES USED TO REPAIR')
      WRITE(NPRNT,200) (RSTATS(4,I),I=1,NCREWS)
200   FORMAT(10(F8.1))
      WRITE(NPRNT,210)
210   FORMAT(1X,'RESOURCE STATS: NUMBER CURRENTLY WAITING')
      WRITE(NPRNT,200) (RSTATS(1,I),I=1,NCREWS)
      WRITE(NPRNT,210)
210   FORMAT(1X,'RESOURCE STATS: TOTAL NUMBER OF WAITS')
      WRITE(NPRNT,200) (RSTATS(2,I),I=1,NCREWS)
      WRITE(NPRNT,220)
220   FORMAT(1X,'RESOURCE STATS: AVERAGE WAITING TIME')
      WRITE(NPRNT,230) (RSTATS(3,I),I=1,NCREWS)
230   FORMAT(10(F8.3))

      RETURN
      END
```

Appendix B

Input Data

Appendix B contains the data and data sources for the T-46A model. Table B.1 is a list of the 74 work unit codes (WUCs) used in this analysis of the T-46A. This table also includes the mean time between failure (MTBF) and mean time to repair (MTTR) for each WUC. The data in Table B.1 is based on the Fairchild Republic Reliability/Maintainability Allocation, Assessments, and Analyses document (A^3 report). The values used for MTBF are the predicted values not the allocated values.

Table B.2 presents the current ATC work center listing along with the number of personnel assigned to the centers by shift. The shift sizes reflect the ATC LCOM Final Report data for Laughlin AFB.

Table B.3 is a list of the scheduled maintenance for the T-46A. This data is also from the A^3 report.

Table B.4 contains the unscheduled maintenance network. Data in this network comes from three sources. The WUCs and MTTRs are from the A^3 report. The node structure comes mainly from the ATC LCOM repair network for the T-37. This network was supplemented by portions of an early ASD LCOM network for the T-46A.

Table B.1

Work Unit Code Data

WUC	Nomenclature	MTBF hours	MTTR hours
11A	fuselage, forward section	468.1669	3.587277
11B	fuselage, center section	1168.2249	0.591818
11C	wing assembly	1642.0352	1.11821
11D	empennage	810.3720	2.391503
11E	engine nacelle	734.2144	1.788432
11F	fuselage, aft section	4290.0000	0.933081
12A	cockpit	722.2833	3.913892
12B	canopy	623.2855	4.386283
12C	ejection seat system	418.9456	2.656802
13A	main landing gear	113.0546	2.219961
13B	nose landing gear	234.0806	1.614848
13C	brake system	912.4177	2.401157
13D	landing gear control system	2164.4912	2.18305
13E	auxiliary landing gear extension	2164.5000	1.528385
13F	nose wheel steering	1237.0099	2.90717
13G	landing gear warning	2134.4690	1.54069
14A	pilot controls	2840.9060	2.298255
14B	roll control	853.9690	3.93062
14C	pitch control	977.0434	4.374974
14D	yaw control	806.2680	1.475129
14E	trailing edge system	793.1480	2.655312
14F	speed brake system	1117.3239	2.416026
23A	engine (core)	359.2000	2.712
23N	ignition/electrical system	1628.6646	1.382284
23P	engine lubrication system	3246.7517	1.681402
23Q	main fuel system	1329.8004	4.136884
23R	engine instrumentation system	346.3588	3.534767
23S	starting system	8271.2920	2.059589
23T	engine control system	305.9016	4.594358
23V	built-up engine	2288.3147	2.138305
41A	cockpit air temp control system	847.4592	1.884295
41B	air conditioning	1519.7465	3.095565
41C	pressurization	1736.1019	3.778195
41D	bleed air system	671.2315	2.992214
41E	anti-ice system	1126.0149	0.842065
41F	windshield de-ice system	2053.6931	1.207701
41G	defog	4032.2629	1.65441
41H	ram air	15290.5068	1.84826
41J	avionic equipment cooling	3581.6770	0.976202

42A	primary DC power system	711.1420	1.707457
42B	AC power system	2233.6328	1.352932
42C	DC emergency system	750.0913	0.730963
42D	external power system	13422.8184	1.469011
42E	AC/DC distribution system	4905.9395	7.621387
44A	exterior lighting system	384.4512	0.788592
44B	interior lighting system	779.8432	0.629052
44C	caution advisory system	2500.0046	0.787688
45A	hydraulic power generation system	589.4842	2.311582
45C	hydraulic indicator system	3601.2700	1.178073
46A	fuel storage installation	30303.0020	12.662677
46B	fuel vent installation	24390.2441	5.105008
46C	fuel quantity indicating system	3579.1226	4.498434
46D	fuel feed system	2077.2627	3.469134
46E	ground refuel system	12048.1924	4.152074
46F	fuel precheck and management system	6655.1367	1.867408
47A	LOX supply system	422.6771	2.029429
49A	fire detection system	1973.1656	2.68424
51A	flight instruments	109.9207	2.141921
51B	navigation instruments	230.9148	2.285361
51C	HARS,AN/ASN-129	590.8571	5.197813
51D	pitot-static system	1436.3468	7.002
51E	cockpit pressure	4672.8999	0.735
52A	stability augmentation system	1218.9034	2.215331
55A	air data record system	710.0895	0.691788
62A	VHF/AM communications system	286.4782	2.130949
63A	UHF communications system	276.0772	1.971631
64A	intercommunications system	681.1048	2.153563
65A	transponder set, AN/APX-100(V)	590.5653	1.513261
71A	VOR/ILS/MB system ARN-127	491.9169	2.436006
71B	TACAN system AN/ARN-118	528.3670	2.623565
91A	pilots emergency equipment	2418.4241	1.640232
91B	crash position indicator system	18222.2124	1.74
97A	canopy removal system	16666.6621	0.605119
97B	ejection seat removal system	4739.3354	3.411

(compiled from 8:A-1 to A-38)

Table B.2 is the file called "crew.dat" used in the T-46A model. The specialty code corresponds to the code used to label the resources in the SLAM code. The SLAM resource code is the ATC LCOM crew code with the alpha character placed first rather than fourth. The fifth character is retained if needed to uniquely identify the specialist. For example, the LCOM crew code 427S5 becomes the SLAM resource code S4275. The shift sizes are in the order of midnight shift, day shift, and swing shift.

Table B.2

Work Center Data

Specialty Code	Shift size M	D	S	Work centers	
R431	0	4	2	T-37	repair and reclamation
F431	3	38	18	T-37	flm
P431	5	5	0	T-37	inspection
S4270	0	2	2	machine	
S4274	2	2	2	metals processing	
S4275	2	6	6	structural repair	
S4271	1	1	1	corrosion control	
S426	3	3	3	T-37	jet engine shop
A426	3	2	3	T-37/38	accessory repair
T426	3	3	0	T-37/38	test cell
F426	3	9	9	T-37	flight line support unit
W431	2	4	3	T-37/38	wheel & tire
S4233	4	4	2	T-37/38	fuel systems
S4230	4	6	6	T-37/38	electrical systems
S4234	6	6	6	T-37/38	pneudraulics systems
S4231	4	4	4	T-37/38	environmental systems
S4232	2	2	2	T-37/38	egress systems
S3280	2	2	2	T-37/38	radio and radar repair
S3281	2	4	4	T-37/38	radio and radar repair
S325	6	10	10	T-37/38	auto flight control

(compiled from 3:3-1 to 3-27)

Table B.3 contains a list of the scheduled maintenance as proposed by Fairchild Republic. It also contains the suggested frequency and an estimate of the maintenance manhours involved.

Table B.3

Scheduled Maintenance Actions

Task	Nomenclature	MTBSM[1]	MMH[2]
special inspection	rsvr, master cyl brk	25	0.266667
spectro analysis	basic engine (F109)	25	0.375002
ADR data extraction	recorder, airborne data	39	0.083333
clean/vacuum interior	cockpit	60	0.266667
special capacitance	battery assembly	60	0.533333
ADR data extraction	recorder, airborne data	66.7	0.083333
special inspection	regulator oil demand	120	2.112
replace oil filter	basic engine (F109)	150	0.58497
washing A/C	airframe	180	12.8
lube due to washing	airframe	180	0.533333
ground handling A/C	200 special inspection	200	0.96
phase		300	21.163869
lubrication		300	4.349602
insp/repack kit	survival kit assy	300	4.544
corrosion prevention	airframe	360	3.2
phase		600	2.235466
insp/repack chute	parachute system L/R	720	8.0
replace brushes	starter/generator	1000	10.8224
engine HSI	basic engine (F109)	1200	10.0
engine build-up	basic engine (F109)	1200	4.8
nondestructive insp	airframe	1500	48.0
lubrication	starter/generator	2000	10.8224

1 Mean time between scheduled maintenance in flight hours.
2 Maintenance manhours.

(compiled from 8:4-10 to 4-15)

Table B.4 is the file "maint.dat" used in the T-46A model. There are two types of records in this file. Type one records contain a WUC, the MTBF for that WUC and then the number of required and possible maintenance actions. Type two records contain a WUC, a node label, a probability of that maintenance action being taken (only for possible maintenance actions), the MTTR, specialty code required, crew size required and a numeric code for the specialty code. Figure B.1 contains examples of the record types from WUC 11D.

Type 1 record

WUC	MTBF	NRMA	NPMA
11D	810.372	1	5

Type 2 record

WUC	Node Label	Probability of Selection	MTTR	Specialty Code	Crew Size Required	Crew Code
11D	114M1	0.196	2.391503	427S0	1	4

Figure B.1. Example of Record Types

The numeric code is dependent on the order in which all resources are declared in the SLAM code. The model has been set up with the crew resources listed first. Since there are 20 specialty codes the crew codes range from 1 to 20. If the order in which resources are declared in the SLAM code changes, the numeric code must be changed. Changing the order also impacts the shift change events in the FORTRAN coding where the loop counter is used as the SLAM resource code (i.e. the crew code). The node label is the node label from the appropriate LCOM model. Nodes with a W as the first letter of the label are from the ASD network. The specialty codes in this table correspond to the specialty codes that were taken from the ATC LCOM Final Report.

The records are arranged in sets in the file. Each set of records represents a repair node in an LCOM network. The first record of each set is a type 1 record. Adding the number of required and possible maintenance actions indicates how many type 2 records follow. For example, examine the node associated with repair of WUC 11D. The first of the set (underlined on page 96) shows there is one required maintenance action and five possible maintenance actions. Therefore, there are six type 2 records in the set for node 11D. The first of these records indicates that three 431F7 repair personnel are needed for 0.8 hours. Next are the records for the five possible actions that will finish the repair of WUC 11D. Each of these has a probability of occurring but only one will be done. Estimates of how long different crews would take to repair the failure are not available. Thus, the Fairchild Republic estimate of the MTTR is used as the repair time for each crew. Figure B.2 shows a graphic representation of node 11D.

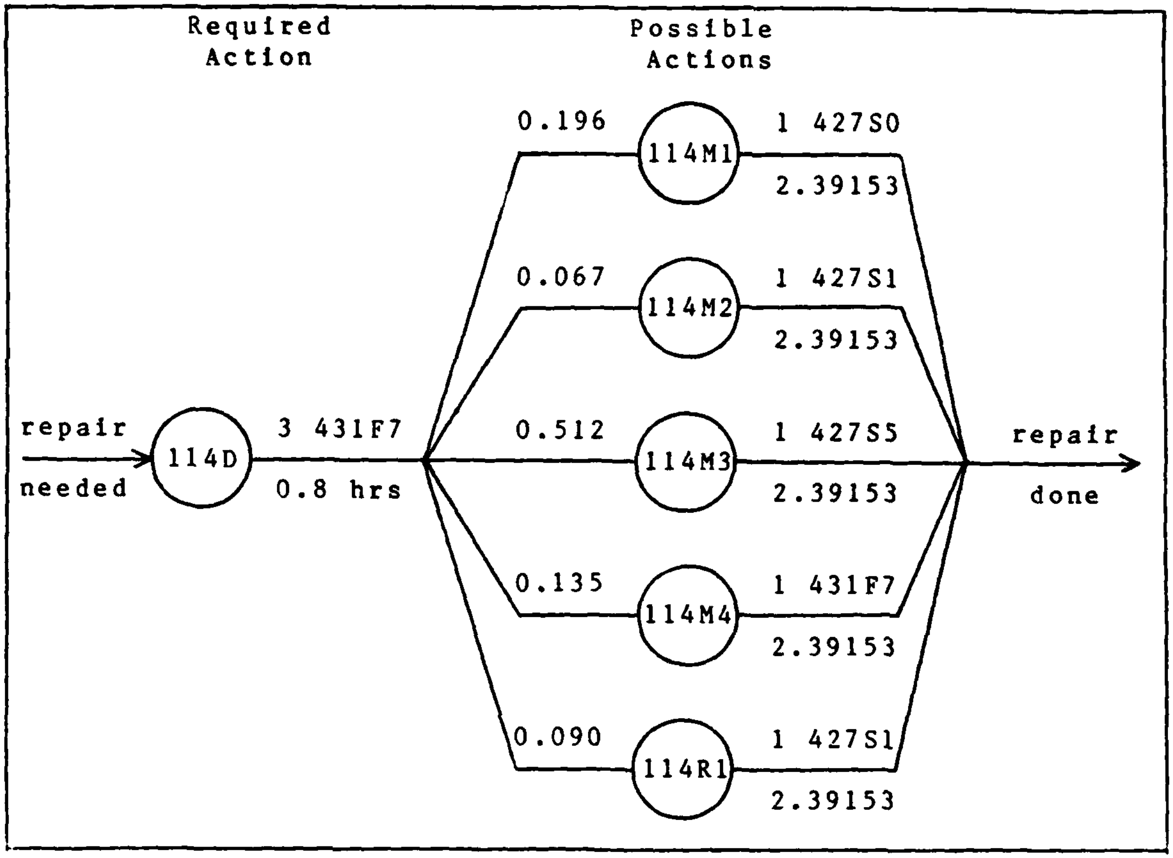


Figure B.2. Repair Node 11D

Table B.4

Unscheduled Maintenance Network

11A	468.1669	0	6			
11A	115M1	0.148	3.587277	427S0	1	4
11A	115M2	0.011	3.587277	427S1	1	7
11A	115M3	0.538	3.587277	427S5	1	6
11A	115M4	0.130	3.587277	431F7	1	2
11A	115R1	0.111	3.587277	431F7	1	2
11A	115R2	0.062	3.587277	431R7	1	1
11B	1168.2249	0	6			
11B	115M1	0.148	0.591818	427S0	1	4
11B	115M2	0.011	0.591818	427S1	1	7
11B	115M3	0.538	0.591818	427S5	1	6
11B	115M4	0.130	0.591818	431F7	1	2

11B	115R1	0.111	0.591818	431F7	1	2
11B	115R2	0.062	0.591818	431R7	1	1
11C	1642.0352		0	6		
11C	113R1	0.018	1.118210	423S3	2	13
11C	113M1	0.020	1.118210	427S1	1	7
11C	113M2	0.628	1.118210	427S5	1	6
11C	113M3	0.106	1.118210	431F7	1	2
11C	113R2	0.106	1.118210	431F7	1	2
11C	113M4	0.122	1.118210	427S0	1	4
11D	810.3720		1	5		
11D	114D		0.8	431F7	3	2
11D	114M1	0.196	2.391503	427S0	1	4
11D	114M2	0.067	2.391503	427S1	1	7
11D	114M3	0.512	2.391503	427S5	1	6
11D	114M4	0.135	2.391503	431F7	1	2
11D	114R1	0.090	2.391503	431F7	1	2
11E	734.2144		0	6		
11E	113R1	0.018	1.788432	423S3	2	13
11E	113M1	0.020	1.788432	427S1	1	7
11E	113M2	0.628	1.788432	427S5	1	6
11E	113M3	0.106	1.788432	431F7	1	2
11E	113R2	0.106	1.788432	431F7	1	2
11E	113M4	0.122	1.788432	427S0	1	4
11F	4290.0000		0	6		
11F	115M1	0.148	0.933081	427S0	1	4
11F	115M2	0.011	0.933081	427S1	1	7
11F	115M3	0.538	0.933081	427S5	1	6
11F	115M4	0.130	0.933081	431F7	1	2
11F	115R1	0.111	0.933081	431F7	1	2
11F	115R2	0.062	0.933081	431R7	1	1
12A	722.2833		0	8		
12A	121M1	0.034	3.913892	325S1	2	20
12A	121M2	0.140	3.913892	423S2	2	17
12A	121R1	0.140	3.913892	423S2	2	17
12A	121M3	0.044	3.913892	427S0	1	4
12A	121M4	0.073	3.913892	427S5	1	6
12A	121M5	0.159	3.913892	431F7	1	2
12A	121R2	0.381	3.913392	431F7	1	2
12A	121R3	0.029	3.913892	431R7	1	1
12B	623.2855		0	8		

```
12B   111R1 0.077   4.386283 423S0 1 14
12B   111M1 0.141   4.386283 423S0 1 14
12B   111M2 0.008   4.386283 427S0 1  4
12B   111M3 0.075   4.386283 427S5 1  6
12B   111M4 0.178   4.386283 431F7 2  2
12B   111R2 0.404   4.386283 431F7 2  2
12B   111M5 0.041   4.386283 431R7 2  1
12B   111R3 0.076   4.386283 431R7 2  1

12C    418.9456    0    2

12C  W12MM1 0.227   2.656809 423S2 2 17
12C  W12MR1 0.773   2.656809 423S2 2 17

13A    113.0546    1    8

13A   131D          0.8      431F7 3  2

13A   131M1 0.235   2.219961 423S0 1 14
13A   131R1 0.130   2.219961 423S0 1 14
13A   131M2 0.289   2.219961 423S4 1 15
13A   131R2 0.141   2.219961 423S4 1 15
13A   131M3 0.075   2.219961 431F7 1  2
13A   131R3 0.069   2.219961 431F7 1  2
13A   131M4 0.038   2.219961 431R7 2  1
13A   131R4 0.023   2.219961 431F7 2  2

13B    234.0806    1    6

13B   132D          0.8      431F7 3  2

13B   132M1 0.177   1.614848 423S0 1 14
13B   132R1 0.110   1.614848 423S0 1 14
13B   132M2 0.269   1.614848 423S4 2 15
13B   132R2 0.108   1.614848 423S4 2 15
13B   132M3 0.115   1.614848 431R7 2  1
13B   132R3 0.221   1.614848 431R7 2  1

13C    912.4177    1    4

13C   134D          0.8      431F7 3  2

13C   134M1 0.579   2.401157 423S4 2 15
13C   134R1 0.146   2.401157 423S4 2 15
13C   134M2 0.010   2.401157 431F7 1  2
13C   134R2 0.265   2.401157 431F7 1  2

13D   2164.4912    1    6

13D   133D          0.8      431F7 3  2
```

```
13D  133M1 0.110  2.183050 423S0 1 14
13D  133M2 0.125  2.183050 423S4 1 15
13D  133M3 0.082  2.183050 431F7 2  2
13D  133R1 0.320  2.183050 431F7 2  2
13D  133M4 0.157  2.183050 431R7 2  1
13D  133R2 0.206  2.183050 431R7 2  1

13E  2164.5000   1   5

13E  136D        0.8       431F7 3  2

13E  136M1 0.134  1.528385 423S0 1 14
13E  136R1 0.075  1.528385 423S0 1 14
13E  136M2 0.443  1.528385 423S4 1 15
13E  136R2 0.254  1.528385 423S4 1 15
13E  136M3 0.094  1.528385 431F7 2  2

13F  1237.0099   1   4

13F  135D        0.8       431F7 3  2

13F  135M1 0.696  2.907170 423S4 2 15
13F  135R1 0.163  2.907170 423S4 2 15
13F  135M2 0.112  2.907170 431R7 2  1
13F  135R2 0.029  2.907170 431R7 2  1

13G  2134.4690   1   8

13G  131D        0.8       431F7 3  2

13G  131M1 0.235  1.540690 423S0 1 14
13G  131R1 0.130  1.540690 423S0 1 14
13G  131M2 0.289  1.540690 423S4 1 15
13G  131R2 0.141  1.540690 423S4 1 15
13G  131M3 0.075  1.540690 431F7 1  2
13G  131R3 0.069  1.540690 431F7 1  2
13G  131M4 0.038  1.540690 431R7 2  1
13G  131R4 0.023  1.540690 431F7 2  2

14A  2840.9060   0   7

14A  141M1 0.069  2.298255 423S0 1 14
14A  141R1 0.121  2.298255 423S0 1 14
14A  141M2 0.190  2.298255 427S0 1  4
14A  141M3 0.117  2.298255 431F7 2  2
14A  141R2 0.193  2.298255 431F7 2  2
14A  141M4 0.212  2.298255 431R7 2  1
14A  141R3 0.098  2.298255 431R7 2  1

14B   853.9690   0   7

14B  141M1 0.069  3.930620 423S0 1 14
```

14B	141R1	0.121	3.930620	423S0	1	14
14B	141M2	0.190	3.930620	427S0	1	4
14B	141M3	0.117	3.930620	431F7	2	2
14B	141R2	0.193	3.930620	431F7	2	2
14B	141M4	0.212	3.930620	431R7	2	1
14B	141R3	0.098	3.930620	431R7	2	1
14C	977.0434		0	7		
14C	142M1	0.126	4.374974	423S0	1	14
14C	142M2	0.096	4.374974	427S0	1	4
14C	142M3	0.128	4.374974	427S5	1	6
14C	142M4	0.092	4.374974	431F7	1	2
14C	142R1	0.284	4.374974	431F7	1	2
14C	142M5	0.202	4.374974	431R7	2	1
14C	142R2	0.072	4.374974	431R7	2	1
14D	806.2680		0	11		
14D	W14GM1	0.006	1.475129	423S4	2	15
14D	W14GM2	0.056	1.475129	426F7	2	11
14D	W14GM3	0.007	1.475129	427S0	2	4
14D	W14GM4	0.010	1.475129	427S5	2	6
14D	W14GM5	0.003	1.475129	427S5	1	6
14D	W14GM6	0.468	1.475129	431R7	2	1
14D	W14GM7	0.010	1.475129	431F7	1	2
14D	W14GR1	0.026	1.475129	426F7	2	11
14D	W14GR2	0.004	1.475129	427S5	1	6
14D	W14GR3	0.394	1.475129	431R7	2	1
14D	W14GR4	0.016	1.475129	431F7	3	2
14E	793.1480		0	8		
14E	144M1	0.442	2.655312	423S4	2	15
14E	144R1	0.112	2.655312	423S4	2	15
14E	144M2	0.039	2.655312	427S0	1	4
14E	144M3	0.051	2.655312	427S5	1	6
14E	144M4	0.067	2.655312	431F7	2	2
14E	144R2	0.041	2.655312	431F7	2	2
14E	144M5	0.158	2.655312	431R7	2	1
14E	144R3	0.090	2.655312	431F7	2	2
14F	1117.3239		0	7		
14F	145M1	0.078	2.416026	423S0	1	14
14F	145M2	0.197	2.416026	423S4	1	15
14F	145R1	0.096	2.416026	423S4	1	15
14F	145M3	0.160	2.416026	427S0	1	4
14F	145M4	0.072	2.416026	427S5	1	6
14F	145M5	0.279	2.416026	431F7	2	2
14F	145R2	0.118	2.416026	431F7	2	2

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23A    359.2000    0    7

23A  W23AM1 0.018   2.712000 325S1 2 20
23A  W23AM2 0.309   2.712000 426S7 2  8
23A  W23AM3 0.036   2.712000 427S0 1  4
23A  W23AM4 0.132   2.712000 427S5 2  6
23A  W23AM5 0.055   2.712000 431F7 2  2
23A  W23AR1 0.273   2.712000 426S7 3  8
23A  W23AR2 0.127   2.712000 431F7 2  2

23N   1628.6646    0    5

23N   23JM1 0.265   1.382284 423S0 1 14
23N   23JR1 0.049   1.382284 423S0 1 14
23N   23JM2 0.278   1.382284 426F7 2 11
23N   23JR2 0.238   1.382284 426F7 2 11
23N   23JM3 0.170   1.382284 427S0 1  4

23P   3246.7517    0    4

23P   23HM1 0.484   1.681402 426F7 3 11
23P   23HR1 0.381   1.681402 426F7 3 11
23P   23HM2 0.041   1.681402 431F7 1  2
23P   23HR2 0.094   1.681402 431F7 1  2

23Q   1329.8004    0    2

23Q   23GM1 0.285   4.136884 426F7 3 11
23Q   23GR1 0.715   4.136884 426F7 3 11

23R    346.3588    0    4

23R   23MM1 0.312   3.534767 325S1 2 20
23R   23MR1 0.615   3.534767 325S1 2 20
23R   23MM2 0.019   3.534767 427S0 1  4
23R   23MR2 0.054   3.534767 431F7 2  2

23S   8271.2920    0    8

23S  W23BM1 0.306   2.059589 426S7 3  8
23S  W23BM2 0.083   2.059589 427S0 1  4
23S  W23BM3 0.222   2.059589 427S5 1  6
23S  W23BM4 0.028   2.059589 431F7 1  2
23S  W23BR1 0.028   2.059589 423S0 3 14
23S  W23BR2 0.194   2.059589 426S7 3  8
23S  W23BR3 0.083   2.059589 431R7 2  1
23S  W23BR4 0.056   2.059589 431F7 1  2

23T    305.9016    0    6

23T  W23LM1 0.811   4.594358 426S7 3  8
23T  W23LM2 0.010   4.594358 427S5 3  6
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23T	W23LM3	0.020	4.594358	431R7	2	1
23T	W23LM4	0.010	4.594358	431F7	2	2
23T	W23LR1	0.139	4.594358	426S7	3	3
23T	W23LR2	0.010	4.594358	431R7	2	1
23V	2288.3147		0	2		
23V	23ZM1	0.093	2.138305	426F7	2	11
23V	23ZR1	0.907	2.138305	426F7	2	11
41A	847.4592		0	5		
41A	W41AM1	0.394	1.884295	426F7	2	11
41A	W41AM2	0.031	1.884295	431F7	1	2
41A	W41AR1	0.031	1.884295	423S1	1	16
41A	W41AR2	0.504	1.884295	426F7	2	11
41A	W41AR3	0.040	1.884295	431F7	1	2
41B	1519.7465		0	11		
41B	W41BM1	0.009	3.095565	423S1	2	16
41B	W41BM2	0.003	3.095565	423S1	3	16
41B	W41BM3	0.245	3.095565	426F7	2	11
41B	W41BM4	0.003	3.095565	427S5	2	6
41B	W41BM5	0.023	3.095565	431F7	2	2
41B	W41BR1	0.023	3.095565	423S1	2	16
41B	W41BR2	0.634	3.095565	426F7	2	11
41B	W41BR3	0.003	3.095565	426F7	2	11
41B	W41BR4	0.003	3.095565	427S0	2	4
41B	W41BR5	0.003	3.095565	427S5	1	6
41B	W41BR6	0.051	3.095565	431F7	1	2
41C	1736.1019		0	6		
41C	W41CM1	0.015	3.778195	423S1	2	16
41C	W41CM2	0.388	3.778195	426F7	2	11
41C	W41CM3	0.015	3.778195	431F7	2	2
41C	W41CR1	0.015	3.778195	423S1	2	16
41C	W41CR2	0.537	3.778195	426F7	2	11
41C	W41CR3	0.030	3.778195	431F7	1	2
41D	671.2315		0	11		
41D	W41BM1	0.009	2.992214	423S1	2	16
41D	W41BM2	0.003	2.992214	423S1	3	16
41D	W41BM3	0.245	2.992214	426F7	2	11
41D	W41BM4	0.003	2.992214	427S5	2	6
41D	W41BM5	0.023	2.992214	431F7	2	2
41D	W41BR1	0.023	2.992214	423S1	2	16
41D	W41BR2	0.634	2.992214	426F7	2	11
41D	W41BR3	0.003	2.992214	426F7	2	11
41D	W41BR4	0.003	2.992214	427S0	2	4

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41D W41BR5 0.003   2.992214 427S5 1   6
41D W41BR6 0.051   2.992214 431F7 1   2

41E  1126.0149    0    3

41E W41EM1 0.243   0.842065 426F7 2  11
41E W41ER1 0.730   0.842065 426F7 2  11
41E W41ER2 0.027   0.842065 431F7 2   2

41F  2053.6931    0   11

41F W41BM1 0.009   1.207701 423S1 2  16
41F W41BM2 0.003   1.207701 423S1 3  16
41F W41BM3 0.245   1.207701 426F7 2  11
41F W41BM4 0.003   1.207701 427S5 2   6
41F W41BM5 0.023   1.207701 431F7 2   2
41F W41BR1 0.023   1.207701 423S1 2  16
41F W41BR2 0.634   1.207701 426F7 2  11
41F W41BR3 0.003   1.207701 426F7 2  11
41F W41BR4 0.003   1.207701 427S0 2   4
41F W41BR5 0.003   1.207701 427S5 1   6
41F W41BR6 0.051   1.207701 431F7 1   2

41G  4032.2629    0   11

41G W41BM1 0.009   1.654410 423S1 2  16
41G W41BM2 0.003   1.654410 423S1 3  16
41G W41BM3 0.245   1.654410 426F7 2  11
41G W41BM4 0.003   1.654410 427S5 2   6
41G W41BM5 0.023   1.654410 431F7 2   2
41G W41BR1 0.023   1.654410 423S1 2  16
41G W41BR2 0.634   1.654410 426F7 2  11
41G W41BR3 0.003   1.654410 426F7 2  11
41G W41BR4 0.003   1.654410 427S0 2   4
41G W41BR5 0.003   1.654410 427S5 1   6
41G W41BR6 0.051   1.654410 431F7 1   2

41H 152[illegible].5068    0   11

41H W41BM1 0.009   1.848260 423S1 2  16
41H W41BM2 0.003   1.848260 423S1 3  16
41H W41BM3 0.245   1.848260 426F7 2  11
41H W41BM4 0.003   1.848260 427S5 2   6
41H W41BM5 0.023   1.848260 431F7 2   2
41H W41BR1 0.023   1.848260 423S1 2  16
41H W41BR2 0.634   1.848260 426F7 2  11
41H W41BR3 0.003   1.848260 426F7 2  11
41H W41BR4 0.003   1.848260 427S0 2   4
41H W41BR5 0.003   1.848260 427S5 1   6
41H W41BR6 0.051   1.848260 431F7 1   2

41J  3531.6770    0   11
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41J  W41BM1 0.009   0.976202 423S1 2 16
41J  W41BM2 0.003   0.976202 423S1 3 16
41J  W41BM3 0.245   0.976202 426F7 2 11
41J  W41BM4 0.003   0.976202 427S5 2  6
41J  W41BM5 0.023   0.976202 431F7 2  2
41J  W41BR1 0.023   0.976202 423S1 2 16
41J  W41BR2 0.634   0.976202 426F7 2 11
41J  W41BR3 0.003   0.976202 426F7 2 11
41J  W41BR4 0.003   0.976202 427S0 2  4
41J  W41BR5 0.003   0.976202 427S5 1  6
41J  W41BR6 0.051   0.976202 431F7 1  2

42A    711.1420    0    4

42A   421M1 0.097   1.707457 423S0 1 14
42A   421R1 0.458   1.707457 423S0 1 14
42A   421M2 0.046   1.707457 426F7 2 11
42A   421R2 0.399   1.707457 426F7 2 11

42B   2233.6328    0    4

42B   421M1 0.097   1.352932 423S0 1 14
42B   421R1 0.458   1.352932 423S0 1 14
42B   421M2 0.046   1.352932 426F7 2 11
42B   421R2 0.399   1.352932 426F7 2 11

42C    750.0913    0    4

42C   421M1 0.097   0.730963 423S0 1 14
42C   421R1 0.458   0.730963 423S0 1 14
42C   421M2 0.046   0.730963 426F7 2 11
42C   421R2 0.399   0.730963 426F7 2 11

42D 13422.8184    0    4

42D   421M1 0.097   1.469011 423S0 1 14
42D   421R1 0.458   1.469011 423S0 1 14
42D   421M2 0.046   1.469011 426F7 2 11
42D   421R2 0.399   1.469011 426F7 2 11

42E   4905.9395    0    6

42E   423M1 0.096   7.621387 328S0 2 18
42E   423R1 0.244   7.621387 328S0 2 18
42E   423M2 0.284   7.621387 423S0 1 14
42E   423R2 0.173   7.621387 423S0 1 14
42E   423M3 0.086   7.621387 431F7 1  2
42E   423R3 0.117   7.621387 431F7 1  2

44A    384.4512    0    5
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44A  441M1 0.156  0.788592 423S0 1 14
44A  441R1 0.045  0.788592 423S0 1 14
44A  441M2 0.049  0.788592 427S0 1  4
44A  441M3 0.068  0.788592 431F7 1  2
44A  441R2 0.682  0.788592 431F7 1  2

44B   779.8432   0   4

44B  442M1 0.490  0.629052 423S0 1 14
44B  442R1 0.329  0.629052 423S0 1 14
44B  442M2 0.043  0.629052 431F7 1  2
44B  442R2 0.138  0.629052 431F7 1  2

44C  2500.0046   0   4

44C W443M1 0.491  0.787688 423S0 1 14
44C W443M2 0.035  0.787688 431F7 2  2
44C W443R1 0.439  0.787688 423S0 2 14
44C W443R2 0.035  0.787688 431F7 2  2

45A   589.4842   0   2

45A  451M1 0.574  2.311582 423S4 1 15
45A  451R1 0.426  2.311582 423S4 1 15

45C  3601.2700   0   2

45C  451M1 0.574  1.178073 423S4 1 15
45C  451R1 0.426  1.178073 423S4 1 15

46A 30303.0020   0  13

46A W46AM1 0.008 12.662677 423S2 2 17
46A W46AM2 0.008 12.662677 423S3 3 13
46A W46AM3 0.008 12.662677 423S3 3 13
46A W46AM4 0.673 12.662677 423S3 2 13
46A W46AM5 0.042 12.662677 426F7 2 11
46A W46AM6 0.008 12.662677 427S0 2  4
46A W46AM7 0.008 12.662677 427S5 1  6
46A W46AM8 0.008 12.662677 431F7 1  2
46A W46AR1 0.008 12.662677 423S3 2 13
46A W46AR2 0.008 12.662677 423S3 3 13
46A W46AR3 0.196 12.662677 423S3 4 13
46A W46AR4 0.008 12.662677 426F7 2 11
46A W46AR5 0.017 12.662677 431F7 4  2

46B 24390.2441   0   6

46B W46CM1 0.500  5.105008 423S3 2 13
46B W46CM2 0.072  5.105008 426F7 2 11
46B W46CM3 0.071  5.105008 427S0 1  4
46B W46CM4 0.143  5.105008 431F7 2  2
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46B	W46CR1	0.143	5.105008	423S3	4	13
46B	W46CR2	0.071	5.105008	431F7	3	2

46C 3579.1226 0 7

46C	W46DM1	0.500	4.498434	426F7	2	11
46C	W46DM2	0.007	4.498434	427S0	1	4
46C	W46DM3	0.007	4.498434	431F7	2	2
46C	W46DR1	0.007	4.498434	423S3	3	13
46C	W46DR2	0.014	4.498434	423S3	4	13
46C	W46DR3	0.458	4.498434	426F7	2	11
46C	W46DR4	0.007	4.498434	431F7	1	2

46D 2077.2627 0 7

46D	W46EM1	0.084	3.469134	423S0	2	14
46D	W46EM2	0.275	3.469134	423S3	2	13
46D	W46EM3	0.083	3.469134	426F7	2	11
46D	W46ER1	0.044	3.469134	423S0	2	14
46D	W46ER2	0.388	3.469134	423S3	2	13
46D	W46ER3	0.082	3.469134	426F7	2	11
46D	W46ER4	0.044	3.469134	431F7	2	2

46E 12048.1924 0 4

46E	W46FM1	0.150	4.152074	423S0	1	14
46E	W46FR1	0.700	4.152074	423S3	4	13
46E	W46FR2	0.050	4.152074	426F7	2	11
46E	W46FR3	0.100	4.152074	431F7	1	2

46F 6655.1367 0 6

46F	W46GM1	0.084	1.867408	423S3	3	13
46F	W46GM2	0.334	1.867408	426F7	3	11
46F	W46GM3	0.083	1.867408	431F7	1	2
46F	W46GR1	0.083	1.867408	423S3	4	13
46F	W46GR2	0.333	1.867408	426F7	2	11
46F	W46GR3	0.083	1.867408	431F7	1	2

47A 422.6771 0 6

47A	W47AM1	0.324	2.029429	426F7	2	11
47A	W47AM2	0.006	2.029429	427S0	2	4
47A	W47AM3	0.033	2.029429	431F7	1	2
47A	W47AR1	0.011	2.029429	423S1	2	16
47A	W47AR2	0.532	2.029429	426F7	2	11
47A	W47AR3	0.094	2.029429	431F7	1	2

49A 1973.1656 0 2

49A	491M1	0.612	2.684240	423S0	1	14
49A	491R1	0.388	2.684240	423S0	1	14

51A	109.9207	0	4			
51A	511M1	0.306	2.141921	325S1	2	20
51A	511R1	0.638	2.141921	325S1	2	20
51A	511M2	0.018	2.141921	427S0	1	4
51A	511M3	0.038	2.141921	431F7	1	2
51B	230.9148	0	2			
51B	512M1	0.432	2.285361	325S1	1	20
51B	512R1	0.568	2.285361	325S1	1	20
51C	590.8571	0	2			
51C	W51FM1	0.500	5.197813	426F7	2	11
51C	W51FR1	0.500	5.197813	426F7	2	11
51D	1436.3468	0	4			
51D	511M1	0.306	7.002000	325S1	2	20
51D	511R1	0.638	7.002000	325S1	2	20
51D	511M2	0.018	7.002000	427S0	1	4
51D	511M3	0.038	7.002000	431F7	1	2
51E	4672.8999	0	3			
51E	W51AM1	0.300	0.735000	426F7	2	11
51E	W51AR1	0.500	0.735000	426F7	2	11
51E	W51AR2	0.200	0.735000	431F7	3	2
52A	1218.9034	0	11			
52A	W14GM1	0.006	2.215331	423S4	2	15
52A	W14GM2	0.056	2.215331	426F7	2	11
52A	W14GM3	0.007	2.215331	427S0	2	4
52A	W14GM4	0.010	2.215331	427S5	2	6
52A	W14GM5	0.003	2.215331	427S5	1	6
52A	W14GM6	0.468	2.215331	431R7	2	1
52A	W14GM7	0.010	2.215331	431F7	1	2
52A	W14GR1	0.026	2.215331	426F7	2	11
52A	W14GR2	0.004	2.215331	427S5	1	6
52A	W14GR3	0.394	2.215331	431R7	2	1
52A	W14GR4	0.016	2.215331	431F7	3	2
55A	710.0895	0	3			
55A	W55BM1	0.278	0.691788	325S1	2	20
55A	W55BR1	0.666	0.691788	325S1	2	20
55A	W55BR2	0.056	0.691788	431F7	1	2
62A	286.4782	0	3			

62A	W62CM1	0.732	2.130949	426F7	2	11
62A	W62CM2	0.014	2.130949	431F7	2	2
62A	W62CR1	0.254	2.130949	426F7	2	11
63A		276.0772	0	4		
63A	W63AM1	0.598	1.971631	426F7	2	11
63A	W63AM2	0.003	1.971631	431F7	2	2
63A	W63AR1	0.396	1.971631	426F7	2	11
63A	W63AR2	0.003	1.971631	431F7	1	2
64A		681.1048	0	6		
64A	W64AM1	0.007	2.153563	328S0	2	18
64A	W64AM2	0.007	2.153563	423S3	2	13
64A	W64AM3	0.389	2.153563	426F7	2	11
64A	W64AM4	0.007	2.153563	431F7	1	2
64A	W64AR1	0.584	2.153563	426F7	2	11
64A	W64AR2	0.006	2.153563	431F7	1	2
65A		590.5653	0	2		
65A	W65AM1	0.812	1.513261	426F7	2	11
65A	W65AR1	0.188	1.513261	426F7	2	11
71A		491.9169	0	2		
71A	712M1	0.259	2.436006	328S1	2	19
71A	712R1	0.741	2.436006	328S1	2	19
71B		528.3670	0	2		
71B	W71ZM1	0.454	2.623565	426F7	2	11
71B	W71ZR1	0.546	2.623565	426F7	2	11
91A		2418.4241	0	1		
91A	W96AD	1.000	1.640232	426F7	3	11
91B		18222.2129	0	1		
91B	W96AD	1.000	1.740000	426F7	3	11
97A		16666.6621	0	2		
97A	W97AM1	0.769	0.605119	423S2	2	17
97A	W97AR1	0.231	0.605119	423S2	2	17
97B		4739.3354	0	1		
97B	W97GD	1.000	3.411000	431F7	1	2

(compiled from 1; 5; 8)

Appendix C

Experimental Design And Output

This appendix contains the design levels for the central composite design as well as the simulation output obtained by setting the factors at the given levels.

	Design		Output	
	MTTR Level	MTBF Level	Aircraft Availability	Sortie Generation Rate
2^2 Factorial	-1.000	1.000	0.9370	2.928
	1.000	1.000	0.9205	2.925
	-1.000	-1.000	0.8819	2.927
	1.000	-1.000	0.8155	2.915
4 Axial Points	-1.414	0.000	0.9295	2.928
	1.414	0.000	0.8939	2.917
	0.000	1.414	0.9327	2.927
	0.000	-1.414	0.6326	2.718
8 Center Points	0.000	0.000	0.9125	2.926
	0.000	0.000	0.9134	2.934
	0.000	0.000	0.9113	2.936
	0.000	0.000	0.9114	2.934
	0.000	0.000	0.9134	2.937
	0.000	0.000	0.9133	2.903
	0.000	0.000	0.9142	2.888
	0.000	0.000	0.9145	2.886

Appendix D

BMDP9R Output

This appendix includes BMDP9R output indicating the 'Best' subset of variables chosen for aircraft availability (Table D.1) and sortie generation rate (Table D.2).

Table D.1

BMDP9R Output Fof Aircraft Availability

```
STATISTICS FOR 'BEST' SUBSET
-----------------------------
MALLOWS' CP                        2.92
SQUARED MULTIPLE CORRELATION     .80720
MULTIPLE CORRELATION             .89845
ADJUSTED SQUARED MULT. CORR.     .77754
RESIDUAL MEAN SQUARE            .001226
STANDARD ERROR OF EST.          .035010
F-STATISTIC                       27.21
NUMERATOR DEGREES OF FREEDOM          2
DENOMINATOR DEGREES OF FREEDOM       13
SIGNIFICANCE (TAIL PROB.)         .0000

NOTE THAT THE ABOVE F-STATISTIC AND
ASSOCIATED SIGNIFICANCE TEND TO BE
LIBERAL WHENEVER A SUBSET OF VARIABLES
IS SELECTED BY THE CP OR ADJUSTED
R-SQUARED CRITERIA.

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VARIABLE NO. NAME	REGRESSION COEFFICIENT	STAND. ERROR	STAND. COEF.	T-STAT.	TOL-ERANCE	CONTRI-BUTION TO R-SQ
INTERCEPT	.917869	.0107198	12.366	85.62		
2 b	.0730662	.0123788	.719	5.90	1.00000	.51669
14 bsq	-.0547960	.0123806	-.539	-4.43	1.00000	.29051

THE CONTRIBUTION TO R-SQUARED FOR EACH VARIABLE IS THE AMOUNT BY WHICH R-SQUARED WOULD BE REDUCED IF THAT VARIABLE WERE REMOVED FROM THE REGRESSION EQUATION.

Table D.2

BMDP9R Output For Sortie Generation Rate

STATISTICS FOR 'BEST' SUBSET

MALLOWS' CP	1.04
SQUARED MULTIPLE CORRELATION	.50907
MULTIPLE CORRELATION	.71349
ADJUSTED SQUARED MULT. CORR.	.43354
RESIDUAL MEAN SQUARE	.001596
STANDARD ERROR OF EST.	.039944
F-STATISTIC	6.74
NUMERATOR DEGREES OF FREEDOM	2
DENOMINATOR DEGREES OF FREEDOM	13
SIGNIFICANCE (TAIL PROB.)	.0098

NOTE THAT THE ABOVE F-STATISTIC AND ASSOCIATED SIGNIFICANCE TEND TO BE LIBERAL WHENEVER A SUBSET OF VARIABLES IS SELECTED BY THE CP OR ADJUSTED R-SQUARED CRITERIA.

VARIABLE NO. NAME	REGRESSION COEFFICIENT	STAND. ERROR	STAND. COEF.	T-STAT.	TOL-ERANCE	CONTRI-BUTION TO R-SQ
INTERCEPT	2.92553	.0122307	55.123	239.20		
2 b	.0383215	.0141235	.527	2.71	1.00000	.27802
14 bsq	-.0349404	.0141257	-.481	-2.47	1.00000	.23105

THE CONTRIBUTION TO R-SQUARED FOR EACH VARIABLE IS THE AMOUNT BY WHICH R-SQUARED WOULD BE REDUCED IF THAT VARIABLE WERE REMOVED FROM THE REGRESSION EQUATION.

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VITA

Captain Roger A. Foley was born on 17 July 1959 in Riverside, California. The son of a career Air Force father, he had the opportunity to live in many parts of the country. He attended high school in Bellevue, Nebraska and graduated as valedictorian in 1977 at which time he entered the United States Air Force Academy in Colorado Springs, Colorado. Upon graduation from the Academy in 1981, he received a Bachelor of Science degree in Operations Research and a commission as a Second Lieutenant in the U.S. Air Force. His first duty assignment was as a Manning Analyst for the Rated Officers' Assignment Branch at Hq TAC DCS Personnel, Langley AFB, Virginia. He served in this assignment until entering the School of Engineering, Air Force Institute of Technology, in June 1984.

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