A SIMULATION MODEL OF THE COMMON STRATEGIC ROTARY LAUNCHER FOR AVAILABILITY(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.

UNCLASSIFIED S J GJERSTAD ET AL. NOV 84
A SIMULATION MODEL OF THE COMMON STRATEGIC
ROVARY LAUNCHER FOR AVAILABILITY

PROJECTIONS

THESIS

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AP1P/GD/08/340-5

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<td>TITLE: A STUDY OF THE EFFECTS OF LAMINAR AND TURBULENT FLOW ON A BODY OF REVOLUTION</td>
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<tr>
<td>AUTHORS: Charles E. Maretzki, Jr., and James E. Freimark, Jr.</td>
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<td>REPORT PREPARED FOR: Air Force Institute of Technology</td>
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Approved for public release: LW AFR 100-17.
The Common Strategic Rocket Launcher (CSRL) is a multipurpose launcher that will be used on the F-32 and F-1 aircrafts. This study develops a SIM model of the CSRL and uses two measures of effectiveness, availability and on-time generation time, to determine the operational suitability of the CSRL. Analysis of variance and regression analysis were used to determine what affect the number of launchers, the number of munitions hat handlers, the frequency of launcher inspections, and the level of repair had on the on-time generation time. The repair concept for the CSRL launcher was modeled as a function. The results of this study indicate that a unit increase in the number of launchers (range from 3 to 12) would decrease the generation time 1.5% and increase in the number of 90% would not significantly decrease the generation time; increasing the frequency of inspections from once a year to twice a year would decrease the time by 25%; and altering flight time repair and exchange of failsafe items would decrease the time by 15%. These results have been statistically processed by a computer program which shows the reliability function. Graphs show the results which are used to calculate the frequency of repairs, the time taken for repairs, and on availability. The results indicate that the frequency and level of repairs has a small effect on the on-time generation time, but a significant effect on the availability. The results also indicate that a small change in the frequency for one year to the other can have a large effect on the availability of the launchers by 25%.

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A SIMULATION MODEL OF THE COMMON STRATEGIC
ROTOR LAUNCHER FOR AVALABILITY
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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November
December 1984

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The purpose of this study was to analyze the operational suitability of the Common Strategic Rotary Launcher (CSRL). This was accomplished by developing a simulation model of the CSRL that measured availability and sortie generation time. The model will be used by AFOTEC to analyze the data obtained during the test program. SAC, the ultimate user of the model, can also use the model to experiment with different management policies before and after the system becomes fully operational.

The model was used to determine the effect of several variables on availability and sortie generation time. Specifically, the model was used to answer the following research questions:

1. What is the expected availability of the CSRL when used on the B-52 and when used on the B-1 aircraft?

2. How much effect does the number of load crews, number of munitions lift trailers (MLTs), level of repair, and frequency of launcher inspections have on sortie generation time?

3. How much effect does the frequency of launcher inspections have on availability?

We wish to acknowledge those people that have provided us with guidance and assistance in preparing this thesis. First, a word of thanks to our advisors, Lieutenant Colonel Charles E. Essling and Major James K. Feldman and also to Lieutenant Colonel Joseph W. Coleman. We would also like to thank our sponsors at AFOTEC, Major Burton McKenzie, Captains Fred Duley, Richard Price, and Chuck Wolfe who were very helpful. Finally, Roxann would like to thank her husband Dean for his patience and understanding throughout the whole effort.

Sarah J. Sjostad
Roxann A. Dylar
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Symbols and Abbreviations

1. APLC - Air Force Logistics Command
2. APOTEC - Air Force Operational Test and Evaluation Center
3. AFSOC - Air Force Systems Command
4. ALCM - Air Launched Cruise Missile
5. ALI - Annual Launcher Inspection (subroutine in program)
6. ALT - Alert (subroutine in program)
7. AVAIL - Availability (variable used in program)
8. CHK - Check (term used in program)
9. CSRL - Common Strategic Rotary Launcher
10. DF - Degrees of Freedom
11. ESIS - Electronic System Test Set
12. EXCHG - Exchange (subroutine in program)
13. FMC - Fully Mission Capable
14. GEN - Generation (subroutine in program)
15. GENRPT - Generation Report (subroutine in program)
16. GENRTN - Generation Time (variable used in program)
17. IMF - Intermediate Maintenance Facility
18. INS - Inspection
19. INIT - Initialize (subroutine in program)
20. LCOM - Logistics Composite Model
21. MLT - Munitions Lift Trailer
22. MTBF - Mean Time Between Failure
23. OIL - Oil Inspection (subroutine in program)
24. OT&E - Operational Test and Evaluation
25. PDU - Power Drive Unit (component on CSRL)
26. PMC - Partially Mission Capable

VIII
27. QINSF - Quarterly Inspection (subroutine in program)
28. REP - Repair (variable used in program)
29. SAC - Strategic Air Command
30. SSR - Sortie Generation Rate
31. SIT - System Interface Test
32. SLAM - Simulation Language for Alternative Modeling
33. SRAM - Short Range Attack Missile
34. SSE - Sum of Squares for Error
35. SSR - Sum of Squares for Regression
36. STG - Storage (variable used in program)
37. TNOW - Time Now (SLAM variable in program)
38. WSA - Weapon Storage Area
Abstract

The Common Strategic Rotary Launcher (CSRL) is a multipurpose launcher that will be used on the B-52 and B-1 aircraft. This study develops a (SLAM) simulation model of the CSRL and uses two measures of effectiveness, availability and sortie generation time, to determine the operational suitability of the CSRL. Analysis of variance and regression analysis were used to determine what effect the number of load crews, the number of munitions lift trailers, the frequency of launcher inspections, and the level of repair have on the sortie generation time. The repair concept for the SLAM launcher was used as a baseline. The results of this study indicate that a unit increase in the number of load crews (crews range from 3 to 12) would decrease the generation time 1-3%; an increase in the number of MFLs would not significantly decrease the generation time; increasing the frequency of inspections from once a year to twice a year would decrease the time by 3-5%; and allowing flight line repair and exchange of failed missiles would decrease the time by 2-5%. These results have been graphically represented in a contour map which shows the various combinations of the above factors which are needed to achieve a specific generation time. This study also determined what effect the frequency of launcher inspections had on availability. The results indicate that frequency of inspections does have a small effect on the availability of the CSRL; increasing the frequency from once a year to twice a year increases the average percentage of available launchers by less than 2%.
A SIMULATION MODEL OF THE COMMON STRATEGIC ROTARY LAUNCHER FOR AVAILABILITY PROJECTIONS

I. Introduction

Background

The Aircraft Logistics Analysis Branch at the Air Force Operational Test and Evaluation Center (AFOTEC/LG4A) is updating the Logistics Composite Model simulation of the B-1 strategic bomber which will be used to derive Sortie Generation Rate (SGR) and the Fully Mission Capable (FMC) rates as part of the B-1 testing effort. The Common Strategic Rotary Launcher (CSRL) is a separate subsystem which will be used on the B-52 and the B-1 aircraft and will impact the SGR and FMC rates. AFOTEC/LG4A has requested the development of a simulation model for the CSRL that can be used to derive CSRL availability values as an input to the B-1 LCOM simulation model.

Thesis Objective

The objective of this thesis is to analyze the operational suitability of the Common Strategic Rotary Launcher (CSRL), a vital subsystem to be used on the B-52 and the B-1 aircraft. This will be accomplished by developing and implementing a computer simulation model for the CSRL.

The primary measure of operational suitability is availability. According to APF 300-13, "availability is a measure of the degree to which an item is in an operational and combatatable state when the mission is called for at a random point in time." For the CSRL, this definition
of availability was translated into a more specific measure of merit. For our model, availability is the percentage of the total launchers that are in working order. If a launcher has failed in storage, it is not available, even though the failure has not yet been detected (either through annual inspections or sortie generation exercises).

According to the test program outline (1:7), one of the critical operational issues for OS&G is the carrier aircraft sortie generation:

"the carrier aircraft sortie generation capability is highly dependent on the operational suitability of the CSRL. The ability to generate a sortie within the time specified [by SAC] will directly affect [SAC's] ability to meet wartime missions".

To evaluate the ability to meet wartime missions a second measure of merit has been defined. Sortie generation time is the time required to get all aircraft ready to launch. The sortie generation time is a function of availability, but it is also a function of the number of crews, support equipment, level of repair, load times and repair times. It not only measures how many launchers are available, but how long it takes to get the launchers in a usable condition (i.e. loaded onto an aircraft).

Evaluating availability and generation time can be accomplished by developing and executing a simulation model of the CSRL system using Simulation Language for Alternative Modeling (SLAM). Both quantities are measured at random points in time in the model and satisfy the APOTEC requirements.

A wing of 16 aircraft is modeled over one year using a scenario specified by APOTEC. The maintenance for the CSRL is modeled in a way similar to the concept for the Short-Range Attack Missile (SRAM) rotary launcher. Existing SRAM support concepts and resource requirements
served as a baseline for modeling the CSRL. The CSRL is modeled for use on the B-52 aircraft. However, the only changes for analysis with the B-1 are with two components; the power drive unit and the power drive unit controller are considered part of the B-1 aircraft system, rather than the CSRL.

In addition to the analysis performed in this thesis, the CSRL model was developed so that it could be used by both AFOTEC and SAC for future analysis.

Currently AFOTEC uses simulation models to analyze the data obtained during the test program. This model was designed to use the outputs from the test program (as defined in the draft test plan) as inputs to the model. Normally, AFSC develops the model and AFOTEC receives it sometime during the test program. By having the CSRL system modeled prior to the start of the test program AFOTEC can exercise the model to identify critical areas of performance before testing begins. This will signal areas that AFOTEC should fully evaluate during testing so that any deficiencies can be corrected before the system is implemented. If necessary, AFOTEC can modify the test plan based on the impacts predicted by the model.

SAC can use the model to experiment with different management policies before and after the system becomes fully operational. This should be an iterative process. As more data becomes available, the model can be updated.

And finally, the availability measures derived from the CSRL model can be used as inputs to the B-52 and B-1 Logistics Composite Models to evaluate the operational readiness of those systems.
Research Questions

The effects of several controllable variables on availability and aircraft generation time were evaluated while simultaneously considering the effects of several estimated reliability and maintainability parameters. Specifically, the analysis focused on how the number of load crews, the number of munitions lift trailers (MLTs), the level of repair (2-level vs. 3-level), and the frequency of launcher inspections affects the measures of operational suitability. Since there are many reliability and maintainability parameters which are estimated and which could affect the results of the analysis, these parameters were included at various levels. These parameters include failure rates, load time for the launcher, time to exchange a missile, and remove and replace times for the relay assembly and missile interface unit. The rationale for choosing these factors is detailed in Chapter III.

The specific questions to be answered in this research are:

1) What is the expected availability of the CSRL when used on the B-52 aircraft; when used on the B-1 aircraft?

2) What is the sortie generation time when used on the B-52; when used on the B-1?

3) How much effect does the number of load crews have on the generation time?

4) How much effect does the number of MLTs have on the generation time?

5) How much effect does the level of repair have on the generation time?

6) How much effect does the frequency of launcher inspections have on the generation time?

7) How much effect does the frequency of launcher inspections have on the availability?
Overview

The remainder of this thesis consists of five chapters. Chapter II gives some background information on the CSML and discusses in detail the operational environment simulated in this research effort. Also included in this chapter are a description of the support and test equipment critical to the CSML. This chapter does not try to tie the operational environment to the model, this is reserved for Chapter IV.

Chapter III discusses the rationale for choosing the research questions. It also discusses some factors which may affect availability and generation time, but were not included in this study.

Chapter IV describes the model developed for the CSML, the assumptions made in the model, the flexibility of the model, and the data sources. It also discusses the steps taken to verify and validate the SLAM model and the computer results.

The analysis and results chapter, Chapter V, describes the research designs which were used in the simulation and the statistical results.

The final chapter discusses the conclusions reached during the course of this research and the recommendations for future analysis. The first section of this chapter reports the significant results obtained from Chapter V. The recommendation section shows how the CSML model can be further developed to analyze other factors affecting availability when the appropriate data becomes available.
II. Operational Background

This chapter gives a brief description of the CSRL operational environment. There are three major events that affect the CSRL: annual inspections, alert status, and sortie generation exercises. These three events as well as the support and test equipment that are expected to be limiting factors in the availability of the CSRL are described.

CSRL Description

The Common Strategic Rotary Launcher (CSRL) is a multipurpose launcher that accommodates current and projected cruise missiles, short-range attack missiles, and gravity weapons. The CSRL will be compatible with three distinct strategic bomber airframes: B-52, B-1B, and advanced technology bomber. The CSRL has eight weapon stations that can carry any certified weapon. This allows uniform loads of any weapon as well as unrestricted mixed loads. (13:1)

The CSRL consists of a launcher shaft, forward and aft launcher support fittings, weapon ejector assemblies, and avionics components. The CSRL interfaces with the aircraft electrical, hydraulic, environmental, avionics, and weapons control and monitor systems. A diagram of the CSRL is shown in Figure 1. (13:1)

Support Equipment. The CSRL is over 22 feet long and when loaded with 3 ALCM missiles it weighs 25,000 pounds. The launcher requires some massive and expensive support equipment to transport it.
Figure 1. Diagram of the CSRL
Among support equipment, the munitions lift trailer (MLT), due to its low reliability, is currently the biggest constraint when loading the pylons. A modified MLT is planned for use with the CSRL.

Test Equipment. The launcher, along with the pylons and missiles, are tested with the Electronic Systems Test Set (ESTS). Each wing has three ESTSs and each one is wired to test two of the three types of equipment. Each type of equipment has a primary ESTS and a backup ESTS.

Operational Environment

Figure 2 shows a picture of the operational environment of the CSRL.

![Diagram of CSRL Operational Environment](image)
Unlike other subsystems on the B-52 or B-1, the CSRL will not be operated or flown during peacetime operations. The launchers remain fully loaded in the weapon storage area (WSA) until removed for one of the following three reasons:

1) annual inspection,
2) uploaded to an alert aircraft,
3) sortie generation exercises.

Each of the activities is further described below with the approximate length of the event indicated in parenthesis.

**Annual Inspections.** Every launcher and missile is inspected annually.

When the launcher is due for an inspection and an Electronic System Test Set (ESTS) is available, the launcher is transported from the WSA to the Intermediate Maintenance Facility (IMF) (.5 hour).

The Inspection crew consists of a team chief plus three other members with AFSC 463XX.

Once in the facility, the launcher is loaded into the test frame (1 hour), the warheads are removed from the missiles and the missiles are downloaded from the launcher (1 hour per missile). The empty launcher is connected to the ESTS (.5 hour) and the empty test is performed (12 hours + repair time). When problems are detected, the test is stopped while repairs are made. The missiles are tested separately on another ESTS (3.5 hours per missile + repair time). The missiles are then reloaded onto the launcher (1 hour per missile). The launcher is downloaded from the frame and a postload inspection is performed (2.5 hours). Finally, the launcher is transported back to the WSA (.5 hour) unless needed for an alert aircraft.
Alert Status. Five aircraft remain on alert status at all times. Approximately every three weeks one alert aircraft is exchanged for another. A launcher (which is not due for an inspection within 90 days) is removed from storage and transported to the flight line (0.75 hours). The load crew consists of a team chief plus four other members with AFSC 462XX, who have trained together for at least three weeks.

The launcher and two pylons are loaded onto the aircraft (1 hour per launcher, 1 hour per pylon). A systems interface test (SIT), which tests the status of the launchers and the missiles, is performed (1.5 hours). If the launchers and missiles are working, the crew performs the postload work (1 hour) and downloads the other aircraft. If not working, the launcher is removed and transported back to the IMP and another launcher is transported to the flight line.

Once a week, while on alert status, a SIT test is performed by the aircrew to ensure alert status is maintained.

Sortie Generation Exercise. Sortie generation exercises are conducted on a no-notice basis quarterly by the base and annually by HQ SAC (OAR). This exercise is similar to bringing an aircraft up to alert status except that all aircraft are brought up to alert status. All launchers in storage and in the IMP are uploaded onto aircraft.

When a launcher is not operational, it is returned to the IMP and repaired, while another launcher is uploaded in its place.

When a missile is found to be non-operational, either the entire launcher is returned to the IMP to exchange the failed missile or the launcher is left in a degraded status. This decision is a judgment call by the commander based on the progress of the exercise thus far.
III. Variables in the Analysis

There are many factors which affect the availability and the generation time of the CSRL. This chapter discusses the factors included in the analysis and why. It also discusses those factors which were considered for inclusion but were omitted.

The factors selected are: number of load crews, available support equipment, level of repair, frequency of launcher inspections, repair rates, mean time between failures, mission schedule, available test equipment, number of spare parts, and the number of maintenance personnel. The following paragraphs discuss these factors individually.

The number of load crews was identified by SAC as a limiting factor and is therefore included in this analysis. The load crew is a team of five members that have trained together for at least three weeks before becoming qualified to load the launchers and pylons onto the aircraft. Although a typical base is authorized 12 load crews, at any given time only 3 to 9 are fully qualified and available for duty.

Of the support equipment, the munitions lift trailers (MLTs) were identified as the limiting resource and have been included in the analysis. The MLTs have had a poor reliability. Although a typical base is assigned 12 or 13 MLTs, only 3 or 9 are usually working at a time.

The current maintenance policy for the SAM launcher does not allow for repair of the launcher or for exchange of a failed missile on the flight line. When a failure is detected, the launcher must be downloaded from the aircraft, transported back to the IMF and repaired. Since a policy change, which would allow flight line maintenance, is
under consideration (3) this analysis evaluates the impact of the level of repair (2-level vs 3-level). With two levels of maintenance, the launcher can be repaired at the IAF or at the depot; with three levels of maintenance, the launcher can be repaired on the flight line, at the IMF or at the depot. Depot repair refers to shipping a failed component of the launcher to the depot for repair and using a spare component to repair the launcher at the base (either on the flight line or in the IMF). In simulation models, depot repair is represented by including a time delay before the failed component is available as a spare part.

The SAAM launcher and the ALCM missiles undergo an inspection annually. The maintenance plan for the CSRL also calls for an annual inspection. Since failures which were undetected in storage would be identified and repaired during an inspection, the effect of increasing the number of inspections would be to increase availability. This is included as a factor in order to find out how much of an impact the frequency of inspections has on availability.

Any evaluation of the factors mentioned above must take into consideration the effects of estimated reliability and maintainability parameters. Specifically, these are load time, repair time, and mean time between failure (MTBF) for the seven major subsystems of the launcher and the missiles.

Although the time to load the SAAM launcher is used as a baseline estimate, the CSRL is considerably larger than the SAAM and may take more time than estimated. Therefore, this factor was included in the analysis.

The time to remove and replace a failed missile and the time to remove and replace the missile interface unit (MIU) and the relay
assembler are other parameters which were included in the analysis. The 41U and the relay assembler are the only two components of the seven major subsystems of the CSRL which could be repaired on the flight line.

The final parameter studied is the mean time between failure for the launcher. Since there are reliable estimates for the MTBF for missiles, this parameter was excluded from consideration. MTBF is expected to have the most significant impact on availability and generation time. In addition, the interaction of MTBF with other factors may have an impact. For example, the level of repair may not have much impact on the generation time if the MTBF is high since there would be few failures to repair. But if the MTBF is low, there may be a significant difference in the time.

Available test equipment, number of maintenance personnel, and spare parts were considered for inclusion, but were not included for the reasons listed below.

The electronic systems test set (ESTS) is the limiting factor for test equipment. This was included in the model as a constraining resource, but was not evaluated at various levels. The number of ESTS is limited by the design of the LMFs which have already been constructed. During normal operations the crew work 2 3-hour shifts for 5 days a week; therefore, the maximum ESTS operating time would be 15 hours a day. However, because of low reliability and periodic ESTS inspections, the ESTS is only available 3 to 4 hours a day. The only way to increase the availability would be to increase the reliability. Although that may be possible, this analysis does not evaluate the availability of the ESTS since only the CSRL was modeled. Since the three ESTSs at a typical base are used to test the launchers, pylons and
missiles, any analysis on this would have to include the pylons and missiles as well as the CSRL to be meaningful.

The number of maintenance personnel was not included as a constraint or as a factor for evaluation, because this was not considered a limiting factor in discussions with SAC personnel. However, this resource could be added to the model in the future.

Spare part stockage levels for the MIU and relay assembler were not evaluated because the maintenance concept for the SRAM launcher is to repair it in the IF, rather than to remove and replace failed components on the flight line. For this reason, there was no baseline data to use for the number of spares. The CSRL model is set up so that spares could be added for future analysis. This is discussed further in Chapter VI.

To summarize, there are four factors to be examined in this analysis - number of load crews, number of MLTs, level of repair, and the frequency of inspections. These will be evaluated while also measuring the effects of four estimated reliability and maintainability parameters - load time for the launcher, remove and replace time for the missile, remove and replace time for the MIU and relay assembler, and MRFP for the launcher.
IV. Model

The first section of this chapter briefly describes the SLAM simulation language and how it was used to develop the CSRL model. The second section gives an overview of the CSRL model while the third section gives a more detailed narrative description of the model and describes the interaction of the FORTRAN and the SLAM network sections of the CSRL model. The last four sections discuss the assumptions made, the flexibility of the model, the data sources, and verification and validation of the model.

SLAM Background

Rather than present a detailed description of SLAM, this section provides a simplified description of SLAM that is necessary for understanding the development of the CSRL model. Further detail concerning SLAM can be found in Pritsker and Pegden (14) and Janks and Carson (2).

SLAM is a special purpose FORTRAN-based simulation language which allows an event-scheduling and/or a process-interaction orientation toward modeling (2:99). The type of orientation one uses depends on the level of complexity needed to model the system and the extent to which the model will have to be embellished for future uses (14:315).

The event-scheduling orientation concentrates on events and how they affect the state of the system. This method uses a FORTRAN model to schedule events to occur and then process the events at the right time. FORTRAN subroutines are used to control the changes associated with each event type, which may entail manipulating files, collecting statistics, and/or printing status reports (14:73). This is called:
discrete-event model because changes in the model occur at discrete points in time.

The process-interaction approach concentrates on entities and the sequence of events and activities they undergo as they flow through the system. The processes are represented by the nodes and branches of a network. Consequently, a network model represents the processes that an entity goes through as it passes through the system. (14:73) The symbols used to describe the processes in the network are included in Table A.1 in Appendix A.

The ability in SLAM to combine the FORTRAN and network models “with interactions between each orientation greatly enhances the modeling power . . . (14:74)”. The interaction of the FORTRAN and network models allows events to alter the flow of entities in the network model and it also allows entities in the network to initiate events in the FORTRAN model.

The SLAM model developed for the CSRL employs both orientations toward modeling. The events are the ORI and the quarterly generation exercises, the annual launcher inspections and the exchange of launchers on alert aircraft. These events are scheduled in the FORTRAN program and when called, cause the launchers to flow through the appropriate segment of the SLAM network. The launchers are modeled as entities and the network represents the process the launchers must go through for each event. This type of model is called a discrete-event network simulation.

Model Overview

In Chapter II a macro view of the CSRL operational environment was presented and was diagrammed in Figure 2. To summarize, the diagram
showed that at base level the launchers could be in one of three locations for a variety of reasons. While at the base the CSRLs can either be in storage, on the flight line, or in the IMP. There are several reasons launchers transfer location. These include but are not limited to: repair of launcher components, required inspection, and generation exercises. The model subdivides the launcher into the seven major subsystems so that the MTBF for each of the components can be checked during testing (refer to Table C.1 for a listing of the subsystems). The launchers that are in storage (and have not failed) or are awaiting inspection are considered available. The next section uses flow charts to show the major decision structures involved in the day-to-day operation of the CSRL. Only the significant decision structures were included; for more specific details on the model refer to Appendix B where the FORTRAN and SLAM network codes are listed. The network flow diagrams are also included in Appendix B. The computer used to implement the simulation model is the VAX 11/780; however, it has also been run on the IBM 4321 computer.

Narrative Description

The CSRL model is a composite discrete-event network simulation that consists of two parts: a FORTRAN model and a SLAM network model. The FORTRAN model interacts with the SLAM network model to simulate the CSRL system. The FORTRAN code consists of two major parts: initialization and assignment of launchers, and event scheduling. The network model consists of five major sections that represent the different activities that the launchers go through during alert, generation exercises, and launcher inspections. The five major sections are: checking for failed components (CIF), repairing failed components
(REP), generating aircraft (GA), performing post generation work (PSTG), and performing annual launcher inspections (ALI).

In the initialization and assignment section of the FORTRAN model the 15 launchers are created and assigned failure times. Each launcher has seven major subsystems and eight missiles; therefore, all seven components and eight missiles are assigned failure times. Whenever a component fails the launcher is considered unavailable. Each launcher is then assigned an annual inspection time with one launcher scheduled every three weeks so that the work load is evenly spread throughout the year.

The first five launchers that are not due an annual launcher inspection within 90 days are put on alert aircraft with the remaining launchers put in storage. The launchers stay in storage (STG) or on alert (ALT) until scheduled for the next event. This is shown in Figure 3, Flowchart for Main Program.

The next part of the code, as illustrated in Figure 4, schedules the events for the CSRL for the simulation time specified by the user. The events are scheduled in decreasing order of importance so that any conflicts can easily be resolved. For example, if there was a conflict between an annual launcher inspection and an ORI the former would be deferred until after the generation exercise was completed. The first event scheduled is the ORI which occurs randomly every 10 to 15 months. The quarterly inspections (QINS) are scheduled next, one per quarter but not overlapping the ORIs since this would not occur in reality. The launchers are then scheduled for an annual launcher inspection (ALI) corresponding to the inspection times assigned earlier, unless the inspection time conflicts with a generation exercise, in which case the
MAIN PROGRAM

for 16
launchers

assign launcher component & missile failure times

assign ALI time (inspect 1 every 3 weeks)

are 3 CSRL on ALT

ALI due in 90 days

ALT

19
Figure 4. Flowchart for Main Program, Event Scheduling
inspection is rescheduled until after the generation exercise. The last event scheduled is the weekly status check of alert aircraft. This event (EXCHG) exchanges failed launchers and launchers that have been on alert for 90 days with launchers from storage or the IMF.

In addition to initializing the model and scheduling events, the FORTRAN code performs the availability checks and prints the results. Since availability is the number of launchers in working order at random points in time, the availability checks are conducted randomly once a month. The availability of launchers in storage and on alert aircraft are checked. The model does not count launchers with undetected storage failures as being available. The number of available launchers is computed to be the percentage of the 16 launchers that are actually in working order.

After scheduling the events to occur the FORTRAN code calls the SLAM input code which processes the events in chronological order. When an event is scheduled to occur the FORTRAN code is called to remove launchers from one file and place them into another file in the network where the processing of the event continues. For example, when an ORI is scheduled the FORTRAN code removes the launchers that are in storage from file 2 and puts them into file 3 where the network processes the launchers and upgrades them to alert status.

When an ORI or quarterly inspection exercise occurs all 11 aircraft not on alert must be readied and upgraded to alert status. Both inspections are collectively referred to as generation exercises. See Figure 5 for the flowchart for generation exercises.

During a generation exercise the launchers and two pylons are the last items loaded onto the aircraft. These are not loaded until all the
other equipment has been loaded and verified as being operational. Once the aircraft is ready and a load crew and a MLT are available the launcher is loaded and each of the pylons are loaded onto the aircraft. The launcher which holds eight missiles is loaded into the bomb bay of the aircraft and the pylons which hold six missiles each are loaded onto the wings of the aircraft. Once the launcher or pylon is loaded the MLT is then returned to the storage area or to the IMF for loading of the next launcher or pylon. Once fully loaded on the aircraft a SIT test is performed to detect any failures on the launcher or the missiles. The SIT test can detect multiple failures; therefore, all failures are repaired before releasing the launcher for the next event. A SIT test is also performed on the pylons but this is not modeled. The pylons are partially modeled during generation exercises because they tie up two of the critical resources for the CSRL (load crews and MLTs) which affect the sortie generation rate for the CSRL. Otherwise, the pylons do not constrain the generation or the availability of the CSRL and are not modeled.

If a failure is detected on the launcher and the component is repairable on the flight line, it will be repaired on the spot. If the component can not be repaired on the flight line, the launcher or pylon will be transported to the IMF, loaded onto the CSS (when one is available), repaired, and returned to the flight line to be loaded onto an aircraft.

If a missile has failed, one of two things can happen which is left to the discretion of the wing commander. Either the whole launcher (including missiles) is returned to the IMF to exchange the failed missile or the launcher is left in a degraded status. The first option
Figure 3. Flowchart for Generation (GEN) Subroutine
would normally occur early in the exercise while the last option would probably occur later in the exercise. The model assumes that this change in decision would occur halfway through the exercise after 3 of 16 launchers have been loaded. This seems like a reasonable assumption but may lead to an inaccurate prediction of availability and thus wartime capability, since at the end of the generation exercise all launchers and missiles are expected to be fully operational.

Once the launcher and pylons are fully loaded onto the aircraft and all have passed the SIF test, the network calls the FORTRAN generation report (GENRPT) subroutine which computes the time it took to generate the aircraft. This is the process followed to generate all aircraft for either an OAI or a quarterly inspection exercise (QINS). The time to generate each aircraft and the total time to generate all 15 aircraft are used by the inspection team to rate the operational readiness of the unit.

Figure 6 shows the flow chart for the annual launcher inspection (ALI). When a launcher is scheduled for its annual inspection it is transported to the IMF where it waits for an ESIS to become available. Although it is not modeled, the inspection can not start until the inspection crew is available. This is not modeled because launcher inspections will occur during normal working hours when an inspection crew will be available. Once the ESIS is available, the launcher is loaded onto the test frame, the warheads are removed from the missiles, the missiles are downloaded from the launcher and an empty test is performed to check for any failures on the launcher. The missiles are also going through their annual inspection on another ESIS (this is not modeled because missile inspections are not constraining). Any failures
ALI

wait for ESFS

load on frame
download missiles
perform empty test

any failures?

Y

REP

N

load missiles
download from frame
loaded/postload insp

release ESFS

SEN in progress

Y

SEN

N

SEN

Figure 3. Flowchart for Annual Launcher Inspection (ALI) Subroutine
that are detected are then repaired. Once all repairs are completed the
missiles are then reloaded onto the launcher, the launcher is downloaded
from the frame and a loaded test or postload inspection is performed.
Again, any failures that are detected are repaired. This completes the
annual launcher inspection and the FST is released for use for other
work.

The next event, Exchange (EXCHG), is shown in figure 7. The EXCHG
event occurs every week unless there is a generation exercise in
progress. Every week the launchers on alert aircraft are checked to see
if they are still operational by performing a SIT test and they are also
checked to see if their 90 day alert time has expired.

If the launcher is operational and it has been on alert for 90 days
it is exchanged with a launcher from storage that is not scheduled
for an annual launcher inspection within the next 90 days. The new alert
launcher and two pylons are transported to the flight line, loaded onto
the aircraft, and checked for failures (a SIT test is performed). If
the launcher and missiles are operational a postload check is
accomplished and the old launcher and pylons are taken off alert and
sent to the IMF for a visual recertification before going back to
storage. Otherwise, the failed launcher is removed and transported back
to the IMF while another launcher is transported to the flight line.

If the launcher or missiles are found to be non-operational the
launcher will be downloaded and sent to repair after another launcher is
put on alert.

The three major events affecting the CSII were modeled in
sufficient detail in order to provide an experimental framework for
which to test the critical factors affecting availability and sortie
Figure 7. Flowchart for Exchange (EXCHG) Subroutine
generation time. However, certain assumptions were made that may affect the actual prediction of availability and sortie generation time.

Assumptions

In addition to the assumptions mentioned in the development of the model, the following assumptions were necessary to limit the scope of the CSAL system in order to focus on the major factors affecting availability and sortie generation time. These assumptions can be changed by modifying the computer code if further analysis requires such changes.

The major assumption in this model is that all other resources (i.e., spare parts, flight line support equipment, and munitions) besides the ones explicitly specified in the model are noncritical. That is, they are available when needed and will not affect availability or sortie generation time.

A second assumption is that all component failures are of equal importance. This seems reasonable since launchers only have two states -- available or unavailable. Therefore, no single component receives priority maintenance.

Since there is no data available on the different failure rates, storage versus operational, they were modeled as being equal. Since storage failures remain undetected, whereas operational failures are detected and sent to repair, the different rates would affect the true availability measure. Once the data becomes available it could easily be incorporated into the model which would give a more accurate prediction of availability.

Another assumption involves the load crew. The load crew is fully modeled during generation exercises when four crews are available around
the clock. There are 2 12-hour shifts during generations. However, during normal operations the crew is not modeled because it is assumed that a load crew will be available when needed for loading launchers on alert aircraft or for loading launchers requiring annual inspections. This is a reasonable assumption because during normal operations the crew are scheduled for two eight-hour shifts for five days a week which coincides with when all the repair work and inspection work is scheduled.

Even with the limiting assumptions the scenario is still representative of a normal day-to-day operation as well as a typical generation operation and will be sufficient to meet the objectives of this study.

Flexibility

The CSRL model is inherently flexible due to the SLAM language and the modular way it was written. The SLAM code was separated into sections according to the function being performed. The functions include: checking for failed components, repairing failed components, generating aircraft (ORI and QVSP), performing post generation work, and performing launcher inspections. The FORTRAN program was broken into subroutines according to the events that the launchers go through. Because of its modularity the CSRL model can be easily expanded by adding events to the FORTRAN code. These events can be scheduled to occur at specific or random times in the initialization subroutine (INITL). If new policies require incrementing existing resources or adding additional resources, these resources can be included in the SLAM code.
There are several internal options that can be initialized to different values before a run. These include level of repair, frequency of launcher inspections, number of crews, number of MLUs, number of ESTSs as well as any of the estimated parameters. All of the estimated parameters can also be made global variables in order to facilitate the experimental design.

In addition to changing input parameters and resources, the model is flexible enough to evaluate measures of effectiveness other than the ones chosen for this study. For example, the model could evaluate the fully mission capable (FMC) rate and the partially mission capable (PMC) rate of the CSRL by changing the generation report (GENRPT) subroutine in the main program to calculate and print the number of launchers loaded in a specific amount of time:

1. with all missiles functioning,
2. with at least five missiles functioning.

In addition to the standard SLAM output file, the model creates two user defined output files that aid in the analysis of the model results. The first output file contains the generation times for each launcher and the availability values taken randomly. This file is useful for monitoring the status of the generation exercises. The second output file records the average availability of the launchers for the simulation time and the average generation time for the launchers. This file is more useful than the average availability and generation values calculated by SLAM because it does not weight the statistics over time.
This section briefly discusses the sources for the input data for the model. Most of the data came from four sources: Boeing Document No. D405-10350-1, Reliability/Maintainability Allocations, Assessment and Analysis Report - CSRL; AFLC 0056 Data for SRAM Missile Work Unit Code (BAJ00), from 1 Oct 83 to 31 Mar 84; SAC maintenance personnel familiar with the SRAM rotary launcher system; and AFOTEC personnel familiar with both the SRAM rotary launcher and the specifications for the CSRL. None of the sources distinguished between storage failure rates and operational failure rates. The Activities Table in Appendix C lists most of the data and the data sources used in the model. The only data not included in this table are the mean time between failure (MTBF) rates for each subsystem. The values used are the predicted and allocated values from the Boeing report. The Boeing report only gives one MTBF for the electronic and electrical systems. Since the Missile Interface Unit (MIU) and the relay assembler can be repaired on the flight line, a MTBF for each component was calculated by using the Boeing MTBF and the percentage of failures for each component obtained from the 0056 data. The MTBF rates used in the model are summarized in the MTBF Table in Appendix C. In addition, comments have been included in the model in Appendix B which lists the source for the particular data used.

Verification and Validation

The utility of this research effort depends heavily on the validity of the simulation model and on the assumptions on which it is based. Numerous methods have been developed to aid in the verification and validation process; most are informal subjective comparisons, while a
few are formal statistical procedures (2:376-377). Verification and validation were conducted simultaneously and two steps were used to validate the projections of availability and sortie generation times for the C3&L. First, the SLAM simulation model was examined to verify that it operated as intended. Then the simulation results were examined for validity. The following sections describe both steps in further detail.

Verification

In order to verify that the simulation model behaved as intended two of the SLAM output options were used; trace and summary report. The SLAM trace routine lists the sequence in which activities are performed and portrays the decision, variable assignments, and branching that occurs at nodes. The trace was used at the beginning of the simulation and at times when major events occurred in order to verify that the simulation was starting out correctly and continuing to operate properly. The traces were thoroughly examined from various simulation runs and it showed that the simulation model accurately reflected the processing of the launchers through the various activities. Therefore it was concluded that the model performed as designed.

Validation

In order to validate the model it is necessary to examine the simulation results and compare it with reality. Comparing the model results with reality can be accomplished using subjective tests and/or objective tests. Subjective tests require the judgements of experts of the system, to determine the validity of the model and its output. Objective tests are more concrete and are used to compare the system's actual performance with the performance produced by the model. Since
the CSRIL is not yet operational, the validity cannot be checked with objective tests. Therefore only subjective tests were used to validate the model results. (2:335)

The degree of validity when using subjective tests is highly dependent on the acceptance by future users of the model, of the assumptions made and the extent to which the results agree with perceived expectations. Throughout the development of the model, the potential users of the model (APTEC) were conferred with to ensure that a realistic model was being built using reasonable assumptions and reliable data. The users concurred with the assumptions. The logic of the model was also checked by using extreme values for critical inputs. These include reliabilities, number of crews, number of MLTs, and type of management policy.

The availability measure seemed to be accurately portrayed when the critical factors were increased or decreased.

The sortie generation times when compared with expectations were a little high with variations of certain factors. This could be attributed to conservative estimates by maintenance personnel on the time to perform certain tasks on a system not yet operational. However, the sortie generation times did increase or decrease as expected when critical factors were changed.

The results from varying the inputs for the most part yielded reasonable output, consistent with expectations. Therefore, the model is considered valid.
V. Analysis and Results

Research Design

The purpose of this research is to evaluate how various factors effect availability and generation time while simultaneously considering variations in several estimated reliability and maintainability parameters. Using regression analysis, the relationships between availability and generation time (dependent variables) and the set of factors and interactions (independent variables) are quantified.

The four factors evaluated are: the number of load crews, the number of munitions lift trailers, the level of repair, and the frequency of launcher inspections. The estimated parameters are: time to load the launchers, time to exchange a missile, time to remove and replace a component on the flight line, and the mean time between failures for the seven subsystems. These MTBFs are combined into one parameter by calculating the MTBF of the launcher:

\[
\frac{1}{\text{MTBF}_{\text{launcher}}} = \sum_{i=1}^{7} \frac{1}{\text{MTBF}_i}
\]

where:

- \(\text{MTBF}_i\) is the MTBF of subsystem \(i\)
  1 = structure
  2 = power drive unit
  3 = power drive unit controller
  4 = missile interface unit
  5 = relay assembler
  6 = other electronic/electrical
  7 = electronic control system

It is difficult to judge, without some preliminary analysis, which of the eight factors and 23 possible two-way interactions significantly impact availability and generation time. With so many potential independent variables a stepwise regression procedure would be necessary. A
stepwise regression procedure, which is notorious for capitalizing on chance, ideally should have 40 times more cases than the number of independent variables. (16:92) Even if the interactions could be narrowed down to 3, through judgement and logic, the regression would require 640 (=16x40) runs.

By dividing the experimental design into two parts, the number of runs needed for the regression is reduced, since the number of factors and interactions simultaneously analyzed is reduced and the number of cases per independent variable is reduced from 40 to 20.

The initial set of runs is based upon a fractional factorial design which evaluates 3 factors at two levels and 29 first-order (two way) interactions. From this design, those factors and interactions which significantly affect the dependent variables were identified.

Once the independent variables which will most likely enter the regression equation have been identified, a regression procedure without the stepwise option can be used to develop a functional relationship between the dependent and independent variables. Without the stepwise option the regression procedure ideally should have 20 times more cases than the number of independent variables. (16:91)

**Structural model**

The structural model is composed of three types of variables which include response variables, control variables, and stochastic variables. The following table lists by type the variables used in the model.
Table 1

Variables Used in Model

<table>
<thead>
<tr>
<th>Response</th>
<th>Control</th>
<th>Stochastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of launchers available</td>
<td># of crews</td>
<td>*failure rates</td>
</tr>
<tr>
<td>generation time</td>
<td># of MLTs</td>
<td>load times</td>
</tr>
<tr>
<td>maintenance policy</td>
<td>frequency of inspection</td>
<td>**Remove/replace times</td>
</tr>
<tr>
<td></td>
<td></td>
<td>repair rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>random avail checks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>inspection times</td>
</tr>
<tr>
<td>*launcher components and missiles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>**launcher components only</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Initial Run

The initial run was used for three purposes:

1) To test for autocorrelation in the availability checks,
2) To evaluate the warm-up period needed to avoid initialization bias,
3) To determine the number of observations needed in each run.

The initial run was for 20,000 hours (approximately 9 quarters) and it checked availability 57 times and generation time 11 times.

The existence of autocorrelation means that an observation is related to the previous observation. Since the number of observations needed is calculated using the assumption of independent observations, the presence of autocorrelation has the effect of overstating the sample size. In simulation autocorrelation can be reduced by increasing the amount of simulated time between observations. (1:434)

To test for autocorrelation, the SPSS regression package on the ASC Cyber computer was used. By requesting a plot of availability (WALL) versus time (TMLW) the program calculated a Durbin-Watson statistic. Initially, availability was checked randomly between 1,000 and 950 hours. The Durbin-Watson statistic was .931 which was clearly in the
unacceptable range. Taking observations half as often decreased the number of observations to 29 and increased the Durbin-Watson statistic to 1.605. The acceptable range for this statistic with more than two variables and 29 observations is 1.58 to 2.42 (11:539). This indicated that with observations taken randomly between 0 and 1,300 hours, autocorrelation is not a problem.

To avoid having the observations biased because of initializing the failures at time zero, a warmup period of 720 hours was used. After 720 hours the network has completed several cycles. The status of the launchers on alert aircraft has been checked four times and repaired, if necessary, and the first launcher has gone through an annual inspection. From the results of the trial run, the designated warmup period is considered more than adequate because the initial values obtained for both availability and generation time were neither the high, nor the low results.

Since availability and generation exercise time are stochastic processes and are checked at random points in time, the initial run was used to calculate the number of observations necessary for analysis. The number of observations needed is based on the variation in the observations of the initial run and the confidence that the sample mean is a good estimate of the population mean. This can be calculated using the following formula (2:439):

\[ n = \left[ \frac{ts}{z} \right]^2 \]

where

- \( t \) is the t-statistic for confidence level \( \alpha \) and \( n-1 \) degrees of freedom
- \( s \) is the standard deviation of the sample
- \( z \) is the half width of the confidence interval
A confidence interval of ± 0.02 for availability and an interval of ± 4 hours (± 10% of 39.5 hours) for generation time were used in determining the number of observations needed for analysis. These values were considered adequate when considering the uncertainty of the estimated parameters and the amount of computer time needed to achieve these results.

Table 2 contains the calculations for availability and generation time. To achieve the chosen confidence interval, the simulation time must be 1 year or 3,760 hours for generation time, but it must be 115 weeks (29 x 4) or 11,433 hours for availability.

<table>
<thead>
<tr>
<th>Availability</th>
<th>Generation Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n = 23, , \alpha = 0.10 )</td>
<td>( n = 11, , \alpha = 0.10 )</td>
</tr>
<tr>
<td>( t_{10, 29} = 1.31 )</td>
<td>( t_{10, 10} = 1.37 )</td>
</tr>
<tr>
<td>( \bar{x} = 37.93 )</td>
<td>( \bar{x} = 37.93 )</td>
</tr>
<tr>
<td>( s = 0.092 )</td>
<td>( s = 39.5 )</td>
</tr>
<tr>
<td>( z = 1.92 )</td>
<td>( z = 4 )</td>
</tr>
<tr>
<td>( N = \left[ \frac{(1.31)(0.232)}{0.02} \right]^2 )</td>
<td>( N = \left[ \frac{(1.37)(6.3)}{4} \right]^2 )</td>
</tr>
<tr>
<td>( N = 29 )</td>
<td>( N = 3 )</td>
</tr>
</tbody>
</table>

**Fractional Factorial**

Factorial designs are useful when there is more than one factor which affects the response variable. This type of design will measure
the effects of the main factors and the interactions among these factors. With 3 factors, a full factorial design would require $2^3$ or 256 combinations or runs of the model. However, it is not necessary to include all of these combinations to obtain enough information to answer the research questions posed in Chapter I.

A reduced factorial design is called a fractional factorial. By not including all possible combinations, "loss of information results from main effects and interactions being entangled [confounded] with other main effects and interactions" (17:1). But with properly chosen combinations these entanglements can be limited to higher order interactions. This is acceptable because "in many experiments, interactions among three or more factors can be considered negligible" (18:2).

Since the higher order interactions in this system should be negligible, this design is a one-fourth of a $2^3$ factorial. This will provide information on the main factors and the first order interactions.

The design used was published as part of the National Bureau of Standards Applied Mathematics Series (13:2). The details are provided in Appendix D.

Results

The fractional factorial design was done using the 3iD2V statistical package on the ASU Cyber Computer. The data, input program and output table are included as Appendix E.

At the 99% confidence level there were three main effects which affected the availability: level of repair, frequency of inspections, and INF. In addition to these three main effects, the interaction of the number of crew, and the frequency of inspections affected availability.
At the 90% confidence level there were five main effects which affected generation time: number of crew, level of repair, time to load the launcher, time to remove and replace components, and MTBF. In addition to the main effects, the generation time is affected by the interactions with the number of crew and: level of repair, frequency of inspection, time to exchange a failed missile, and MTBF.

Regression Analysis

The fractional factorial design indicated that there are four potential independent variables needed to explain availability; nine needed to explain generation time. With 9 potential independent variables and 20 cases per independent variable, 180 runs are needed. The following are the factors that were varied and the names given to them for the rest of the analysis:

- number of load crews (Crew)
- level of repair (Level)
- frequency of inspections (Inspection)
- time to load the launcher (Load)
- time to remove and replace a component (R&R)
- time to exchange a missile (Missile)
- mean time between failures (MTBF)

When two terms interact, the effect of the first term is dependent upon the level of the second term and vice versa. This type of relationship can be represented by a cross-product term. \((12:232)\) From the previous variables, the interaction variables were calculated:

- Crew-Level = Crew x Level
- Crew-Inspection = Crew x Inspection
- Crew-Missile = Crew x Missile
- Crew-MTBF = Crew x MTBF
The names used during the rest of the analysis for the dependent variables are:

- Average percentage of available launchers (AVAIL)
- Sortie generation time (ENTSIM)

The regression analysis was done using the SPSS statistical package on the ASD Cyber Computer. The input data, input program and summary output tables are included in Appendix C.

To determine if a linear relationship between the independent and dependent variables was appropriate, a scattergram function of SPSS was used to produce plots of each independent variable with the dependent variables. All the plots indicated linear relationships except the plot of AVAIL vs. MTBF. To obtain linearity, new variables were created by using logarithmic transformations:

\[ \text{LMAVF} = \log(\text{MTBF}) \]
\[ \text{LMTBF} = \log(\text{MTBF}) \]

The scattergram function was rerun and the plot of AVAIL vs. LGMTBF appeared to have a linear relationship.

**Availability**

Availability can be explained with the following equation:

\[ \text{AVAIL} = 1.034 + 0.393(\text{LMAVF}) + 0.316(\text{LISP}) \]

where

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVAIL</td>
<td>% of launchers available</td>
<td>.15, .31*</td>
</tr>
<tr>
<td>LMTBF</td>
<td>log of the life in years</td>
<td>.15, .31</td>
</tr>
<tr>
<td>IASP</td>
<td>/ of times each launcher is inspected per year</td>
<td>.54, 2.1</td>
</tr>
</tbody>
</table>

*LMTBF will be negative for this range of IASP.*
Almost 95% of the variation in availability can be explained by this regression equation. Although the initial results indicated that LEVEL and CWXINSPI were significant, these did not enter the regression equation.

**Generation Time**

Generation time can be explained with the following equation:

\[
\text{GENTIM} = 74.919 - 2.739(\text{CREW}) + 2.051(\text{LOAD}) - 37.194(\text{MTBF}) \\
- 5.317(\text{LEVEL}) - 0.171(\text{CWXINSPI}) + 0.143(\text{CWXINSPI}) \\
+ 1.629(\text{CWXINSPI}) + 0.037(\text{CWXLEVEL})
\]

where

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEN TIM</td>
<td>generation time in hours</td>
<td>3,12</td>
</tr>
<tr>
<td>CREW</td>
<td># of crews</td>
<td>1,0,1.5</td>
</tr>
<tr>
<td>LOAD</td>
<td>most likely time in hours to load a launcher</td>
<td>1,0,1.5</td>
</tr>
<tr>
<td>MTBF</td>
<td>mean time between failures in years</td>
<td>.15,.51</td>
</tr>
<tr>
<td>LEVEL</td>
<td>level of repair (flight line repair = 3, otherwise = 2)</td>
<td>2 or 3</td>
</tr>
<tr>
<td>CWXINSPI</td>
<td># of load crews x frequency of inspections</td>
<td>.54,2.13</td>
</tr>
<tr>
<td>CWXINSPI</td>
<td># of load crews x most likely time to exchange a missile</td>
<td>1.5,3.5</td>
</tr>
<tr>
<td>CWXMTBF</td>
<td># of load crews x MTBF</td>
<td></td>
</tr>
<tr>
<td>CWXLEVEL</td>
<td># of load crews x level of repair</td>
<td></td>
</tr>
</tbody>
</table>

This regression equation explains 75% of the variation in generation time. Although the initial results indicated that MTBF was significant, it did not enter the regression equation. The easiest way to evaluate how much effect each of the factors being evaluated has, is to
take the partial derivative and compute its value by holding the other factors at their high, most likely, and low values:

\[
\frac{\partial G_{ENTIM}}{\partial \text{CREW}} = -2.738 - 0.171(\text{INSPI}) + 0.143(\text{HSL}) + 1.629(\text{MBF}) + 0.377(\text{LEVEL})
\]

\[
\frac{\partial G_{ENTIM}}{\partial \text{LEVEL}} = -5.317 + 0.377(\text{CREW})
\]

\[
\frac{\partial G_{ENTIM}}{\partial \text{INSPI}} = -0.171(\text{CREW})
\]

These effects are summarized in Tables 3 and 4.

**Table 3**

**Effects of Unit Changes in Input Levels**

<table>
<thead>
<tr>
<th>Change in GENTIM/Unit Change in Factor</th>
<th>high</th>
<th>medium</th>
<th>low</th>
</tr>
</thead>
<tbody>
<tr>
<td>CREW</td>
<td>-1.3</td>
<td>-1.0</td>
<td>-0.5</td>
</tr>
<tr>
<td>LEVEL</td>
<td>-2.3</td>
<td>-1.5</td>
<td>-0.9</td>
</tr>
<tr>
<td>INSPI</td>
<td>-2.0</td>
<td>-1.7</td>
<td>-1.4</td>
</tr>
</tbody>
</table>

**Table 4**

**Effects of Potential Changes in Input Levels.**

<table>
<thead>
<tr>
<th>potential change</th>
<th>change in gentin</th>
</tr>
</thead>
<tbody>
<tr>
<td>from</td>
<td>to</td>
</tr>
<tr>
<td>CREW</td>
<td>8</td>
</tr>
<tr>
<td>LEVEL</td>
<td>2</td>
</tr>
<tr>
<td>INSPI</td>
<td>.5</td>
</tr>
</tbody>
</table>

The results of this regression can be represented graphically with a contour map (13:613). The map shown in Figure 6 shows the contours for various combinations of number of crew, frequency of inspections,
level of repair, and MTBF which are needed to achieve a 35 hour average generation time.

Figure 9 shows how to read the graph when the MTBF is .3 years (or 2,330 hours). The MTBF line intersect four contours, which means there are four possible combinations which yield the same generation time.

![Contour Map](image)

**Figure 9. 35 Hour Contour Map at MTBF = .3**
The combinations from Figure 9 are summarized in Table 5.

Table 5

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CREW</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>LNSP</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>LEVEL</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Contour Maps can be drawn for any level of GENDIM, and can be useful when dealing with the question “what is needed to achieve a specific generation time?”
VI. Conclusions and Recommendations

Conclusions

The research questions posed in Chapter I can be answered from the analysis in Chapter V.

1) What is the expected availability of the CSAL when used on the B-52 aircraft; when used on the B-1 aircraft? The average percentage of launchers in working order at any given time, using the failure rates predicted by Boeing, is .902 for the B-52 and .917 for the B-1. With less optimistic failure rates (Boeing's allocated rates) the availability drops to .746 for the B-52 and .348 for the B-1. The B-1 is higher because the power drive unit (PDU) and the PDU controller are considered a part of the aircraft, rather than part of the launcher.

2) What is the sortie generation time when used on the B-52; when used on the B-1? Using the maintenance concept and the current resources for the SRAM launcher as a baseline for prediction, the average sortie generation time predicted by the model is approximately 39.5 hours for the B-52 and 33.3 hours for the B-1. However, as mentioned in the validation section, the generation times appear to be about 10-20% too high. Although the availability of the B-52 was lower (caused by the PDU and PDU controller), this does not have much effect in the generation time. This is because failures on the PDU controller can be detected and repaired (if necessary) every time the aircraft is flown, whereas failures on the other subsystems are detected only during the generation exercises or inspections.

3) How much effect does the number of load crews have on the generation time? Of all the factors in this analysis, the number of
load crews can have the most significant impact. For every unit increase in the number of crews, there is a 1-5% decrease in the generation time. This decrease is more pronounced when the MTBF is low and/or when the maintenance concept does not permit flight line repair.

4) How much effect does the number of MLTs have on the generation time? The results of this analysis indicate that increasing the number of available MLTs above eight does not significantly reduce the generation time. Although a launcher might have to wait for an MLT at the weapon storage area, it may have to wait for a load crew or for a 3-52, if an MLT were available and the launcher were transported to the flight line.

5) How much effect does the level of repair have on the generation time? Changing to a 3-level maintenance policy causes a 2-6% decrease in the generation time. The maximum decrease occurs when there are only eight load crews.

6) How much effect does the frequency of launcher inspections have on the generation time? Increasing the frequency of inspections from once a year to twice a year decreases the time by 3-5%. Decreasing the frequency to once every two years increases the time by 1-3%.

7) How much effect does the frequency of launcher inspections have on the availability? The regression equation indicates the frequency of inspections has an effect on the availability, but this effect is very small. Increasing the frequency from once a year to twice a year increases the average percentage of available launchers by less than 2%.

In summary, the number of load crews has the most impact on generation time. Trade-offs can be made among the number of crews, the level of repair and the frequency of inspections in order to achieve a specific generation time. Availability can be explained almost entirely
as a function of MTBF, with the frequency of inspections having a slight impact.

Recommendations for Future Analysis

There are three areas which warrant more analysis - the number of MLTs, spare parts, and the frequency of inspections.

The fact that the number of MLTs did not affect the generation times, even though people who work with the system feel they are a limiting resource, may indicate that the MLTs were not modeled correctly or that the transport time estimates are too low. This area could be re-evaluated.

The inclusion of spare parts for the two components which can be removed and replaced on the flight line (MIU and relay assembler) could be added with minor changes to the network. The spare parts could be modeled as entities which would be held in a queue node until needed; a match node would match the spare with the launcher when a failure has occurred; the entity representing the failed spare would flow through a decision node which would represent whether the spare was to be repaired at the depot or at the IMF; after repair it would be routed back to the queue node.

The CSRL was modeled so that when the launcher was inspected, the missiles were inspected also. The fact that the frequency of periodic inspections had more effect on the generation time than the availability (which only checks the status of the launchers) indicates that the inspections had more of an impact on the missiles than on the launchers. The analysis could be repeated testing the effects of inspecting the missiles twice a year, but only inspecting the launchers once a year.
Appendix A
SLAM Network Symbols

SLAM Network Symbols and Statements for Discrete Modeling

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCUMULATE</td>
<td></td>
<td>ACCUMULATE, FR, SR, SAVE, M.</td>
</tr>
<tr>
<td>ACTIVITY</td>
<td></td>
<td>ACTIVITY, IN, J, O, DUR, PROB or COND, NLBL,</td>
</tr>
<tr>
<td>ASSIGN</td>
<td></td>
<td>ASSIGN, VAR=VALUE, VAR=VALUE, M.</td>
</tr>
<tr>
<td>COLCT</td>
<td></td>
<td>COLCT, TYPE or VAR, ID, NCEL, MLow, HWIN, M.</td>
</tr>
<tr>
<td>CREATE</td>
<td></td>
<td>CREATE, TBC, TF, MA, MC, M.</td>
</tr>
<tr>
<td>GOON</td>
<td></td>
<td>GOON, M.</td>
</tr>
<tr>
<td>MATCH</td>
<td></td>
<td>MATCH, NATR, GLBL/MLBL, NLBL, NLBL repeats</td>
</tr>
<tr>
<td>QUEUE</td>
<td></td>
<td>QUEUE, IFI, 10, QC, BLOCK or BALK (NLBL), GLBL</td>
</tr>
<tr>
<td>SELECT</td>
<td></td>
<td>SELECT, QSR, SSR, BLOCK or BALK (NLBL), GLBL</td>
</tr>
<tr>
<td>SELECT VARIATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TERMINATE</td>
<td></td>
<td>TERMINATE, TC.</td>
</tr>
<tr>
<td>ALTER</td>
<td></td>
<td>ALTER, RLBL/CCM</td>
</tr>
<tr>
<td>AWAIT</td>
<td></td>
<td>AWAIT, IFI, RLBL/UR or GLBL, MC</td>
</tr>
<tr>
<td>CLOSE</td>
<td></td>
<td>CLOSE, GLBL, M.</td>
</tr>
<tr>
<td>FREE</td>
<td></td>
<td>FREE, RLBL/UR, M.</td>
</tr>
<tr>
<td>GATE</td>
<td></td>
<td>GATE, RLBL, OPEN or CLOSE, IFLA</td>
</tr>
<tr>
<td>OPEN</td>
<td></td>
<td>OPEN, GLBL, M.</td>
</tr>
<tr>
<td>PREEMPT</td>
<td></td>
<td>PREEMPT, IFI, PR, RLBL, SNBL, NATR, M.</td>
</tr>
<tr>
<td>RESOURCE</td>
<td></td>
<td>RESOURCE/RLBL (RCL), IFLA</td>
</tr>
</tbody>
</table>

List of variables/functions from which assignment values can be obtained:

<table>
<thead>
<tr>
<th>Variable Function/Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant: A constant real value</td>
</tr>
<tr>
<td>TNOW: Current time</td>
</tr>
<tr>
<td>ATRIB: Attribute I of current entity</td>
</tr>
<tr>
<td>SSIV: Value of state variable I</td>
</tr>
<tr>
<td>DXXI: Value of the derivative of state variable I</td>
</tr>
<tr>
<td>IXXI: Value of global variable I</td>
</tr>
<tr>
<td>NACTI: Number of active entities in activity I at current time</td>
</tr>
<tr>
<td>NINCNT: The number of entities that have completed activity I</td>
</tr>
<tr>
<td>NNGGAT/LGLLJ: Status of gate GLBL in current time 0 = open 1 = closed</td>
</tr>
<tr>
<td>NNRSLGRL: Current number of units of resource type RLBL available</td>
</tr>
<tr>
<td>NREI: Number of entities in state I at the current time</td>
</tr>
<tr>
<td>STOPALJ: Specifies the end of an activity upon a call to subroutine STOPALJ</td>
</tr>
<tr>
<td>USERRI: A sample obtained from the user-written function</td>
</tr>
<tr>
<td>RELI: Specifies the completion of an activity upon release of node i</td>
</tr>
</tbody>
</table>

Definitions of some important discrete event variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATRIB</td>
<td>Buffer for the nth attribute value of an entity to be inserted or removed from the file storage area</td>
</tr>
<tr>
<td>MSTOP</td>
<td>Set by the user to -1 to stop a simulation run before time TFIN</td>
</tr>
<tr>
<td>NCLNR</td>
<td>The file number of the current calendar</td>
</tr>
<tr>
<td>MNROR</td>
<td>The unit number from which SLAM input statements are read</td>
</tr>
<tr>
<td>NINRUN</td>
<td>The number of the current simulation run</td>
</tr>
<tr>
<td>NSECT</td>
<td>The dimension of the array NSET/OSET</td>
</tr>
<tr>
<td>NFRINT</td>
<td>The unit number to which SLAM output is to be written. Normally set to 6 to denote the line printer</td>
</tr>
<tr>
<td>NSET/OSET</td>
<td>Equivalenced arrays employed by SLAM for storing file entities</td>
</tr>
<tr>
<td>NTAEPE</td>
<td>The unit number of a scratch tape</td>
</tr>
<tr>
<td>TNRW</td>
<td>The value of current simulated time</td>
</tr>
<tr>
<td>TNET</td>
<td>The time of the next scheduled discrete event</td>
</tr>
<tr>
<td>IXII</td>
<td>The nth global variable. Time between statistics will be collected if IXII is specified on the TIMST input statement</td>
</tr>
</tbody>
</table>

Random Sampling Functions:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAND(US)</td>
<td>A pseudo-random number</td>
</tr>
<tr>
<td>EXPOX(KMS)</td>
<td>A sample from an exponential distribution</td>
</tr>
<tr>
<td>UNFRM(ULO, UHI)</td>
<td>A sample from a uniform distribution</td>
</tr>
<tr>
<td>WEIBL(BETA, ALPHA)</td>
<td>A sample from a Weibull distribution</td>
</tr>
<tr>
<td>TRIAG(KLO, XMODE, XMS)</td>
<td>A sample from a triangular distribution</td>
</tr>
<tr>
<td>RNGRM(XMIN, STD)</td>
<td>A sample from a normal distribution</td>
</tr>
<tr>
<td>RLOGN(XMIN, STD)</td>
<td>A sample from a lognormal distribution</td>
</tr>
<tr>
<td>ERLNG(EMN, XX)</td>
<td>A sample from an Erlang distribution</td>
</tr>
<tr>
<td>GAMABETA(ALPHA)</td>
<td>A sample from a gamma distribution</td>
</tr>
<tr>
<td>BETAMTHETA</td>
<td>A sample from a beta distribution</td>
</tr>
<tr>
<td>NPSNN(XMIN)</td>
<td>A sample from a Poisson distribution</td>
</tr>
</tbody>
</table>

SLAM Library of Subprograms:

- Subroutine COLCT (IVAL, KCOLCT) |
- Subroutine COPY (RANK, IFILE, A) |
- Subroutine FILER (IFILE, A) |
- Function NFRNO (RANK, IFILE, NATR, MCODE, X, TOL) |
- Subroutine PMOVE (RANK, IFILE, A) |
- Subroutine SCHED (JEVENT, DT, A) |
- Subroutine STOPALD |
Appendix B
CSRL Model and Output

This appendix contains the CSRL simulation model developed for this study. Both the input and output files are listed.

The first section lists the CSRL FORTRAN code which is composed of the following subroutines:

INILC EVENT AVAIL
EXCHG NEWALT POUCHK
ORIGEN ORGEN ANYISP
AVGPRF CHKMIS CHKSKH

All of the subroutines are explained in the FORTRAN code.

The next section lists the CSRL SLAM code and the CSRL SLAM network diagrams. The SLAM code has been modularized into the following functions:

simulation control statements - beginning
definitions of variables, files, and resources
storage (STG) and alert (ALT) queues
repair network (REP)
missile exchange network (EXCHG)
generation network (GEN)
post generation network (PSIS)
annual launcher inspection (ALI) network
shift network
simulation control statements - ending

The last section lists the significant output generated by the CSRL model. The model generates three output files: "csrl.out", "csrlall", and "csrlavg". The "csrl.out" file is a SLAM generated output file which contains the following:

1. statistics for time-persistent variables
2. file statistics (queue and await files)
3. activity statistics
4. resource statistics
5. gate statistics (shift control gates)
6. table and/or plot of AVAIL vs TDW

Only the statistics for items 1, 4, and 6 are included in this appendix.
The "csrlall" and "csrlavg" files are output files generated by the FORTRAN code. The "csrlall" file contains the generation times for each launcher and the availability values taken randomly. This appendix only lists a sample of the output contained in this file. The "csrlavg" file contains the average generation time and average availability for the simulation run time.

To run the CSRL model on the VAX 11/730 computer at APL, the user must first create the two FORTRAN files "csrlall" and "csrlavg", and compile the FORTRAN model. The compile command is given below:

```
f77 -c csrl.f
```

The run command for the CSRL model is as follows:

```
slamlc -i csrl -m csrl.o -o csrl.out
```

where

- `csrl` is the SLAM input code,
- `csrl.o` is the compiled FORTRAN code,
- `csrl.out` is the output file the SLAM code writes to.

If the last option (-o csrl.out) is omitted from the run command, SLAM will write to a file called SLAMOUT.
### Contents of Output Files:

**CSRLAVG** - this contains the average availability and the average generation times

**CSRLALL** - this contains the generation times for each launcher, and the availability values taken randomly

---

```fortran
program main
  dimension nset(12000)
  common/scml/atrib(100),ddl(100),dtnow,li,mfs,mstop,ncldr
  ,ncrdr,nprnt,nrun,nset,ntape,ssl(100),ssl(100),tnext,tnow,xx(100)
  common qset(12000)
  equivalence(nset(1),qset(1))
  equivalence(simend,xx(3))
  nset=12000
  ncrd=5
  open(3,file="csrlavg",status="old")
  open(7,file="csrlall",status="old")
  nprnt=6
  ntape=7
  open(7,status="scratch")
call slam
  stop
end
```

---

```fortran
subroutine intlc
  dimension nset/atrib(100),ddl(100),ddl(100),dtnow,li,mfs,mstop,ncldr
  ,ncrdr,nprnt,nrun,nset,ntape,ssl(100),ssl(100),tnext,tnow,xx(100)
  common/scml/nogen,tnav,avgen
  common/ucomal/avcstr,tcavg,avavl
equivalence(simend,xx(10))
```

---

### Variables:

- `insp` = daily insp time
- `qtr` = qtrly insp time
- `schk` = availability check time
- `altchk` = alert time for scrlng
- `bytr` = time at beg of yr
- `xx` = time at beg of qtr
- `totgen` = sum of generation times
- `avgen` = average generation times
- `avavl` = average availability
real slend,oinsp,qlinsp,all,avchck,altchck
integer k,1
qlinsp=0.0
oinsp=0.0
qctr =0.0
bqctr=0.0
l=0
k=0
all=0.0
achck=0.0
avchck=0.0
altchck=0.0
totgen=0.0
noazn=0.0
avgen=0.0
avctr=0.0
totavi=0.0
avavl=0.0
*** assign launcher $i,$subsystem and missle failures for 16 launchers
***
  do 10 i =1,16
    atrib(l)=1
    do 20 j=6,13
      atrib(j)=tnow+expon(xx(13),1)
  20   continue
    do 25 j=14,20
      atrib(j)=tnow+expon(xx(j),1)
  25   continue
*** assign annual launcher inspection every 3 weeks***
  k=k+1
  atrib(2)=k*xx(7)
*** assign 5 launchers to alert aircraft that aren't due an annual
*** inspection for 90 days(file 3) - assign the rest to storage
*** (file 1)***
  if(1.1t.5.and.atrib(2).gt.2160.0) then
    atrib(4)=tnow-xx(7)+1
  endif
*** atrib(4) is the time the launcher went on alert***
  atrib(5)=3.0
  l=l+1
  call filem(3,atrib)
else
  atrib(5)=0.0
  call filem(2,atrib)
endif
  continue
****** on assigning atrib to launchers ******
******** schedule events ********
******** schedule to print averages ***
call schnd(7,slend,atrib)
*** schedule first on during second quarter ***
oinsp=unfra(2160.0,4320.0),0)
*** schedule subsequent inspections 10-15 months apart ***
30 if(oinsp.le.simen) then
    oinsp=oinsp+unfrm(7320.0,10980.0,5)
call schdl(4,oinsp,trib)
go to 30
endif

*** schedule quarterly inspection ***
40 if(qinsp.le.simen) then
    qinsp=bqctr+unfrm(0.0,2160.0,5)
evting=100.0
    call chksch(qinsp,evting)
call schdl(5,qinsp,trib)
qctr=qctr+1.0
ogqtr=qctr*2160.0
30 to 40
endif

*** schedule annual launcher inspection ***
50 if(all.1e.simen) then
    k=k+1
    if (k.gt.100) then
        print*,"more than 100 inspections scheduled"
go to 60
    endif
    all=k*xx(7)
evting=20.0
    call chksch(all,evting)
call schdl(6,all,trib)
go to 50
endif

*** schedule check and exchange of alert launcher weekly (153 hrs) ***
launched exchanged after 90 days or if failure has occurred ***
60 if(altnch.1e.simen) then
    altnch=altnch+163.0
    call schdl(3,altnch,trib)
go to 65
endif

*** schedule random availability checks ***
70 if(avcnk.1e.simen) then
    avcnk=avcnk+unfrm(0.0,1300.0,5)
call schdl(1,avcnk,trib)
go to 75
endif

*** This section will print the event calendar by deleting "*" in col 1. ***
ext=next(ncntr)
80 if(next.eq.).0) go to 90
* call copy(*next,1,trib)
* print*, 'event code = ', attrib(xx(25)+1)
* print*, 'event time = ' ,attrib(xx(25)+2)
* next = sucrt(next)
* go to 80
* continue

**** set up output file ****
* write(unit=9,fmt='100)
 100 format(1x,1x,"T4OW",3x,"AVAIL",3x,"OBS",2x,"TOTAL",3x,"TONW", + 3x,"GEN",1x,"SENTIM",lx,"OBS","TOTAL")
* write(unit=9,fmt='110') xx(39),xx(40)
110 format(1x,2x,2f5.4)
return
end

******************************************************************************
* event
******************************************************************************
* subroutine event(1)
  common/scoral/*trib(100),dd(100),dmi(100),dtow,li,sta,stop,xclnr, l,ncrdn,aprt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
  equivalence(simend,xx(3))
  go to (1,2,3,4,5,6,7,3),1
  1 call avail
  return
  2 call genrpt
  return
  3 call exchg
  return
  4 call origan
  return
  5 call qtrgen
  return
  6 call aninsp
  return
  7 call avgrpt
  return
  8 call c,mis
  return
end

******************************************************************************
* (event 1)
******************************************************************************
* This subroutine checks the status of the launchers in storage (file 2)
* and onalert(file 3) to see if any have failed; it calculates the percent available.
* subroutine avail
  common/scoral/*trib(100),dd(100),dmi(100),dtow,li,sta,stop,xclnr, l,ncrdn,aprt,nnrun,nnset,ntape,ss(100),ssl(100),tnext,tnow,xx(100)
  common/wcom2/avtr,totavl,avavl

33
equivalence(simend,xx(3))
if (tnow.le.720.0.or.xx(12).gt.0.0) go to 50

****** Determine availability of launchers in storage ******
1
next = mmfe(2)
xx(1) = 0.0
10 if (next .eq. 0.0) go to 20

****** have accessed last entry - search ends
      call copy(-next,2,attrib)
do 12 i=14,20
       if (attrib(i).lt.tnow) go to 17
*        if component has failed its not avail, check next launcher
12 continue
*        no failures for this launcher - increment # avail
      xx(1) = xx(1) + 1.0
17 next = nscnr(next)
go to 10
20 continue
*      determine avail of launchers on ALT
next = mmfe(3)
30 if (next .eq. 0.0) go to 40

****** have accessed last entry - search ends
      call copy(-next,3,attrib)
do 32 i=14,20
       if (attrib(i).lt.tnow) go to 37
32 continue
xx(1) = xx(1) + 1.0
37 next = nscnr(next)
go to 30
40 continue
*      compute % avail
      xx(2) = xx(1)/16.0
*      update average avail
      avc$t=avc$t+1.0
      totavl=totavl+xx(2)
      avavl=totavl/avc$t
      write(unit=9,fmt=200) tnow,xx(2),avc$t,totavl
200 format(1x,f5.0,2x,f5.3,2x,f3.0,2x,f7.3)
50 continue
return

****************************************************************
******  GENDRT (event 2) ******
****************************************************************
*       This subroutine calculates the time it took to generate each
*       aircraft and computes the average time to generate 10 aircraft.
****************************************************************
subroutine gendnt
      common/score,attrib(100),dd(100),ddi(100),dtnow,ii,afi,ntop,nclmr
      ncrd,ncat,nacun,nsat,ntape,ss(100),ssl(100),txxt,tnow,xx(100)
      common/ucore/nagen,tugen,avgen
equivalence(simend,xx(3))
      if (attrib(3) .eq. 1.0) then
         ****************************************************************
         ****
         return
         ************************************************************************
         55
If (attrib(3).eq.2.0) then

******** QUARTERLY GENERATION

gentime=tnow-xx(21)
endif

if(xx(3).gt.10.0) then

* update average gentime
nogen=nogen+1.
totgen=totgen+gentime
sgen=totgen/nogen

endif

write(unit=9,fmt=300)attrib(1),tnow,xx(3),gentime,nogen,
+ totgen
300 format(1x,27x,f3.0,1x,f6.0,2x,f3.0,1x,f5.1,2x,13,1x,f6.1)
return
end

*******************************************************************************
* EXCHG (event 3)  *
*******************************************************************************
* This subroutine checks to see how long an aircraft has been on alert; if more than 90 days, it goes to storage and NEWALT is called. If less than 90 days, it is checked for failures. All the launchers are checked for pdu failures. *
*******************************************************************************

subroutine exchgd

common/scom/atrib(100),d(100),dd(100),dtow,ii,mfa,mstop,nclr
l,ncdr,ncrp,nrun,nset,ntsps,ss(100),tss(100),tnext,tnow,xx(100)

equivalence(simend,xx(3))

if (xx(12).ge.1.0) go to 30

* when G&N is in progress EXCHG is not performed

call pduchk

* check for pdu failures

nochgd=0

* check alt time for alt a/c & check all alt a/c for failures

next=mafe(3)

if (next.eq.0) go to 15

call snova(~next,3),attrib

atitme=tnow-attrib(4)

if (atitme.ge.2015.0) then

attrib(5)=1.0

nochgd=nochgd+1.0

call fille(13,attrib)

else

attrib

endif

go to 30

call fille(13,attrib)

endif

10 continue

if (nnochgd.le.1) go to 30

15 nl=1,nnochgd

* replace every a/c coming off alt with a new one

call newalt

20 continue

30 continue
return
end

* Subroutine finds a launcher which is not due an annual inspection in the next 90 days and removes it from storage (file 2) and places it on alert (file 3).

subroutine newalt
common/scoml/attrib(100),dd(100),dnl(100),dtmpl ii,na,stop,ncint
l,nrdr,nrnt,nnset,ntape,ss(100),ss(100),twait,ttmpl,xx(100)
equivalence(smlnd,xx(3))
!
* check storage for new alert 1/c
next=nafe(2)
10 continue
call copy(next,2,attrib)
if (attrib(2).gt.ttmpl+2160.0) then
  call remove(next,2,attrib)
  ! found launcher not due ALL in 90 days for ALT duty
  attrib(4)=ttmpl
  attrib(5)=3.0
  call filea(3,attrib)
  go to 20
endif
! = i+1.0
if (i.gt.16) go to 20
! error check - at most should check 16 launchers
next=nsuec(next)
go to 10
20 continue
return
end

* PDUCHK

* Subroutine checks for pdu failures by removing the launcher from storage (file 2) and putting it in the network (file 14).

subroutine pduchk
common/scoml/attrib(100),dd(100),dnl(100),dtmpl ii,na,stop,ncint
l,nrdr,nrnt,nnset,ntape,ss(100),ss(100),twait,ttmpl,xx(100)
equivalence(smlnd,xx(4))
!
* checks launchers in storage for pdu failure
3 next=nafe(2)
10 if (next.eq.0) go to 30
  call copy(next,2,attrib)
  if (attrib(16).gt.ttmpl) then
    next=nsuec(next)
    go to 10
  else
    !
failure detected - send to REP
   call rmove(-next, 2, atri)
   atri(3)=1.0
   atri(5)=5.0
   call filem(5, atri)
continue
   xx(3)=0.0
   go to 50
40 print*, "******no launchers in storage when orl called", tnow
50 continue
return
end

****************************************************************************************************
* qtrgen (event 5) *
****************************************************************************************************

This subroutine starts the generation by placing the launcher in file 5.
****************************************************************************************************

subroutine qtrgen
common/scall/atri(100), dd(100), dtnow, li, mfa, astop, aclr
, ncrd, nprint, nrunt, nsset, natape, ss(100), ssl(100), tnext, tnow, xx(100)
equivalence (xx, send, xx(3))
xx(12)=1.0
xx(21)=tnow
xx(3)=0.0
k=nit(2)
if (k.eq.0) go to 40
do 20 i=1,k
   call rmove(1,2,atri)
   atri(3)=2.0
   atri(5)=5.0
   call filem(5,atri)
20 continue
   xx(21)=tnow
   xx(3)=0.0
   go to 50
40 print*, "******no launchers in storage for qtrgen"***
50 continue
return
end

****************************************************************************************************
* ANINS2 (event 6) *
****************************************************************************************************

This subroutine finds the launcher which is due an inspection and puts it in the inspection part of the network(file 4).
****************************************************************************************************

subroutine aninsp
common/scall/atri(100), dd(100), dtnow, li, mfa, astop, aclr
, ncrd, nprint, nrunt, nsset, natape, ss(100), ssl(100), tnext, tnow, xx(100)
equivalence (xx, send, xx(3))
if (xx(12).ge.1.0) go to 50
* when GEN is in progress, ANINS is not performed
* find the launcher due an annual inspection and send it to aninsp
  nrank=nfind(1,2,2,0,tnow,5.0)
* searches for ALL time = tnow + j
  if(nrank.eq.0.0) go to 40
  go to 43
  nrank=nfind(1,2,2,-2,tnow,5.0)
* searches for ALL time < tnow
  if(nrank.eq.0.0) go to 45
* sending launcher with attrib(2) = tnow to be inspected
  call raove(nrank,2,attrib)
* remove from storage; assign next insp time based insp policy
  attrib(2)=attrib(2)+(16*xx(7))
  attrib(5)=4.0
  do 44 i=1,13
       if(attrib(i).lt.tnow) attrib(i)=tnow+exp(x(13),1)
* missile has failed & was detected & repaired during all
* assign next failure
  44 continue
  call filae(4,attrib)
* send to ALI
  go to 50
  45 print*, "****no launcher in stg with aninsp =",tnow
  50 continue
  return
end

******************************************************************************
* AVGPRS (event 7)                                                          *
******************************************************************************
* This subroutine prints the averages for generation time and                *
* availability. It also prints a counter for run 3 and a code.               *
******************************************************************************
subroutine avgprt
  common/scaal/attrib(100),dd(100),ddl(100),tnow,li,mf,ms,ncrn,ncrd,npr
  nrun,nnset,nset,ttape,ss(100),ssl(100),tnext,tnow,xx(100)
  common/ucn/on/gen,totgen,avggen
c=attrib(130)
dd=attrib(131)
dd=dv(xx(13))
  c=crr.+3.
  write(unit=3,fmt=200)
  200 format(1x,"# OBS",1x,"RND CODE",1x,"AVGGEN",1x,"AVGAVL")
  write(unit=3,fmt=300)cxx(33),xx(43),avggen,avavl
  300 format(2x,4.3,1x,2f5.4,1x,f5.2,1x,f5.4)
  return
end

******************************************************************************
* CKMIS (event 9)                                                            *
******************************************************************************
* This subroutine checks for missile failures and counts how               *
* many need repair.                                                         *
******************************************************************************
subroutine ckmis
  common/scaal/attrib(100),dd(100),ddl(100),tnow,li,mf,ms,astp,ncrn,ncrd
  npr,nrun,nnset,ttape,ss(100),ssl(100),tnext,tnow,xx(100)
equiv
ene(lc( end, x( ))
  do 10 i=6,13

*** count # of missile failures & reassign failure time
  if(atrib(1).lt. tnow) then
    attrib(22)=attrib(22)+1.0
    attrib(1)=tnow+expn(x(13),1)
  endif
  10 continue
  return
end

**********************************************************************
   CHKSCH
**********************************************************************

  This subroutine checks the event calendar for schedule conflicts.
  Events are rescheduled based on a conservative estimate for the
  longest generation time. Events are scheduled so that nothing else
  occurs during a GEN exercise.
  
  subroutine chksch(time,avtlng)
  common/scal/attrib(100),dll(100),dtlow,ll,nsf,nstop,nclr
  l,nccdr,prnt,nnun,nsset,ntaps,ss(100),ssl(100),tnext,tnow,x(100)

equivalence(simend,x(3))
  next=nnsccr(nclr)
  10 if(next.eq.0) go to 20
     call copy(-next,nclr,attrib)
  **** if evt code is .le. 0 then it is a system defined code so
  **** we want to ignore it for schdl conflicts
  if(atrib(x25)+1).le.0.0) go to 13
     evttm=attrib(x25)+2
  if((evttm,le.time,evtlng).and.(time+avtlng,le.evttm+50.)) then
    time=evttm+51.0
  endif
  15 if((evttm,le.time).and.(time,le.evttm+50.)) then
    time=evttm+51.0
  endif
  13 next=nnsccr(next)
     go to 10
  20 continue
     return
  end

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Variables xx(8) & xx(25) must be initialized in intlc stat before running the CSRL SLAM model. xx(3) = simulation end time; must be set to the value declared in the LIMITS stat (this is used to schedule events for the entire simulation time). xx(25) = MAX which is the second value declared on the LIMITS card.

```plaintext

gen,gjersdal and oyler,csrl,10/06/84,1,yes,no,yes,no,yes,72;
limits,21,23,300;
intlc,xx(1)=0.0,xx(2)=0.0,xx(3)=0.0,xx(4)=0.0,xx(5)=0.0,;
intlc,xx(5)=2.0,xx(7)=504.0,xx(8)=20000.0,;
x(12)=0.0,xx(13)=11300.0;
intlc,xx(14)=120232.0,xx(15)=230390.0,xx(16)=10674.0,;
x(17)=43015.0,xx(19)=83744.0,xx(19)=41971.0,xx(20)=23034.0;
intlc,xx(25)=23.0;
record,tnow,tnow,0,6,640.0,720.0,,yes;
var,xx(2),a,availability,0,1;
tlimst,xx(1),launchers avail;
tlimst,xx(2),availability;
tlimst,xx(3),avail in gen;
tlimst,xx(3),time completed;
network;

Variables:
xx(1) launchers available (in storage & on alert aircraft)
xx(2) % of launchers available
xx(3) # of launchers available at end of generation
xx(4) tnow, used to calculate end of generation
xx(5) time to complete generation exercise
xx(5) maintenance policy (1= flt line remove & replace,
2= no flt line repair)
xx(7) time between annual launcher inspections
xx(8) simulation end time, used for scheduling = simend
xx(12) flag for generation exercises
0.0 = no generation exercises in progress
1.0 = generation exercise is in progress
xx(13) missile mean failure rate = 11300.0, used for attrb(6-13)
est. from AFOSR
xx(14) to xx(20) mean failure rates - Boeing estimates
xx(14) structure mean = 123232.0
xx(15) power drive unit = 23090.0
xx(16) power drive unit controller = 10674.0
xx(17) missile interface unit = 43016.0
xx(18) relay assembly = 83744.0
xx(19) other electronic/electrical = 41971.0
xx(20) electronic control system = 23034.0
xx(21) quarterly inspection time
xx(22) art inspection time
xx(23) time ests is available for use
xx(24) time ests is unavailable for use = 24.0 - xx(23)
xx(25) trust

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```
Attributes:

(1) launcher number
(2) time of launcher yearly inspection on ESIS
   (a launcher is inspected approx every 3 wks = 504 hrs)
(3) is a code for type of generation
(4) is the time an launcher went on alert
(5) is the file a launcher should be returned to after repair
   0.0 = stg queue  4.0 = in repair
   3.0 = alt queue  5.0 = done (in gen network)
(6) time of failure for missile 1
(7) time of failure for missile 2
(8) time of failure for missile 3
(9) time of failure for missile 4
(10) time of failure for missile 5
(11) time of failure for missile 6
(12) time of failure for missile 7
(13) time of failure for missile 8
(14) time of structure failure
(15) time of power drive unit failure
(16) time of PDU controller failure
(17) time of missile interface unit failure
(18) time of relay assembly failure
(19) time of other electrical/electronic failure
(20) time of environmental control system failure
(21) # of failures found at one time
(22) # of non-working missiles during generation
(23) # of failed missiles left unexchanged during generation

Files:
1 - waiting for alt for missile exching
2 - in storage queue until scheduled to go elsewhere
3 - sent from storage to alert (alt)
4 - sent from storage to annual inspection (alt)
5 - sent from storage to generation exercise
6 - waiting for alt for electronic repair
7 - shift clock date
8 - crew
9 - ets
10 - waiting for ets
11 - waiting for alt
12 - waiting for alt
13 - waiting for alt for structure repair
14 - pdu queue
15 - waiting for ets (dummy after generation exercise)
16 - waiting for ets
17- waiting for ests
19- repair queue
17- waiting for alt for ecs repair
20- waiting for alt for mla repair
21- waiting for alt for relay assembly repair

Random Number Streams:
1 - failures
2 - repair times
3 - load times
4 - transport
5 - availability clock
6 - inspections
7 - asts shift clock

Events:
1 - availability check
2 - generation report
3 - exchange alert launcher
4 - ori exercise
5 - ori exercise
6 - annual launcher inspection
7 - average geatim & avg avail

resoure/crew(4,3);
resource/mlt(9),21,20,1,19,13,12,11,10,6;
resource/ests(1),15,17,16,9;
gats/shft,open,7;

Storage Network - The launchers are stored here until scheduled
for a generation exercise, an annual inspection, or until they
are needed on alert.

stg queue(2);

Alert Network - 5 launchers remain on alert. Every week they
are checked (evt3) for repairs and for length of time on alert.

alt queue(3);

Repair Network
The repair network identifies the type of failure and whether it can
be repaired on the flight line. If so, the launcher is repaired or a
single missile is exchanged, the launcher is uploaded, and returns to
the point where the Systems Interface Test is performed (31). If not,
it must be returned to the IMF and repaired.

crk queue(13);
act;
goon,1;
act/1,,atrib(14).lt.tnow,rep1;
act/2,,atrib(15).lt.tnow,rep2;
act/3,,atrib(17).lt.tnow,rep4;
act/4,,atrib(18).lt.tnow,rep5;
act/5,,atrib(19).lt.tnow,rep6;
act/6,,atrib(20).lt.tnow,rep7;
act;
ckn event,3; determines # of missile failures
          goon,1;
act/7,,atrib(22).gt.0.0,go mis; there are failed missiles
act;
pdu queue(14); checked once a week
act/8;
go on,1;
act/9,,attrib(16).lt.tnow,rep3;
act,,,ok;
ok go on,1;
act/10,,attrib(5).eq.3.,alt;
act/11,,attrib(5).eq.5.0,done;
act/12,,attrib(5).eq.0.,stg;
repl go on,1;
await(13),alt,1;
act/13,unfrn(1.25,1.5,4); Transport time back to IMF.
go on;
act/14,triag(6.0,9.0,10.0,2); download and upload missiles
go on;
asm act/15,triag(1.9,2.4,2.9,2); structure repair, D056 data
assign,attrib(14)=tnow+expon(xx(14),1),attrib(21)=attrib(21)+1.0;
free,alt/1,1;
act,,,chk;
rep2 assign,attrib(15)=tnow+expon(xx(15),1),attrib(21)=attrib(21)+1.0;
go on;
act/16,triag(3.5,4.5,6.0,2),chk; repair
rep3 assign,attrib(16)=tnow+expon(xx(16),1);
go on;
act/17,triag(3.5,4.5,6.0,2),attrib(5).eq.0.0,stg; repair
act/18,triag(3.5,4.5,6.0,2),chk; repair
rep4 assign,attrib(17)=tnow+expon(xx(17),1),attrib(21)=attrib(21)+1.0;
go on;
act/19,xx(6).ge.2.0,rp4a;
act/20,triag(3.0,6.0,9.0,2); remove and replace missiles for access
go on;
act/21,triag(1.0,1.5,2.0,2),chk; r/c MIU, wag
rp4a await(20),alt,1;
act/22,unfrn(1.25,1.5,4);
go on;
act/23,triag(3.0,6.0,9.0,2);
go on;
act/24,triag(1.0,1.5,2.0,2); r/c relay assblr, wag
free,alt/1,1;
act,,,chk;
rep5 assign,attrib(14)=tnow+expon(xx(13),1),attrib(21)=attrib(21)+1.0;
go on,1;
act/25,xx(5).ge.2.0,rp5a;
act/26,triag(3.0,6.0,9.0,2); remove and replace missiles for access
go on;
act/27,triag(1.5,2.0,3.0,2),chk; remove and replace relay ass.
rp5a await(21),alt,1;
act/28,unfrn(1.25,1.5,4);
go on;
act/29,triag(3.0,6.0,9.0,2);
go on;
free,act/30,triag(1.5,2.0,3.0,2);
This network exchanges a failed missile on the flight line.

gmis goon,1;
act/37,xx(3).ge.4.0,lvms;
act/38,xx(6).eq.1.3,gmsl;
act/39,xx(5).eq.2.0,gms2;
gmsl goon;
act/40,triag(xx(33),xx(34),xx(35),3); time to exchange 1 missile
assign,atrib(22)=atrib(22)-1.0,1;
act/41,atrib(22).gt.0.0,lvms;
act,,chk;
lvms assign,atrib(23)=atrib(23)+1.0,atrib(22)=atrib(22)-1.0,1;
act/43,atrib(22).gt.0.0,lvms;
act,,chk;
gms2 await(1),mlt,1;
act/44,unfrn(1.25,1.5,4); transporting to/from to IMF
.gz goon;
act/45,triag(2.5,3.3,3.5,3); exchange 1 asl, est from SAC base
assign,atrib(22)=atrib(22)-1.0,1;
act/46,atrib(22).gt.0.0,g3;
act;
free,mlt/l,l;
act,,chk;

Generation network

This group of networks is used to estimate the time to generate
all 15 aircraft (representing the 311 and the quarterly readiness
inspections.

gen queue(5);
act(l)/47,triag(1.0,2.0,4.0,4); waiting for B-52.
aw3 await(3),crew/l;
aw10  await(10), alt/1;
  act/43, triag(.75,1.0,1.25,3); estimate from SAC base
  
g20  goon,2;
  act/49, , aw11;
  act/50, unfrn(1.25,1.5,4); delay for alt, estimate from SAC base
  
fl1  free, alt/1,1;
  term;
  
aw11  await(11), alt/1;
  act/51, triag(1.0,1.25,1.5,3); pylon
  goon,2;
  act/52, , aw12;
  act/53, unfrn(1.25,1.5,4); delay for alt, estimate from SAC base
  
fm2  free, alt/1,1;
  term;
  
aw12  await(12), alt/1;
  act/54, triag(1.0,1.25,1.5,3); estimate from SAC base
  goon,2;
  act/55, , g21;
  act/56, unfrn(1.25,1.5,4); delay for alt, est. from SAC base
  
fl3  free, alt/1,1;
  term;
  
g21  goon;
  act/57, 1.5,, chk;
  
S1F ; At this point an aircraft is finished and the number available
; (xx(3)) can be incremented, the time to generate is computed in
; event2.
  done goon;
  act/58, triag(.75,1.0,1.5,3); postload, est. from SAC base
  
flc1  free, crew/1,1;
  asl0  assign, xx(3)=xx(3)+1.0, xx(4)=tnow;
  goon,1;
  act/59, xx(21).gt.xx(22), asl3;
  act/60, xx(22).gt.xx(21);
  asl4  assign, xx(5)=xx(4)-xx(21);
  act/61, , event2;
  asl5  assign, xx(5)=xx(4)-xx(22);
  event2  event, 2;
  goon;
  act/32, , post3;

; post generation
;
  pstg  goon;
  act/53;
  assign, attrb(5)=0., attrb(21)=0., attrb(22)=0., attrb(23)=0.;
  goon,2;
  act/54, , pstg;
  act/55, xx(3).le.10, tra;
  act/56, xx(3).gt.10;
  asl0  assign, xx(12)=0.0; generation exercise is over
  await(15), ests/1,1; delay other work
  act/67, 34.0;
  fl1  free, ests/1,1;
  tran term;
annual Launcher inspection

queue(4);
act/68,,aw7;
free,ests/1,1;
aw7 wait(7),shift,1;
wait(3),ests/1,1;
wait for ests
act/69,,nagat(shift).eq.1.0,fe2;
act/70,,nagat(shift).eq.0.0;
act/71,triag(.75,1.0,1.25,6);
upload to ests
act/72,triag(6.0,8.0,10.0,6);
Download missiles
act/73,triag(12.0,12.5,13.3,6);
empty test
free,ests/1,1;
wait(7),shift,1;
wait(15),ests/1,1;
wait for ests
act/74,,nagat(shift).eq.1.0,fa3;
act/75,,nagat(shift).eq.0.0;
get goon,1;
act/76,triag(1.9,2.4,3.4,2),atrib(14).lt.tnow,asa1;
act/77,triag(3.5,4.5,5.0,2),atrib(15).lt.tnow,asa2;
act/78,triag(3.5,4.5,5.0,2),atrib(16).lt.tnow,asa3;
act/79,triag(6.4,7.4,3.9,2),atrib(17).lt.tnow,asa4;
act/80,triag(5.2,5.2,7.7,2),atrib(18).lt.tnow,asa5;
act/81,triag(10.3,13.8,16.3,2),atrib(19).lt.tnow,asa6;
act/82,triag(3.5,4.5,6.0,2),atrib(20).lt.tnow,asa7;
act;
free,ests/1,1;
wait(7),shift,1;
wait(17),ests/1,1;
wait for ests
act/83,,nagat(shift).eq.1.0,fe4;
act/84,,nagat(shift).eq.0.0;
act/85,triag(6.0,3.0,10.0,6);
Upload and SST
act/86,triag(2.5,3.0,3.5,6);
Loaded test
act/87,triag(6.0,3.0,1.0,0);
Load warheads
act/88,triag(2.0,2.5,3.0,6);
Download from frame and postload insp.
free,ests/1,1;
act;
assign,trib(5)=0.0;
act/89,xx(12).eq.3.0,sta;
go to act/3, no rel in progress
act/90,xx(12).eq.1.0,gen;
gen exercise in progress, go to gen
asa1 assign,trib(14)=tnow+expox(xx(14),1),1;
act/91,,get;
asa2 assign,trib(15)=tnow+expox(xx(15),1),1;
act/91,,get;
asa3 assign,trib(13)=tnow+expox(xx(15),1),1;
act/91,,get;

53
assign, atriD(17) = tnow + expon(xx(17), 1), 1;
act/31, , get;
assign, atriD(13) = tnow + expon(xx(19), 1), 1;
act/91, , get;
assign, atriD(19) = tnow + expon(xx(19), 1), 1;
act/91, , get;
assign, atriD(20) = tnow + expon(xx(20), 1), 1;
act/91, , get;

; snift network
;
create;
gt4 close, snft;
assign, xx(23) = unfrm(3.0, 10.0, 7), xx(24) = 24.0 - xx(23);
act/92, xx(24), xx(12).eq.0.0;
act/93, 0.0, xx(12).eq.1.0;
ogt4 open, snft;
act/94, xx(23), , gt4;

;end=work;
; simulation time for CSRL model = 20,001.0 hours = 333 days
; = 2.23 years
init, 0, 20001.0;
montr, clear, 729.0;
fin;
Figure 3.1. Repair Network (1 of 8)
Figure B.2. Repair Network (2 of 8)
Figure 4.3. Repair Network (3 of 5)
Figure B.4. Repair Network (4 of 8)
**Figure 3.9. Missle Exchange Network (1 of 2)**
Figure 5.12. Generation (GEN) Network (2 of 3)
Figure B.13. Generation (GEN) Network (3 of 3)
A SIMULATION MODEL OF THE COMMON STRATEGIC ROTARY LAUNCHER FOR AVAILABILITY(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB ON SCHOOL OF ENGI..

S J GJERSTAD ET AL. NOV 84
Figure 5.15. Annual Launcher Inspection (ALI) Network (1 of 3)
Figure 5.16. Annual Launcher Inspection (ALI) Network (2 of 3)
Figure 5.18. Shift (SHFT) Network
**This is from the C3RL.OUT file**

**slam summary report**

current time .2000e+05
statistical arrays cleared at time .7200e+03

**statistics for time-persistent variables**

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**resource statistics**

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**Plot of Availability vs Time**

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<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
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<td>Availability</td>
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**Scales of Plot:**
- **X-axis:** Time (hours)
- **Y-axis:** Availability

**Minimum:** \(0.7300 \times 10^9\)
**Maximum:** \(1.0000 \times 10^9\)
## Sample of the "CSRLALL" Output File

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## The "CSRLAVE" Output File

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Appendix C

Input Data

This appendix lists the input data and data sources used in the model. The data has been separated into three parts: MTBF rates for the seven launcher subsystems, activity duration, and decision structures. Table C.1 lists the MTBF rates, Table C.2 lists the types of activities and duration of the activities, and Table C.3 lists the conditions used for routing launchers through the network.

Table C.1

MTBF by Subsystem

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</tr>
<tr>
<td>PDU Controller</td>
<td>10,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Electrical/Electronic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missile Interface Unit (MIIU)</td>
<td>48,915</td>
<td>21,753</td>
</tr>
<tr>
<td>Relay Assembler</td>
<td>33,744</td>
<td>37,933</td>
</tr>
<tr>
<td>Other Electronic/Electrical</td>
<td>41,971</td>
<td>41,971</td>
</tr>
<tr>
<td>Environmental Control System</td>
<td>23,334</td>
<td>5,120</td>
</tr>
</tbody>
</table>
The activities table lists the events and the duration of the events that the launchers go through in the network. The data and data sources are displayed in Table C.2 by activity number in the order in which it occurs in the network. This table also lists the distribution used for the data, gives a code for the type of event that is being processed, and gives a brief description of the event. The codes used for the type of event are:

- G - generation exercise
- A - launcher inspection
- R - repair
- T - trailer activity

The following are the sources for the data used in the model:

1. D056 - repair times for the SRAM launcher from the AFLC database (1 Oct 33 - 31 Mar 34); used triangular distribution.
2. Boeing - estimates from Boeing Document No. 0405-10350-1, Reliability/Maintainability, Allocations, Assessment and Analysis Report - CSRL.
3. SAC - expert opinion from maintenance personnel familiar with the SRAM launcher; used triangular distribution with pessimistic, most likely and optimistic time estimates.
4. WAC - educated guess from maintenance personnel.
<table>
<thead>
<tr>
<th>Act/Code</th>
<th>Duration</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>13/22U</td>
<td>unfrn(1.25,1.5,4)</td>
<td>Transport time back to IMF</td>
<td>SAC</td>
</tr>
<tr>
<td>143</td>
<td>triag(6,9,3,10,0)</td>
<td>Download and upload missiles</td>
<td>SAC</td>
</tr>
<tr>
<td>15A</td>
<td>triag(1,9,2,4,2.9)</td>
<td>repair structure</td>
<td>D056</td>
</tr>
<tr>
<td>16A</td>
<td>triag(3,5,4,5,6.0)</td>
<td>repair of PDU</td>
<td>D056</td>
</tr>
<tr>
<td>17/13R</td>
<td>triag(3,5,4,5,6.0)</td>
<td>repair of PDU controller</td>
<td>D056</td>
</tr>
<tr>
<td>20/26R</td>
<td>triag(3,0,6,0,9.0)</td>
<td>r/c missiles for access</td>
<td>SAC</td>
</tr>
<tr>
<td>21A</td>
<td>triag(1,0,1,5,2.0)</td>
<td>r/c HIJ</td>
<td>WAG</td>
</tr>
<tr>
<td>23A</td>
<td>triag(3,0,5,0,9.0)</td>
<td>r/c missiles</td>
<td>SAC</td>
</tr>
<tr>
<td>24/27R</td>
<td>triag(1,0,1,5,2.0)</td>
<td>r/c relay assembler</td>
<td>WAG</td>
</tr>
<tr>
<td>28/31T</td>
<td>unfrn(1,25,1,5)</td>
<td>transport time back to IMF</td>
<td>SAC</td>
</tr>
<tr>
<td>29/32R</td>
<td>triag(3,0,5,0,9.0)</td>
<td>r/c missiles</td>
<td>SAC</td>
</tr>
<tr>
<td>30A</td>
<td>triag(1,5,2,0,3.0)</td>
<td>r/c relay assembler</td>
<td>WAG</td>
</tr>
<tr>
<td>33A</td>
<td>triag(10,8,13,3,15.3)</td>
<td>repair electrical</td>
<td>D056</td>
</tr>
<tr>
<td>34T</td>
<td>unfrn(1,25,1,5)</td>
<td>transport time back to IMF</td>
<td>SAC</td>
</tr>
<tr>
<td>35R</td>
<td>triag(3,0,6,0,9.0)</td>
<td>r/c missiles</td>
<td>SAC</td>
</tr>
<tr>
<td>36A</td>
<td>triag(3,5,4,5,6.0)</td>
<td>repair ECS</td>
<td>D056</td>
</tr>
<tr>
<td>40R</td>
<td>triag(2,0,2,5,3.5)</td>
<td>time to exchange 1 missile</td>
<td>SAC</td>
</tr>
<tr>
<td>44T</td>
<td>unfrn(1,25,1,5)</td>
<td>transport time to IMF</td>
<td>SAC</td>
</tr>
<tr>
<td>45R</td>
<td>triag(2,5,3,0,3.5)</td>
<td>exchg 1 missile</td>
<td>SAC</td>
</tr>
<tr>
<td>47G</td>
<td>triag(1,0,2,0,4.0)</td>
<td>waiting for B-52</td>
<td>SAC</td>
</tr>
<tr>
<td>49T</td>
<td>triag(.75,1,0,1,25)</td>
<td>upload launcher</td>
<td>SAC</td>
</tr>
<tr>
<td>50/53T</td>
<td>unfrn(1,25,1,5)</td>
<td>delay for MLT</td>
<td>SAC</td>
</tr>
<tr>
<td>51/54G</td>
<td>triag(1,0,1,25,1,5)</td>
<td>upload pylon</td>
<td>SAC</td>
</tr>
<tr>
<td>56T</td>
<td>unfrn(1,25,1,5)</td>
<td>delay for MLT</td>
<td>SAC</td>
</tr>
<tr>
<td>573 1.5</td>
<td>SIT test</td>
<td>AFOTEC</td>
<td></td>
</tr>
<tr>
<td>585 34.0</td>
<td>Dummy, delay other work in IMF</td>
<td>SAC</td>
<td></td>
</tr>
<tr>
<td>67G</td>
<td>triag(.75,1,0,1,5)</td>
<td>postload work</td>
<td>SAC</td>
</tr>
<tr>
<td>71A</td>
<td>triag(.75,1,0,1,25)</td>
<td>upload to ests</td>
<td>SAC</td>
</tr>
<tr>
<td>72A</td>
<td>triag(6,0,3,0,1,0)</td>
<td>download missiles</td>
<td>SAC</td>
</tr>
<tr>
<td>73A</td>
<td>triag(12,0,12,5,13.0)</td>
<td>empty test</td>
<td>Boeing</td>
</tr>
<tr>
<td>75A</td>
<td>triag(3,5,4,5,6.0)</td>
<td>repair structure</td>
<td>D056</td>
</tr>
<tr>
<td>77A</td>
<td>triag(3,5,4,5,6.0)</td>
<td>repair PDU controller</td>
<td>D056</td>
</tr>
<tr>
<td>78A</td>
<td>triag(6,4,7,4,3.9)</td>
<td>repair HIJ</td>
<td>D056</td>
</tr>
<tr>
<td>79A</td>
<td>triag(5,2,6,2,7.7)</td>
<td>repair relay assembler</td>
<td>D056</td>
</tr>
<tr>
<td>81A</td>
<td>triag(10,8,13,3,15.3)</td>
<td>repair other electronic/electrical</td>
<td>D056</td>
</tr>
<tr>
<td>82A</td>
<td>triag(3,5,4,5,6.0)</td>
<td>repair CCS</td>
<td>D056</td>
</tr>
<tr>
<td>85A</td>
<td>triag(6,0,3,0,1,0)</td>
<td>upload and SIT</td>
<td>SAC</td>
</tr>
<tr>
<td>86A</td>
<td>triag(2,5,3,0,1,5)</td>
<td>loaded test</td>
<td>Boeing</td>
</tr>
<tr>
<td>87A</td>
<td>triag(.0,3,0,1,0)</td>
<td>load warheads</td>
<td>SAC</td>
</tr>
<tr>
<td>88A</td>
<td>triag(2,0,2,5,3.0)</td>
<td>download &amp; postload inspection</td>
<td>SAC</td>
</tr>
<tr>
<td>91A</td>
<td>xx(24)</td>
<td>shift off or ests down</td>
<td>SAC</td>
</tr>
<tr>
<td>92G 0.3</td>
<td>xx(24)</td>
<td>no shift down time during 38H</td>
<td>SAC</td>
</tr>
<tr>
<td>94A</td>
<td>xx(23)</td>
<td>time shift and ests working</td>
<td>SAC</td>
</tr>
</tbody>
</table>
### Table C.3

#### Condition Table

<table>
<thead>
<tr>
<th>Act/Code</th>
<th>Condition</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1FG</td>
<td>attrb(14).lt.tnow</td>
<td>structure failure</td>
</tr>
<tr>
<td>2FG</td>
<td>attrb(15).lt.tnow</td>
<td>PDU controller failure</td>
</tr>
<tr>
<td>3FG</td>
<td>attrb(17).lt.tnow</td>
<td>MIU failure</td>
</tr>
<tr>
<td>4FG</td>
<td>attrb(18).lt.tnow</td>
<td>relay assembler failure</td>
</tr>
<tr>
<td>5FG</td>
<td>attrb(19).lt.tnow</td>
<td>electrical/electronic failure</td>
</tr>
<tr>
<td>6FG</td>
<td>attrb(20).lt.tnow</td>
<td>ECS failure</td>
</tr>
<tr>
<td>7FG</td>
<td>attrb(21).lt.tnow</td>
<td>missile failure(s)</td>
</tr>
<tr>
<td>8FG</td>
<td>attrb(22).lt.tnow</td>
<td>PDU failure</td>
</tr>
<tr>
<td>9FG</td>
<td>attrb(5).eq.3.0</td>
<td>return Launcher to ALT</td>
</tr>
<tr>
<td>10G</td>
<td>attrb(5).eq.5.0</td>
<td>return Launcher to 3EN</td>
</tr>
<tr>
<td>12S</td>
<td>attrb(5).eq.0.0</td>
<td>return Launcher to STG</td>
</tr>
<tr>
<td>19/25FG</td>
<td>xx(6).ge.2.0</td>
<td>r/r missiles in IMF</td>
</tr>
<tr>
<td>26FG</td>
<td>xx(6).lt.2.0</td>
<td>r/r missiles on flight line</td>
</tr>
<tr>
<td>37G</td>
<td>xx(3).ge.8.0</td>
<td>leave failed missile</td>
</tr>
<tr>
<td>38G</td>
<td>xx(6).eq.1.0</td>
<td>exchg misl on flight line</td>
</tr>
<tr>
<td>39G</td>
<td>xx(6).eq.2.0</td>
<td>exchg misl in IMF</td>
</tr>
<tr>
<td>41/43/46G</td>
<td>attrb(22).gt.0.0</td>
<td>loop to exchg all misl failures</td>
</tr>
<tr>
<td>59G</td>
<td>xx(21).gt.xx(22)</td>
<td>OLI in progress</td>
</tr>
<tr>
<td>60G</td>
<td>xx(22).gt.xx(21)</td>
<td>QLSR in progress</td>
</tr>
<tr>
<td>69G</td>
<td>xx(3).le.1.0</td>
<td>exercise still in progress</td>
</tr>
<tr>
<td>55G</td>
<td>xx(3).gt.1.0</td>
<td>exercise is over, tie up 55FS</td>
</tr>
<tr>
<td>69/74/33G</td>
<td>mngst(shift).eq.1.0</td>
<td>work shift closed, wait</td>
</tr>
<tr>
<td>77/75/34G</td>
<td>mngst(shift).eq.0.0</td>
<td>work shift swap continue work</td>
</tr>
<tr>
<td>76FG</td>
<td>attrb(14).lt.tnow</td>
<td>assign next structure failure</td>
</tr>
<tr>
<td>77FG</td>
<td>attrb(15).lt.tnow</td>
<td>assign next PDU failure</td>
</tr>
<tr>
<td>73FG</td>
<td>attrb(16).lt.tnow</td>
<td>assign next PDU controller failure</td>
</tr>
<tr>
<td>79FG</td>
<td>attrb(17).lt.tnow</td>
<td>assign next MIU failure</td>
</tr>
<tr>
<td>80FG</td>
<td>attrb(18).lt.tnow</td>
<td>assign next relay assembler failure</td>
</tr>
<tr>
<td>81FG</td>
<td>attrb(20).lt.tnow</td>
<td>assign electrical/electronic</td>
</tr>
<tr>
<td>82FG</td>
<td>attrb(21).lt.tnow</td>
<td>assign next ECS failure</td>
</tr>
<tr>
<td>99/92FG</td>
<td>xx(12).eq.0.0</td>
<td>no 3EN in progress, go to 3EN/normal shifts</td>
</tr>
<tr>
<td>90/93FG</td>
<td>xx(12).eq.1.0</td>
<td>3EN in progress, go to 3EN/24 hr shifts</td>
</tr>
</tbody>
</table>
Appendix D

Experimental Design

This Appendix contains the fractional factorial research design used in this research effort. The information was obtained from the National Bureau of Standard Applied Mathematics Series (13:22). The codes used for the one-fourth of a $2^3$ factorial design are given in the table below:

Table D.1
Factors Used in Factorial Design

<table>
<thead>
<tr>
<th>Factor</th>
<th>Code</th>
<th>Code Definition</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a</td>
<td>number of crew</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>b</td>
<td>number of MLTs</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>c</td>
<td>maintenance policy</td>
<td>3-level</td>
<td>2-level</td>
</tr>
<tr>
<td>4</td>
<td>d</td>
<td>inspection frequency</td>
<td>257 hrs</td>
<td>504 hrs</td>
</tr>
<tr>
<td>5</td>
<td>e</td>
<td>launcher load time$^\circ$</td>
<td>.75,1.0,1.25</td>
<td>1.0,1.5,2.0</td>
</tr>
<tr>
<td>6</td>
<td>f</td>
<td>remove/replace missile$^\circ$</td>
<td>2.0,2.5,3.5</td>
<td>2.5,3.0,4.0</td>
</tr>
<tr>
<td>7</td>
<td>g</td>
<td>remove/replace relay$^\circ$ assembler</td>
<td>1.0,1.5,2.0</td>
<td>1.5,2.0,3.0</td>
</tr>
<tr>
<td>8</td>
<td>h</td>
<td>failure rate</td>
<td>allocated</td>
<td>predicted</td>
</tr>
</tbody>
</table>

For example, ab means the high values are used for number of crews and number of MLTs, while holding all other factors at low values.

$^\circ$ The low, medium, and high values are given for the triangular distribution.
Table D.2
Fractional Factorial Design

The following combinations of factors were used in the analysis of the CSRL:

\[
\begin{align*}
(1) & \quad c_{ijgh} \quad abc \quad abdh \quad bdefh \quad bcdfg \quad acdefgh \quad aef \\
abcfg \quad abdf \quad fh \quad cdfg \quad acdeg \quad aeh \quad bde \quad bcgh \\
bcdeg \quad beh \quad ade \quad acegh \quad cefgh \quad df \quad abfn \quad abcfg \\
abcdh \quad acefg \quad bcdefg \quad bef \quad ab \quad abcgh \quad e\bar{g} \quad du \\
acdef \quad cd\bar{f} \quad abcefh \quad abdefg \quad bdg \quad bch \quad ncd \quad agn \\
abcdefh \quad bg \quad edfh \quad acdf \quad afg \quad bdfgh \quad bcf \\
bcdfh \quad bfg \quad ad\bar{f}gh \quad acf \quad ce \quad degh \quad abeg \quad abcdeh \\
abcd \quad bch \quad bdf \quad bgh \quad abefgh \quad abcd\bar{e} \quad cefh \quad defg
\end{align*}
\]
Appendix E

BMDP and SPSS Input/Output

This appendix lists the input data, input programs and relevant output for the two part statistical analysis. The order of presentation is given below:

1. SPSS Autocorrelation Analysis
2. BMDP Fractional Factorial Design
   a. ANOVA for Generation Time
   b. ANOVA for Availability
3. Regression Analysis
   a. Regression for Generation Time
   b. Regression for Availability
THIS IS THE SPSS INPUT PROGRAM, INPUT FILE AND OUTPUT USED TO CHECK
FOR AUTOCORRELATION AMONG THE AVAILABILITY OBSERVATIONS.

* VAR NAME AVAILABILITY
* VARIABLE LIST NOW,AVAIL
* INPUT FORMAT FIXED
* INPUT METHOD CASES
* N OF CASES 57
* REGRESSION /REGRESSION=(/VAR=NOW,AVAIL/
                        =AVAIL WITH NOW/RESIDUALS
* STATISTICS ALL
* OPTIONS 11.2
* READ INPUT DATA
* FINISH

THIS IS THE OUTPUT FOR AUTOCORRELATION WHEN THE OBSERVATIONS FOR
AVAILABILITY ARE TAKEN ON THE AVERAGE OF EVERY TWO WEEKS.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STANDARD DEV</th>
<th>CASES</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOW</td>
<td>10375.3333</td>
<td>9479.1153</td>
<td>57</td>
</tr>
<tr>
<td>AVAIL</td>
<td>911.4386</td>
<td>77.3060</td>
<td>57</td>
</tr>
</tbody>
</table>

NUMBER OF CASES PLOTTED 57.

VON NEUMANN RATIO 0.94383  DURBIN-WATSON TEST 0.93193

THIS IS THE OUTPUT WHEN OBSERVATIONS ARE TAKEN ON THE AVERAGE OF
EVERY FOUR WEEKS.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STANDARD DEV</th>
<th>CASES</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOW</td>
<td>10371.1379</td>
<td>5510.2433</td>
<td>29</td>
</tr>
<tr>
<td>AVAIL</td>
<td>916.2414</td>
<td>32.1034</td>
<td>29</td>
</tr>
</tbody>
</table>

NUMBER OF CASES PLOTTED 29.

VON NEUMANN RATIO 1.36252  DURBIN-WATSON TEST 1.60519
THIS IS THE INPUT DATA, EMOP INPUT PROGRAM AND OUTPUT TABLE FOR THE
FRACTIONAL FACTORIAL ANALYSIS.

| 1 01 | 0.0000 | 0.0000 | 44.79 | .7610 |
| 1 02 | 0.0011 | 0.0111 | 38.40 | .9139 |
| 1 03 | 0.0000 | 0.0101 | 37.59 | .9298 |
| 1 04 | 0.0011 | 0.1011 | 43.35 | .7231 |
| 1 05 | 0.0100 | 0.1111 | 39.47 | .9276 |
| 1 06 | 0.0011 | 0.1000 | 46.23 | .7456 |
| 1 07 | 0.0000 | 0.1111 | 37.19 | .9265 |
| 1 08 | .0011 | .0110 | 48.35 | .7231 |
| 1 09 | .0000 | .0101 | 37.59 | .9298 |
| 1 10 | .0011 | .1011 | 51.73 | .7359 |

INPUT FILE FOR GENERATION TIME

* /PROBLEM TITLE IS "THESIS". 
* /INPUT VARIABLES ARE 9. 
* FORMAT IS "(7X,4F1.0,1X,F5.2,6S)". 
* UNIT IS 1. 
* /VARIABLE NAMES ARE A,B,C,D,E,F,G,H. 
* /DESIGN FORM IS "3G,F". 
* INCLUDED ARE 1,2,3,4,5,6,7,8,12,13,14,15,16,17,19, 
* 23,24,25,26,27,28,31,35,36,37,38,45,46,47,48, 
* 56,57,58,67,68,73. 
* /END
### Analysis of Variance for 1-St Dependent Variable - Centim

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F</th>
<th>Prob.</th>
</tr>
</thead>
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<tr>
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<td>104042.17043</td>
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<td>104042.17043</td>
<td>59503.82</td>
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<td>373.65041</td>
<td>216.58</td>
<td>0.0000</td>
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<tr>
<td>B</td>
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<td>1</td>
<td>0.22039</td>
<td>.01</td>
<td>.9133</td>
</tr>
<tr>
<td>C</td>
<td>12.02975</td>
<td>1</td>
<td>12.02975</td>
<td>6.83</td>
<td>.0142</td>
</tr>
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<td>D</td>
<td>2.26900</td>
<td>1</td>
<td>2.26900</td>
<td>1.15</td>
<td>.6980</td>
</tr>
<tr>
<td>E</td>
<td>10.11313</td>
<td>1</td>
<td>10.11313</td>
<td>5.79</td>
<td>.0233</td>
</tr>
<tr>
<td>F</td>
<td>2.79629</td>
<td>1</td>
<td>2.79629</td>
<td>1.60</td>
<td>.2163</td>
</tr>
<tr>
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<td>1</td>
<td>5.47581</td>
<td>3.70</td>
<td>.0649</td>
</tr>
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<td>774.11732</td>
<td>442.77</td>
<td>0.0000</td>
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<tr>
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/DESIGN
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THIS IS THE SPSS REGRESSION INPUT FILE

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CSAL ANALYSIS

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INPUT MODIJA 
CARDS.

N OF CASES 
UNKNOWN

RECODE 
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COMPUTE 
MTBF=MTRF/MTRF

COMPUTE 
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COMPUTE 
CMXINSF=CREW+INSF

COMPUTE 
CMXMTBF=CREW+MTBF

COMPUTE 
LMTRF=LMTRF+LMTRF

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CMXMTBF,CMXINSF,CMXMTBF,CMXINSF,CMXMTBF

REGRESSION=CMXMTBF WITH CREW TO CMXMTBF/RESIDUALS

STATISTICS 
ALL

OUTPUT 
2,3,3,11,22

SCATTERGRAM 
AVAIL WITH LMTRF

REGRESSION 
VARIABLES=INSF,LMTRF,AVAIL/
REGRESSION=AVAIL WITH LMTRF,INSF/RESIDUALS

STATISTICS 
ALL

OUTPUT 
2,3,3,11,22

READ INPUT DATA
FINISH
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VARIABLE LIST: Y, THAT, RESIDUAL

INPUT FORMAT: FIXED(26X, 2F13.7, F15.7)

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SCATTERGRAM: RESIDUAL WITH Y AT

SCATTERGRAM: Y AT WITH RESIDUAL

READ INPUT DATA

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ADJ R SQUARE .7400 COEFF OF VARIABILITY 5.13%

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**AJ R SQUARE .9433 COEFF OF VARIABILITY 1.9PCT**

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Bibliography


AFOSEC/LG4A, Kirtland AFB '79, undated.


VITA

Captain Sarah J. Gjerstad was born on 22 January 1956 in Marquette, Michigan. She attended the University of Minnesota from which she received a Bachelor of Arts degree in Mathematics, in December 1979. She received a commission in the USAF through OTS in June 1981. Her first assignment was to the Aeronautical Systems Division at Wright-Patterson AFB, OH. She worked as an Operations Research Analyst in the Life Cycle Cost Management Division until being reassigned to the Air Force Institute of Technology, WPAFB, OH in May 1983.

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