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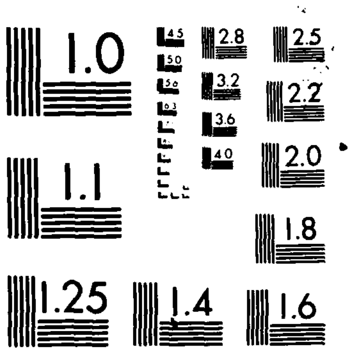

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LIMITATIONS TO EUROPEAN C-130 DEPLOYMENT

THESIS

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LIMITATIONS TO EUROPEAN C-130 DEPLOYMENT

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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Preface

The purpose of this study was to analyze the limitations to the rapid deployment of CONUS based C-130s (active duty and Air Reserve Forces) to Europe during a major NATO contingency. Of interest were delays caused by bottlenecks and resource constraints at enroute bases and less than optimal routings of the C-130 squadrons.

A simulation model was built to study the movement of the C-130 aircraft from CONUS departure bases through the North Atlantic route structure (competing with strategic airlift aircraft for necessary support activities at enroute bases) to beddown bases in Europe. Additionally, integer programming techniques were used to develop improved routing plans for the C-130 squadrons.

Results of the analysis do not indicate that resource limitations at enroute bases are a constraint to the rapid deployment to the C-130s. However closure time of the C-130s can be reduced with the use of optimized routing plans. Additionally, more rapid generation of the C-130s would appear to allow significantly reduced closure times.

Many people have contributed greatly to the success of our research. Major Skip Valusek, our faculty advisor, was very patient in his guidance and criticism of our work. Mr Tom Kowalsky and Maj Glenn Moses, from Hq MAC/XPS, cheerfully provided a great deal of much needed background information and data extracted from the M-14 simulation model.

Lastly, but not least in their efforts, Maj Brian Jones and Maj Bob Rhodes, from Hq MAC/XOS, enthusiastically provided the problem description and additional essential background information.

Lastly, neither of us could have completed this successfully without the understanding of our wives, who waited with "the patience of Job" on those many days when we paid much more attention to our work than to them.

Mark S. Donnelly

James E. Hill

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Abstract

While the strategic airlift flow during a major European conflict has been thoroughly analyzed in other AFIT theses and by HQ MAC, using the M-14 simulation, the interaction with deploying C-130 units has not been addressed. This project quantifies the competition for resources at such enroute facilities as Goose Bay and Lajes. The activities modeled include ramp space, refueling units, maintenance, and air traffic control restrictions.

The methodology was to build a simulation model using SLAM (Simulation Language for Alternative Modeling). The simulation was used to analyze the interactions and bottlenecks that occur as strategic airlift flow rates and C-130 deployment flow rates vary.

The objective was to provide MAC contingency planners with a tool to verify the feasibility of their deployment plans. The results of the analysis identify resource constraints and flow limitations in the European scenario. The methodology allows study of deployments to other theaters with some changes to the simulation.

LIMITATIONS TO EUROPEAN C-130 DEPLOYMENT

> The ability of the United States to successfully deter aggression, limit conflict, or wage war depends on our ability to rapidly deploy and sustain fighting units. Airlift provides the capability to deliver forces where they are needed in time to make a difference.
>
> Joint SECAF and CSAF Memorandum, 29 September 1983 (12:1)

I. Problem Formulation

Introduction

United States defense strategy hinges on the concepts of forward basing of U.S. troops throughout the world and the capability to rapidly reinforce, support, and sustain these forces (12:x). This policy is evident in U.S. support of NATO. The capability of permanently stationed forces in Europe falls far short of that which would be required to stop a Warsaw Pact offensive into NATO territory. This defensive shortfall is compensated for by the capability to rapidly mobilize and deploy forces overseas. U.S. reinforcement capability is provided not only by airlift, but also sealift, rail transport, and trucking. While the bulk of the load will be moved by surface transportation,

> ...in almost all instances the urgent early demands of a crisis must be met entirely by airlift. This airlift capability may mean the difference between victory and defeat... (12:II-1)

Deployment Forces. During the first few days of a NATO conflict, strategic airlifters (C-141, C-5, KC-10, and the Civil Reserve Airlift Fleet) will deploy personnel and equipment into the combat theater. This intertheater airlift is generally long-range, transoceanic in nature and is conducted into main operating bases well behind the front lines (12:II-7).

Additionally, Air Reserve and active duty forces will mobilize and deploy with C-130 aircraft to augment the two C-130 units permanently stationed in Europe (31:88). These intratheater, or tactical, airlifters must move deploying forces from the seaports and strategic airlift main operating bases that function as theater ports of entry to the forward operating locations near the front where the forces and equipment will be employed. Once in the combat theater, the intratheater airlifters normally fly relatively short missions that allow frequent returns to their in-theater beddown locations for maintenance and crew changes. The intratheater airlift units are essential to the deployment and resupply effort because they possess both the equipment and trained personnel necessary to operate into austere airfields, landing zones, and drop zones located near the front.

Deploying the Airlifters. In a major contingency, nearly 30 active duty and reserve C-130 units will deploy with over 400 aircraft to the combat theater (19). Each of these aircraft will require at least one refueling stop during its approximately 13 to 20 hour transatlantic crossing (30:2,4). Currently, C-130 units plan and train to deploy and employ in squadron units. Each squadron will carry all support assets necessary to operate upon arrival in the combat theater. A benefit of this deployment concept is that squadrons will be self supporting during their deployment, because they will be carrying their own maintenance personnel and equipment and limited spare parts (21:3).

Enroute stops on the Atlantic routes are normally scheduled for the two large Military Airlift Command stations at Goose Bay, Labrador, and Lajes Field, the Azores. Additional capability may be generated by transiting lesser used stations in Bermuda, Iceland, and Canada. The strategic airlift system between the U.S. and Europe has been studied, planned, simulated, and reviewed for feasibility of the intertheater deployment plans (14;16). However, the interaction between the tactical airlift deployment and the strategic airlift flow has not been analyzed. This interaction will entail competition for such airfield resources as parking space, refueling pits and trucks, and runway usage.

Specific Problem

During a major NATO contingency, both the strategic airlift flow and deploying C-130s must compete for limited resources at a small number of enroute stations. While the enroute support requirements for the intertheater airlift system are well understood and documented, the interaction with deploying C-130s remains unanswered (14;16). Therefore, the problem is to analyze the interactions between the intertheater airlift flow and the deploying C-130s as they transit enroute facilities along the transatlantic routes. This analysis should identify resource requirements and bottlenecks. Additionally, it should prove a methodology that will allow contingency planners to test the feasibility of their proposed or existing plans.

Research Question

Given the deployment of a specific number of CONUS active duty and Air Reserve Force C-130 aircraft (moving by unit) to Europe during a major contingency and given a massive ongoing strategic airlift to support US forces in Europe during the contingency, what are the tradeoffs between the support requirements for the strategic airlift and the deploying C-130s?

Research Objectives

To answer the research question, the following more specific questions were answered:

1. Given the flow of C-130 and strategic airlift aircraft through an enroute station, what is the limiting factor to the flow of aircraft: availabile ramp space for parking, available refueling crews and facilities, local air traffic control procedures, or some other airfield limitation?

2. What is the impact on the aircraft flow of probabilistic events such as maintenance breakdowns on the ground, variations in enroute flight times, and variations in refueling times?

Additionally, as a by-product of the research, the following questions were answered:

3. What are the total fuel requirements at each enroute station for the movement of the deploying C-130 aircraft?

4. How many refueling trucks will be required at each enroute station to support the transient aircraft?

Finally, the analysis produced a methodology and model to answer the following questions:

5. Is the specified deployment plan feasible, given the required strategic airlift flow?

6. Which of a group of given deployment plans provides the best overall system effectiveness?

Literature Review

In the past years, many researchers have used quantitative techniques to analyze problems similar to the problem of this proposal. Several analysts have used simulation to optimize the structure of airlift networks for specific scenarios. Bowers analyzed the intratheater airlift requirements for a scenario deploying an Army light infantry brigade to forward locations in western Alaska to counter Soviet incursions into Alaska. In his scenario, airlift also supported the increased logistics requirements of F-4 aircraft on alert at forward locations and ground control intercept (GCI) radio stations. A force of 18 C-130 aircraft provided the airlift. A relatively simple route structure was modeled (4).

The C-130 aircraft typically flew a round robin mission and, if the crew had a long enough remaining crew duty day, several other missions. The system was essentially closed, with inputs from outside the theater occuring only at Elmendorf AFB, the onload location. Airlift requirements included the movement of all personnel, equipment, and supplies of the Army forces (possibly 400 missions including multiple sorties); and fuel for the forward F-4 locations. Requirements were well known from contingency planning and periodic exercises (4).

Bowers modeled the scenario with a network of five bases, and computerized the simulation with SLAM (Simulation Language for Alternative Modeling) (4). He concluded

> ... that the simulation model tailored to the particular combination of conditions in Alaska can effectively be used to analyze Alaskan theater airlift system performance. Although the model does not include the detail of the system, general estimates of system capability and performance can still be obtained (4:114).

Bowers was able to determine the optimal crew ratio for the C-130 force to maximize the movement of personnel and equipment. He was also able to specify the factors that provided the most significant impact to the operation of the system; the number of aircraft, and the number of aircrews (4:115-116). The theater airlift network modeled in Bower's study is similar to that of many strategic networks. The methodology he used is therefore applicable to the analysis of strategic airlift route structures.

Holck and Ticknor use a simulation model to determine the

> ... factors within the military airlift system which produce significant changes in system capability as measured in tons of cargo delivered after 30 days of system operation. The airlift mission is set in a scenario which requires the reinforcement of Europe against a Warsaw Pact attack. This reinforcement is provided by C-141 and C-5 aircraft (16:viii).

Their study uses a very simple model to reduce the complexity of the analysis. Only two bases are used; a single "aggregate" base in Europe and a single aggregate base in the CONUS (16:17). No other operating locations within Europe or the CONUS are modeled. The only routes involved are the routes between the aggregrate bases. Because of the length of the legs, a crew can fly only one mission in a crew duty day (16:17). The measure of effectiveness is the utilization rate of the aircraft (16:76).

The simulation model was created using the SLAM simulation language and includes "... the four major subsystems within the airlift system; these subsystems are aircrew, maintenance, supply, and aerial port" (16:viii). Significant factors discovered for their scenario are the number of aircraft available and the time to zero War Readiness Material (WRM). The authors conclude that the model, though simple, does provide usable results (16:75-76). They also state

> In many cases, the value of a small, workable model that gives approximate results may be worth the loss of the detail contained in larger models (16:76).

Holck and Ticknor contend that simulation is an effective tool for the analysis of strategic airlift systems (16:75). The simplicity of their model detracts from the direct applicability of their results. However, their work does promise that a more detailed model should allow a determination of the tradeoffs between strategic airlift and the deployment of C-130s.

Cooke attempts to maximize the combat power deployed in a contingency using the Rapid Deployment Force (RDF). Goal programming is used "to maximize the combat power delivered, and to minimize the time it takes to deliver it" (7:7). The problem is formulated into a series of equations that reflect the goals of the study, requirements of the deployed forces, or constraints. Constraints on airlift are specified as numbers of aircraft available, maximum utilization rate of the aircraft, maximum size of the cargo that will fit in the cargo compartment, and maximum rates at which an aircraft can transit on offload location (7:73-74). He discovers several limiting factors for airlift affecting overall performance; the maximum utilization rate for the C-141, the ground time of the C-5 at the offload base, the size of the offload base, and the availability of cargo handling equipment at the offload base (7:130-131).

Cooke discovers valuable information about the limitations of airlift during the deployment of a large army force over intercontinental distances during a crisis. However, the goal programming methodology he uses does not furnish specific information about the limitations, constraints, or choke points of the route structure. In addition, the enroute structure is not modeled. Therefore, his goal programming analysis can not determine the tradeoffs necessary in a competition for resources at enroute bases.

Using a simulation model, Cuda examined the congestion of parking spaces at a transit base during conditions of sustained heavy activity. He discovered that the percentage of cargo diversion increases as arrival rate exceeds available parking. Also, the study showed significant amounts of diverted cargo for parking levels believed sufficient to accommodate the arrivals (10). He also discovered that parking congestion depended greatly on the length of ground time of the aircraft (10). The model used in Cuda's research proved to be of value in the development of the model of ground support activities at an enroute base.

MAC/XPS operates the M-14 model, a large simulation model of the strategic airlift system. This model includes the entire route structure, as well as a detailed examination of the ground operations at enroute bases. It identifies the capabilities and limitations of the strategic system. The movement of C-130 aircraft, however, has not been incorporated into the model. HQ MAC contingency planners and operations analysts have identified lack of knowledge about the interaction of strategic airlift with the deployment of C-130s as a significant limitation (19;25).

Methodology Overview

Theoretical Framework. A model of the MAC route structure over the North Atlantic Ocean to Europe was constructed. Several typical departure locations from the CONUS were included in the model, as well as applicable CONUS "jumping off" bases for the oceanic legs. Appropriate destinations in the European theater also were included.

The demands of strategic airlift were modeled by allowing arrivals of strategic airlift aircraft at appropriate bases at random intervals but at average rates expected from the flow during a major European contingency. The resources required by strategic airlift at the enroute bases were also included in the model. Crew and cargo management for the strategic airlift does not impact the

C-130 flow and was not included.

Required maintenance and service activities at enroute bases were modeled to determine the existence of any "choke points", any activities or conditions that would limit the flow rates of transient aircraft. Activities at the enroute bases that were examined include:

1. Ramp Space. Ramp space was allocated for each transient aircraft to determine if available ramp space is sufficient for the flow.

2. Fuel Supplies. Total fuel usage by deploying C-130s was modeled to identify additional station fuel required for their support.

3. Refueling trucks, and fuel pits were modeled to determine if the planned capability will refuel aircraft quickly enough to support the flow of aircraft.

4. Maintenance Breakdowns. C-130 system malfunctions were modeled stochastically, causing ground times to vary due to required maintenance. The effect of the longer ground times on the flow rate of aircraft was examined.

5. Crew Rest. Crew rest was included for missions with delays precluding mission completion within established maximum crew duty periods.

Four hundred C-130s flowed through the airlift network to determine if the system becomes saturated at any time.

Measures of Effectiveness. An effective deployment plan will allow the C-130s to complete their deployment to Europe (close) in the minimum amount of time (closure time). Ideally, closure will occur with minimal impact on the strategic airlift flow. Therefore, the primary measure of effectiveness is closure time of the C-130. In this study closure is defined as the time at which 95 percent of the C-130s have arrived at their beddown bases. The 95 percent figure was selected to reduce the variability generated by late arriving stragglers while assuring that an adequate force has arrived in the theater. Strategic airlift departure reliability is an additional measure of merit. The change in percentage of on-time strategic airlift departures indicates the effect of the C-130 deployment on the strategic airlift flow.

Solution Technique. A simulation of the North Atlantic route structure was conducted for the initial nine days of a conflict. C-130 flow rates were varied systematically in separate runs (low to high rates) to determine the tradeoffs between the C-130 deployment and strategic airlift flow. Last, the sensitivity of the flow to variations of the input parameters was determined.

Summary

The deployment of active duty Air Force and Air Reserve Force C-130s to Europe is an essential element in NATO's defense strategy. This deployment will transit some of the same stations that will be needed by the strategic airlifters as they transport critical personnel and equipment to the European theater. These aircraft; the C-141s, C-5s, KC-10s, and CRAF aircraft of the strategic airlift flow and the deploying C-130s, will compete for limited resources at the small number of enroute servicing locations available between CONUS and Europe.

This study develops a methodology to evaluate a specified C-130 deployment flow and its impact on stategic airlift. The results will allow contingency planners to validate their proposed deployment plans and investigate alternative courses of action.

II. System Development

Introduction

The combat commander must be able to anticipate when and where his reinforcing units will arrive in order to plan current and future operations. The goal of the airlift forces in a contingency is to transport fighting forces to their destinations no later than the time the combat commander has planned for these forces to be in place. The entire airlift network is dedicated to providing this responsiveness. The scenario selected to demonstrate the effects of C-130 deployment to Europe requires modeling the many aspects of a transatlantic enroute structure that impact the desired system responsiveness. In the hypothesized scenario increasing world tensions will allow some advance warning of the need to execute the contingency plan and the capability to preposition a small number of crews at enroute bases, but aircraft deployment does not begin until the specified execution time.

In order to model this airlift system, it may be broken down into two component parts. The first part is the overall enroute network of departure, enroute support, and destination airfields. The second component is the activity at each enroute station. Station operations include runway use, refueling, parking, maintenance, cargo handling, and aircrew planning and control. The two components, while described separately, interact because they are affected by fuel use (which affects ground time and depends on enroute time) and crew duty day (which depends on ground and flight time and affects both ground time and routing).

This chapter will expand both of these system components and describe how they were modeled. It will also give the sources for data used to build the model. Finally, it will explicitly state and support the assumptions made to simplify the model.

The Enroute System

The enroute system consists of three areas of interest: the departure bases, the enroute support bases, and the destinations. In this section each of these areas of interest will be described. Also, the problem of routing aircraft between these stations will be discussed.

Departure Bases. For the strategic airlift forces, the departure bases are the originating airfields for the combat or support element being airlifted. They may be carrying any cargo, from a tactical fighter squadron originating at Luke AFB, or an Army National Guard infantry company from Detroit, to a load of Navy torpedos or mines from a defense contractor in Dallas. The analyst can greatly simplify the enroute system by assuming that the strategic airlift flow may be modeled by having these aircraft operate only at the enroute bases, rather than throughout the system. This assumption is adequate for the purpose of studying the interaction at enroute stations, where the overall strategic airlift routing is unimportant. This simplification also allows the analyst to disregard the air refueling capabilities of many strategic airlift aircraft because the enroute station interarrival times account for all arrivals, air refueled or not. Therefore, in this study of interactions at enroute bases the origin of the strategic airlifters is not important; the only important strategic airlift characteristic is the interarrival time at enroute stations. For this reason the strategic airlift departure bases were not modeled.

For the deploying C-130 units the departure bases will be the home station of the deploying unit. These units are scattered across the US at many military and civilian airfields (1). While the time that a C-130 unit will begin its deployment is important, the station from which it departs is not. In order to demonstrate the methodology used to solve the deployment problem, the C-130s originate at three consolidated departure fields representing three areas of the country (Figure 1). This consolidated base assumption allows the sample routing selected by the analysts to be more generic, rather than resembling any specific contingency plan and reduces model fidelity only by the difference in flying time between a consolidated base and an actual base, one or two hours at most. To determine flight times from each of these consolidated bases, three regular Air Force C-130 home stations were selected. Flight

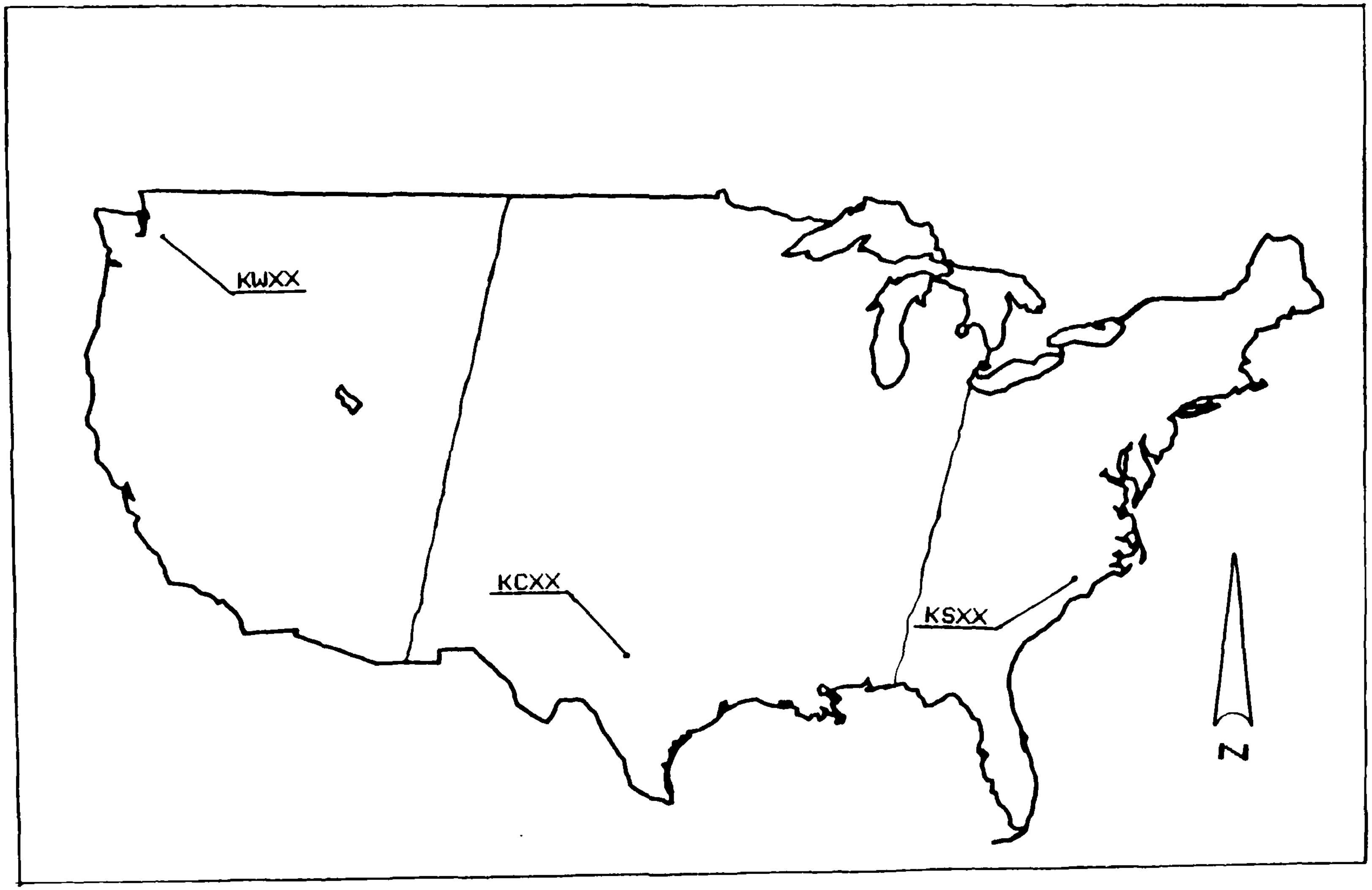

Figure 1. CONUS C-130 Departure Bases.

times from these three stations, McChord AFB, Dyess AFB, and Pope AFB (representing KWXX, KCXX, and KSXX, respectively), were extracted from Military Airlift Integrated Reporting System (MAIRS) historical data provided by HQ MAC, Directorate of Current Operations (3). While the aggregated departure station assumption is adequate to validate the methodology proposed in this analysis, greater fidelity may be obtained by using the flying time from the departure station actually specified in the contingency plan to be analyzed rather than using the time from the aggregated departure base.

US forces, upon receiving execution orders for an operation, have a specified amount of time in which to react. The reaction may involve such responses as: immediately launching an aircraft, mobilizing a squadron for departure within one day, or recalling members of a reserve unit to active duty. Whatever their response, each unit tasked by the order is expected to immediately begin preparations for executing their portion of the overall plan. At the C-130 departure bases each unit has a specified time at which they must launch their first aircraft and a latest time by which they must have launched their last. These times take into consideration such things as the component of the unit (regular or reserve), the maximum rate at which the base is able to generate launches, and the capacity of the enroute system. Each squadron's initial departure time and the time between departures within a squadron should have an impact on unit closure time.

Enroute System. The transatlantic enroute system consists of a small number of regular MAC airlift stops and several civil fields that could be used in a contingency. While MAC may build up support at some of the civil fields during a contingency, to demonstrate the C-130 deployment methodology only major MAC enroute support stations were modeled. The bases selected span both the North Atlantic routes and the Mid-Atlantic (Figure 2). The first base, KNEX, is a jumping off base in the northeastern CONUS. Units from western and central US bases may stop here for fuel before embarking on the long overwater legs. Resource and flying time data from Hanscom AFB were obtained for the KNEX model. The next northern base, CYXX, is along the Newfoundland coast and models the airfield at Goose Bay, Labrador. This area is excellent for enroute stops since a great circle routing brings northern and western CONUS departures near here. The final northern station, BIXX, models Keflavik NS, Iceland. This station would be used mainly for aircraft with shorter range (C-130A) and to relieve congestion at CYXX. Along the Mid-Atlantic route the enroute station, LPXX, models Lajes AB, the Azores. LPXX is an excellent enroute stop for aircraft originating in the southeast US or those destined for southern Europe. An additional station on the European mainland, LEXX, models the major MAC station at Torrejon AB, Spain. This base

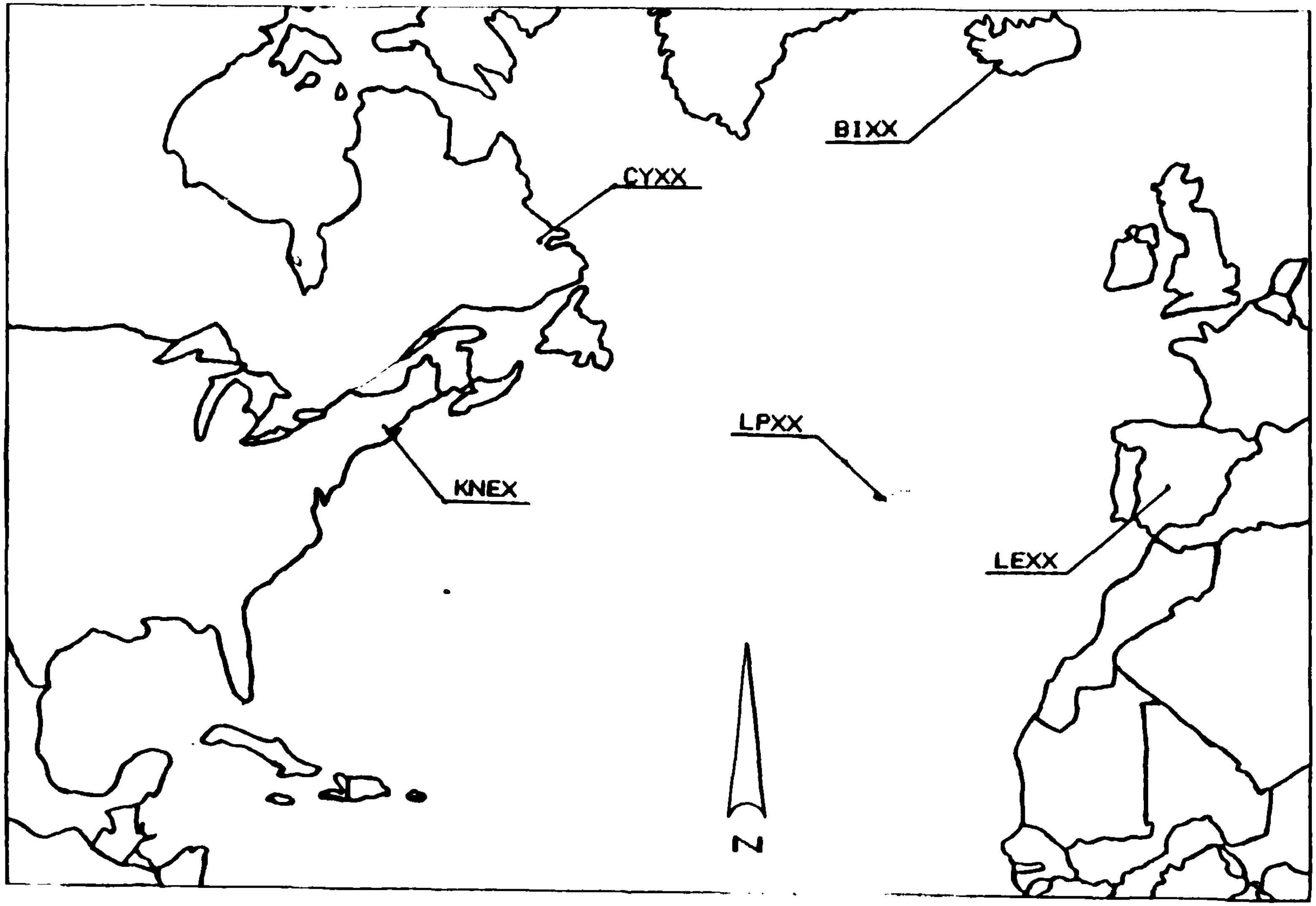

Figure 2. Enroute Support Bases.

would be used by aircraft continuing to the easternmost regions of southern Europe. These bases were chosen by the analysts, based on their strategic airlift experience, as typical enroute stops that are commonly used during exercises and normal operations. Flying times from these bases were extracted from MAIRS (3).

Destination Airfields. Strategic airlift destinations, like departure bases, may be at any airfield large enough to handle jet transport aircraft. Since this study is only concerned with the interactions between strategic airlift and C-130s at enroute bases, the strategic airlifters are assumed to exist only until departure from those bases. This simplification detracts little from the model's use in validating the methodology required to analyze the stated problem. The only inadequacy concerns the refueling time for the strategic airlifters at the enroute base. This fault is minimized by selecting a flight time to a typical destination base (from the MAIRS enroute time history) and stochastically selecting a flight time within a reasonable range of this mean time to represent other possible destinations.

The deploying C-130s will terminate at their designated in-theater beddown bases. The tactical airlift units will 'fight the war' using these beddown bases as their home stations. Since C-130 in-theater operations are beyond the scope of this study, the beddown bases are assumed to be adequate to support the C-130s when they arrive. The validity of this assumption is outside the scope of this analysis, however discussions with HQ MAC contingency planners tend to support its use (28). Since the destinations do not need to be modeled in detail, three aggregate bases were again used for destinations. The three bases, EGXX, EDXX, and LGXX, represent destinations in northern, central, and southern Europe, respectively (Figure 3). Flying times to three major airlift stations (RAF Mildenhall, in England, Ramstein AB, in Germany, and Athens Airport, in Greece) were extracted from the MAIRS history to represent the three consolidated European destinations (3).

Routing. The routing between origins and destinations is an important factor in deploying the C-130s promptly. Currently, deployment routing is obtained from the MAC FLOGEN (Flow Generator) model, a model intended to move cargo using strategic airlift, not to plan C-130 movement (19). Using this method it is not possible to analyze the feasibility of a prospective plan or to compare the relative efficiency of two or more plans. In the airlift system, routing is an important factor in arrival time. Therefore, in an attempt to compare alternatives, routing was varied as a factor to be analyzed in the model. Three routings were selected for comparison. The first routing was intended to include all possible reasonable routings from each of the three departure bases to each destination. No consideration was given to limiting the number of squad

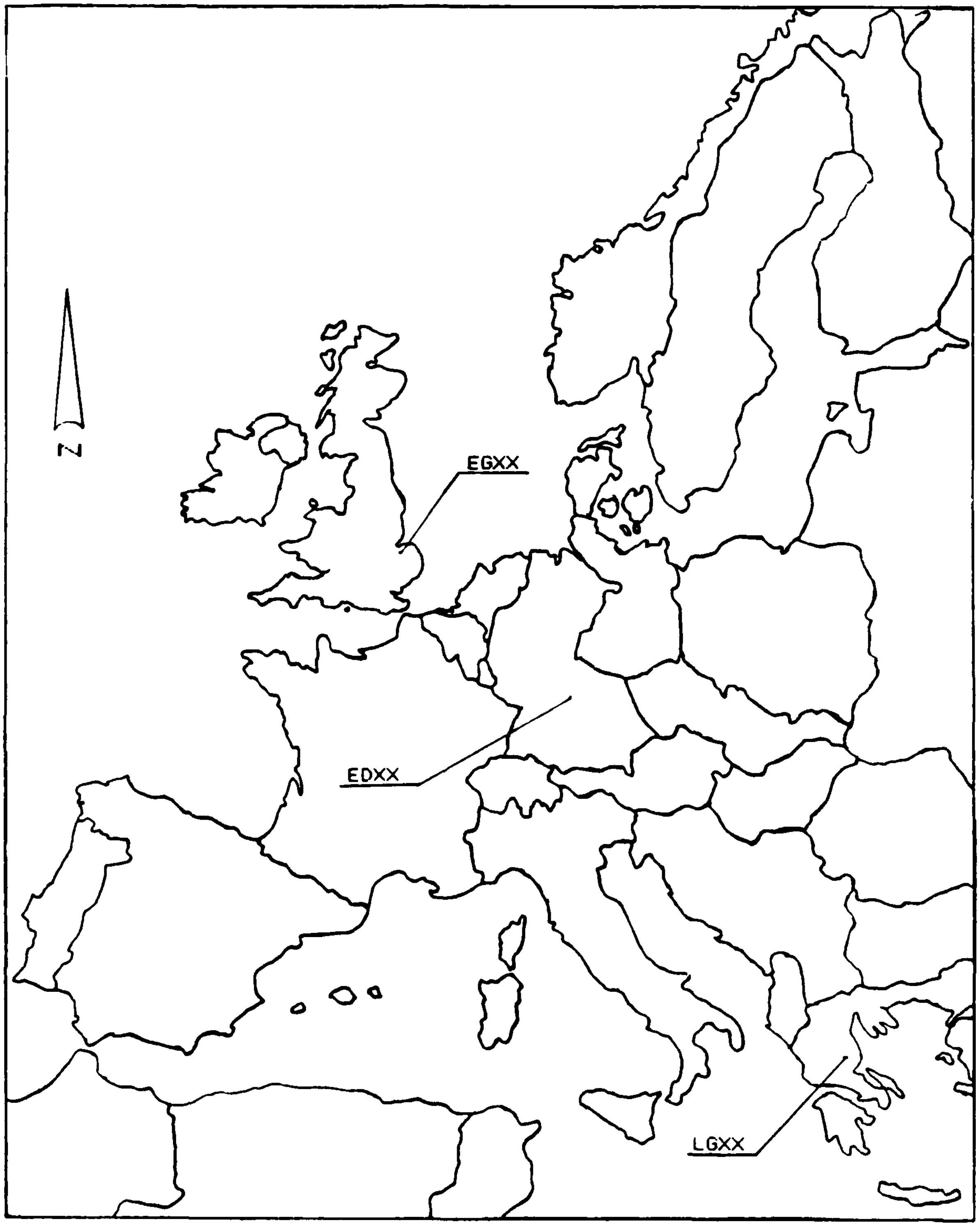

Figure 3. European C-130 Destinations

rons transiting an enroute station or to minimizing any squadron's enroute time. Next, an optimization technique was applied to minimize the total enroute time, while constraining the number of squadrons through each enroute station to reduce congestion and queueing. A network flow problem was constructed, as described by Jensen and Barnes, and solved using an integer programming computer algorithm (6:47-62; 17:59-65). Finally, a compromise between these two extremes was developed by solving the network problem again with an additional constraint requiring a certain number of squadrons from each departure base to deploy to each European arrival area. The three resulting routing systems are depicted in Table I.

Throughout the model, the flying times extracted from MAIRS are for 90% worst wind conditions. This means 90% of the aircraft flying the route did so within this length of time. To account for seasonal variation the 90% worst wind times from the best and the worst months were averaged. Also, in this study all C-130s were assumed to be alike. To account for the shorter range of the C-130A model, some squadrons were restricted to routings with shorter maximum length legs.

The Station Model

Enroute station activities occur during three distinct time periods: the arrival period, the servicing period, and the departure period. This section will describe each of

Table 1. C-130 Routing.

Level 0
Minimize Total Enroute Time.

Squadrons	Itinerary	Staging Base
1-4	KWXX - CYXX - EDXX	CYXX
5	KCXX - CYXX - BIXX - EDXX	CYXX
6	KCXX - CYXX - EGXX	CYXX
7-13	KCXX - KNEX - EGXX	KNEX
14-20	KSXX - LPXX - LGXX	LPXX
21-23	KSXX - BIXX - EDXX	BIXX
24-25	KSXX - CYXX - BIXX - EDXX	CYXX

Level 1
Minimize Total Enroute Time (Destination Specified).

Squadrons	Itinerary	Staging Base
1-2	KWXX - CYXX - EDXX	CYXX
3	KWXX - KNEX - EGXX	KNEX
4-6	KCXX - KNEX - LPXX - LGXX	LPXX
7	KCXX - CYXX - BIXX - EDXX	CYXX
8-9	KCXX - CYXX - EDXX	CYXX
10-12	KCXX - KNEX - EGXX	KNEX
13-16	KSXX - LPXX - LGXX	LPXX
17-18	KSXX - BIXX - EDXX	BIXX
19-20	KSXX - CYXX - BIXX - EDXX	CYXX
21-24	KSXX - BIXX - EGXX	BIXX
25	KWXX - CYXX - EGXX	CYXX

Level 2
Typical Deployment Routings Represented.

Squadrons	Itinerary	Staging Base
1-2	KWXX - CYXX - EGXX	CYXX
3-4	KWXX - KNEX - BIXX - EDXX	KNEX
5-6	KCXX - KNEX - LEXX - LGXX	LEXX
7	KCXX - CYXX - LPXX - LGXX	LPXX
8-9	KCXX - CYXX - BIXX - EDXX	BIXX
10	KCXX - CYXX - EDXX	CYXX
11-12	KCXX - KNEX - EGXX	KNEX
13	KCXX - KNEX - BIXX - EGXX	KNEX
14-15	KSXX - CYXX - LEXX - LGXX	LEXX
16-17	KSXX - LPXX - LGXX	LPXX
18-19	KSXX - CYXX - EDXX	CYXX
20-21	KSXX - KNEX - BIXX - EDXX	BIXX
22-23	KSXX - CYXX - EGXX	CYXX
24-25	KSXX - KNEX - BIXX - EGXX	BIXX

these periods and how they are simplified for easier modeling.

<u>Arrival</u>. During the arrival period the aircraft land, taxi to the parking ramp, park, and complete aircrew post-flight procedures. As stated previously, in order to simplify the system model strategic airlift aircraft are created at each enroute station based only on arrival rates, not on enroute time from any particular origin base. Strategic airlift interarrival times for this study were extracted from the output of the M-14 simulation. They represent average arrival rates for the first week of a European contingency deployment scenario. After the strategic airlifters appear at each enroute base, all aircraft compete equally for resources at that base.

Upon arrival in the local air traffic control area at an enroute base the aircraft are sequenced for landing. While all types of aircraft compete equally for runway usage, air traffic control procedures dictate that airborne aircraft have priority for runway use. Therefore, landing aircraft are handled on a first come, first served basis, but take priority over departures. According to data analysis accomplished for the M-14 model, once an aircraft is permitted to land, it will complete its landing and clear the runway in 3.2 to 4 minutes (uniformly distributed) (14:67).

After landing and clearing the runway, the aircraft must taxi to the parking area. Another product of the M-14 construction effort is this taxi time. Taxi time normally doesn't vary by type of aircraft, but it does vary by distance to the ramp (14:67).

Upon reaching the parking ramp, the aircraft must find space to park. Each base has a limited amount of ramp space, and only a portion may be allocated to airlift aircraft by contingency planners. The ramp space may be further restricted by size, obstructions, or weight bearing capacity limitations that might prove hazardous to larger aircraft, but not for smaller ones. Ramp space was calculated for each enroute station. The C-130 was used as the standard, with a station's capability expressed in terms of C-130 parking spaces. Resource usage for the larger aircraft were calculated in terms of C-130 size equivalents. In general, a narrow body aircraft is equivalent to about two C-130s and a wide body aircraft about four. Station capacities were provided by HQ MAC analysts and are given in Table II.

After parking, the aircrew completes postflight duties at the aircraft. These duties include a postflight inspection of the aircraft for such obvious malfunctions as missing panels or fluid leaks. While the inspection is being conducted, another crewmember must complete the aircraft flight status, maintenance discrepancy, and flying time logs. In some cases, aircraft malfunctions will warrant extended maintenance debriefing during this period. Fin-

Table II. Airfield Capacities.

Maximum Number of Aircraft on the Ground			
Station	C-130	C-141	C-5
KNEX	63	21	7
CYXX	84	42	24
BIXX	46	22	14
LPXX	83	51	27
LEXX	14	12	4

ally, the aircrew must offload personal luggage if they will be turning the aircraft over to a fresh crew at that station. After the aircrew postflight, the maintenance personnel are free to begin the servicing phase of the ground time.

Servicing. During the servicing period the maintenance personnel refuel and repair the aircraft. Cargo handling is not addressed since the stations modeled are enroute rather than terminal stops. While all aircraft must be refueled at these enroute stops, more than half require no maintenance. Since only mission essential repairs (those absolutely necessary to continue the mission) would be attended to at a wartime enroute stop, only 40 percent of the aircraft must be repaired. Of the repairs that must be accomplished, ten percent require actuation of systems that would preclude refueling during the maintenance (25). Maintenance that might preclude concurrent refueling would include radar operation, engine runs, or electrical system operation. The remainder of the aircraft requiring repair may be maintained concurrently with the refueling operation, thereby speeding ground operations. Maintenance malfunction rates and servicing times were obtained from M-14 model output provided by HQ MAC (25).

The Air Force Logistics Command (AFLC) maintenance data base contains a three year maintenance history for all Air Force aircraft. This data is recorded in a form unadaptable to the maintenance model conceptualized for this study. The AFLC data was, however, suitable for comparisons between aircraft types. The Mean Time Between Maintenance (MTBM) and Mean Time To Repair (MTTR) data proved to be statistically the same for the C-130 and C-141 (means and standard deviations were equal at one percent significance). Therefore, C-141 maintenance distributions were used for the C-130 maintenance modeling.

Another simplifying assumption for this study is that maintenance personnel and spare parts need not be modeled. Since the C-130s deploy as units, they carry all personnel and equipment necessary to maintain their aircraft (21:3). This organic maintenance capability allows the analyst to assume no competition for maintenance assets between the C-130s and the strategic airlift aircraft. Strategic airlift maintenance personnel and supply restrictions are already accounted for in the maintenance time distributions extracted from M-14 (14:35).

In addition to repair, the aircraft must be refueled as quickly as possible. There are two means to refuel the airlifters, fuel trucks and fuel pits. While all bases possess fuel trucks, not all have the more efficient fuel pits. To refuel from a pit, the ground crew must only roll a fuel pump to the aircraft, attach hoses to the pit outlet and the aircraft refueling system, and start pumping fuel onboard. While fuel trucks are as simple to hook up, they carry only 32,000 pounds of fuel. This may be enough for a C-130 on a short or medium length leg, but not for a larger aircraft or longer mission. Each additional fuel truck that must be used takes another 10 to 20 minutes to hook up, increasing total refueling time greatly. For this analysis, refueling times are based on empirical equations extracted from the M-14 model (14:71). Fuel usage figures are rules of thumb used by schedulers in the FLOGEN model and allow only for enroute fuel burnoff (19). Required holding and alternate airport fuel is assumed to still remain on board, as it was not needed on the inbound leg.

Departure. During the departure phase a new crew will receive the aircraft if the station is a specified crew change (stage) base. If the inbound crew remains with the aircraft they must insure they will be able to complete the next leg of their mission within the remainder of their maximum crew duty period. During normal operations the maximum crew duty period is sixteen hours from the time the crew shows for duty, an hour and a half prior to initial takeoff (11:12). An assumption used in this study is that in a contingency crews could be expected to receive automatic two hour extensions to crew duty day (to 18 hours). While not addressed in contingency regulations, war planners agree with the analysts' experience that extensions of this length are not uncommon and would be virtually automatic in a contingency (28). If the crew will be unable to complete the next leg within the specified time the mission must be delayed for fourteen hours (twelve hours crew rest and two hours for predeparture preparation) if no other crew is available. In the actual airlift system crew duty time is constantly monitored and the crew retired as soon as an extended delay (beyond maximum crew duty day) is identified. This study assumes that crew duty day is tested once just prior to taxi, simplifying the modeling without introducing large errors (less than one hour) in the enroute time.

When servicing is complete, the aircrew must perform preflight checks, start engines, taxi to the runway, and take off. The first three of these functions, checklists, engine start, and taxi, were grouped together in this study, as they are in the airlift system with checklists running from arrival at the aircraft until takeoff. To model these activities, the analysts selected a hypothetical probability distribution that reflected their airlift experience. Once the aircraft are cleared for takeoff (after any arriving aircraft land) they clear the runway in two minutes (25).

Summary

The transatlantic airlift system is complex, but may be simplified in order to be modeled without losing fidelity. The major assumptions of consolidated arrival and departure bases relieve the modeler of the necessity of building a large number of terminal stations when only the flying time to or from these stations is important. Also, the restriction of stategic airlift to each enroute station, rather than throughout the system, eliminates a system that has already been studied while maintaining the interactions at the enroute stations. The next chapter will describe how the conceptual model was converted into a computer model.

III. Model Development

Developing the Model

Chapter II describes the logical structure of the model used in the simulation of the deployment of C-130s to Europe. This chapter describes the coding of the model in the Simulation Language for Alternative Modeling (SLAM) for use on the VAX 11/785 Classroom Support computer (CSC) at the Air Force Institute of Technology (AFIT). Additionally several FORTRAN subroutines were written to assist in the definition of the model. The SLAM and Fortran coding are fully described in Appendix A to this thesis.

Verification.

Reasonableness of Results. After the model was completed, it was carefully checked by both authors for accuracy. Careful examination of the logic verified that entities (aircraft) travelled through the system as desired. Additionally, output statistics and activity counts were used to insure that results were reasonable. Activity counts confirmed that appropriate numbers of entities were transiting maintenance, refueling, and other service activities at enroute stops and that proper numbers of C-130s (16 aircraft) were arriving at each beddown base. Output statistics revealed that ground times at enroute bases were within reason and that total enroute times for the C-130s between departure from their CONUS home bases to their European beddown bases were reasonable. Output statistics also showed that the number of crews having to crew rest at an enroute base (because the crews did not have enough duty day to fly to their staging base or destination) was reasonable.

Flow Diagrams. Flow diagrams were constructed, as shown in Figures 4 and 5, to help verify that the model performed as intended. Also, extensive documentation was used within both the SLAM and Fortran coding of the model to ease the difficulty of debugging and verifying the logic of the code.

Stress Test. A stress test of a simulation model will determine if the model behaves as expected with high rates of activity (with a large number of entities passing through service activities). This model, in a version with the first aircraft from each C-130 squadron departing at hour 18, confirmed the expected: congestion at the enroute bases.

Traces. Traces displaying the values of attributes of entities (aircraft) were run (for a portion of a simulation) to ensure that entities travelled as expected through the model and that the attributes assumed reasonable and logical values.

Validation and Calibration.

Face Validity. Close examination of the model by the authors and other personnel experienced with strategic airlift established face validity of the model (i.e. verified that the logic of the model accurately represented the MAC

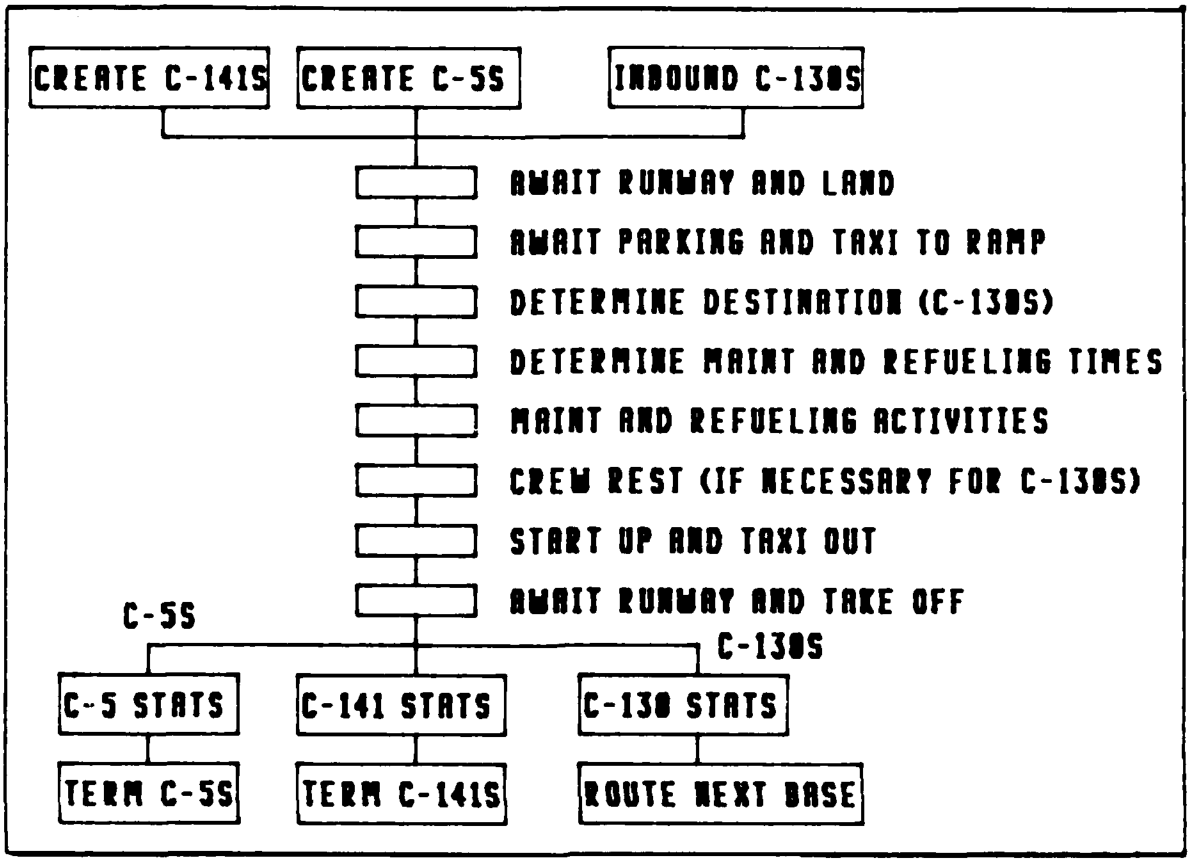

Figure 4. Enroute Base Flow Diagram.

North Atlantic route structure, that the service activities at the enroute bases were realistic, and that all significant service activities at the enroute bases were modelled). Additionally, a careful examination of assumptions used in the model helped to validate the reasonableness of the structure.

Comparison with M-14 Model. The primary method used to validate this model was to compare the results of the model with the results of the M-14 model. The measure of effectiveness used for the comparison was enroute station depar-

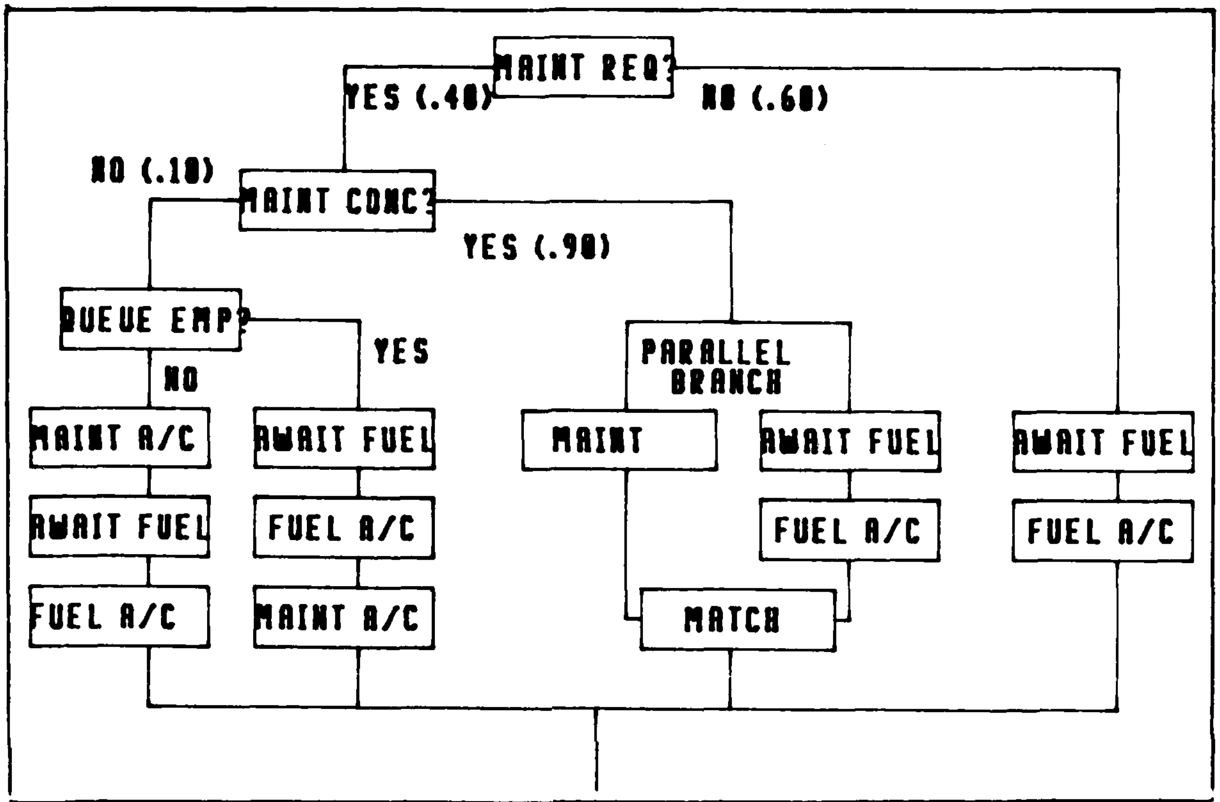

Figure 5. Maintenance and Refueling Activities

ture reliability. The version of the model used for validation included only strategic airlift aircraft because the M-14 model only includes strategic airlift. The M-14 model is used by HQ MAC/XPS to simulate the flow of strategic airlift aircraft at over 500 bases around the world during different contingencies affecting the United States, including a general conventional war between the NATO forces and the Warsaw Pact. The M-14 model is very complex and detailed, modelling the flow of C-5, C-141, and CRAF aircraft through every base used during the contingency. Results of simulations using the M-14 model are used to calculate aircrew ratios (ratio of the number of crews available to the number of aircraft available) and the maximum utilization rate (hours/day) of aircraft under surge conditions, to evaluate the feasibility of wartime planning, and in budgetary planning. Therefore the M-14 model can be considered an accurate representation of the strategic airlift system.

As would be expected, initial runs did not compare well with the M-14 model. Narrow body aircraft had generally higher departure reliabilities than the M-14 model, and wide body aircraft had lower reliabilities than expected. It was necessary to adjust the model to bring the enroute base departure reliability more into agreement with the M-14 model. Adjustment of the model was accomplished by altering the flying times used at the different bases for the strategic airlifters. After adjustment, results of the model much more closely agreed with the M-14 model. Table III compares the overall departure reliabilities of the two models, and also the departure reliabilities of the narrow body and wide body fleets. Table IV compares the departure reliability figures of the two models, at each of the five enroute bases used by both the models, for both narrow body and wide body aircraft. Five replications of the model were run and 90% confidence intervals developed to compare the model results with a single replication of the M-14 model.

Table III. Overall Model Comparisons.

COMPARISON OF MODELS (OVERALL DEPARTURE RELIABILITY) (ALPHA = 0.1, N = 5, $t_{0.05,4} = 2.132$)		
	MODEL (CONF INTERVAL)	M-14 MODEL (1 RUN)
OVERALL	$.685 < u < .707$	.696
C-141	$.694 < u < .716$	.705
C-5	$.650 < u < .702$	.672

The overall departure reliabilities of the two models (all strategic aircraft considered) are statistically the same. The departure reliabilities of C-141 and C-5 aircraft, when considered individually, are also statistically the same for the two models.

At the enroute bases, significant differences occur between the two models for both wide body and narrow body aircraft. The M-14 model exhibits significant variation between bases in departure reliability, while this research model only strays somewhat from the overall average for each class of aircraft. This result should be expected, however, because maintenance repair times were averaged over all five bases for this model (using data extracted from the M-14

Table IV. Model Comparison by Base.

COMPARISON BY BASES (DEPARTURE RELIABILITY)		KNEX	CYXX	BIXX	LPXX	LEXX
C-141	MODEL	.674 - .753	.561 - .741	.662 - .706	.698 - .740	.703 - .748
	M-14 MODEL	.96	.78	.97	.57	.39
C-5	MODEL	.414 - .536	.742 - .872	.477 - .547	.714 - .847	.707 - .862
	M-14 MODEL	.95	.47	.96	.5	.56

model), while in the M-14 model maintenance times are calculated separately for each base.

One should remember as well that only one replication of the M-14 model is used for comparison purposes. The M-14 model is a stochastic model that because of its size does not exhibit much variation between runs. In spite of this, some uncertainty in the output should be expected. Therefore, more variation should be expected between bases for the single run of the M-14 model than for the five runs of this research model. Therefore, only general agreement between the two models should be considered satisfactory, and one can conclude that the overall results of the model are statistically valid.

IV. Experimental Design and Experimentation

Factors and Ranges of Interest.

Four different factors, each with three different levels, were selected as candidates for inclusion in the initial screening designs. These factors were selected because they were controllable and thought to be influential to the response variables: closure time of the 380th C-130 to its beddown base (95% of the C-130s have closed) and strategic airlift departure reliability at the enroute bases. These factors, with selected levels, are summarized in Table V.

Table V. Complete Factorial Design

OVERALL FACTORIAL DESIGN

3^4 DESIGN (REQUIRES 81 COMBINATIONS)

	0	1	2
RATE	.7 HOURS	1.0	1.3
FIRST	12,22,32, 42,52 HOURS	15,27,39 51,63	18,34,50 66,82
ROUTE	0	1	2
TRUCKS	PLANNED	SHIFT	PLANNED + 2

Time of First Launch (First). Active duty and Air Reserve Force (ARF) C-130 squadrons can generate (depart) from their home bases beginning at specified times after the contingency begins. Generally one squadron at a base will be prepared for quick reaction, and will generate first. Other squadrons generate at later times. Active duty squadrons also normally generate sooner than ARF squadrons. Different levels used in this study reflect a range of possible actual values, but none reflect actual real world data. Level "0" represents the case when the first squadrons are generated beginning at hour 12 after the order to deploy, the second group of squadrons at hour 22, and other squadrons at hour 32, 42, or 52. Level "1" represents the case when the first group of squadrons generate beginning at hour 15, and other squadrons generate at hour 27, 39, 51, or 63. Level "2" represents the case when the first squadrons generate at hour 18, and the other squadrons at hour 34, 50, 66, or 82.

Interval Between Launches (Rate). Once a squadron begins deploying aircraft, aircraft can be generated from the squadron at certain maximum rates. Level "0" represents the case when aircraft are generated approximately every 0.7 hours. Level "1" represents the case where aircraft are generated every 1.0 hour. For level "2", aircraft are generated approximately every 1.3 hours. The interval between launches represents the time necessary to perform all maintenance and cargo loading on the aircraft prior to takeoff.

Route Structure (Route). Three different route structures from the home bases of the 25 C-130 squadrons in the CONUS to their beddown bases in Europe were selected for study as representative of the different route structures the aircraft could use. Level "2" is typical of current deployment plans. Levels "1" and "0" represent optimal routing plans (minimizing enroute time) obtained from an integer programming optimization routine. The integer program was written using the Multi Purpose Optimization System (MPOS) (6) and run on the Cyber computer belonging to Aeronautical Systems Division at Wright-Patterson AFB. Level "1" represents the routes obtained when the beddown location for each squadron is fixed (the same beddown locations as for level "2"), but the routes used are optimized for minimum overall flying time. Level "0" represents the optimal route structure obtained when only the the numbers of squadrons at each beddown location are fixed, and the departure points and route structure are unconstrained.

Fuel Trucks (Trucks). Fuel trucks are moved to enroute bases to handle the large number of transiting aircraft expected in an contingency. Other trucks are permamently assigned to the locations. Level "0" represents the number of trucks presently called for in unclassified contingency planning (25). Level "1" has the same total number of fuel trucks as level "0", buts redistributes them between bases to relieve congestion at overcrowded bases. The distribution of Level "1" was determined by observing congestion at enroute bases during pilot runs and adjusting the location of fuel trucks to relieve the congestion. Level "2" adds two trucks to each base above the number used in level "0" without regard for the source of the additional resources.

Initial Screening Design.

A full factorial design for the problem, with four factors each at three levels (3^4), would require 81 combinations of factors (each with n replications). While such a design is feasible, it is costly in computer and model configuration time and is unnecessary to discover important effects and interactions.

A 2^4 initial screening design, with the levels for each factor selected at the extremes, discovers effects and interactions of interest. For this project, a 2^4 factorial design was run, with five replications for each case. Factors and levels for this design are shown in Table VI. A 2^4 design requires 16 combinations of factors. Each series of five replications requires approximately 5 - 5 1/2 minutes of computer CPU time, and all 16 runs about 88 minutes of CPU time.

Following completion of the simulation, a statistical analysis was conducted of the results. It is interesting to study a graph of one response variable (closure time for the C-130s) versus the other response variable (departure reliability for the strategic airlift aircraft at the enroute bases). This graph is shown in Figure 6. Surprisingly, the

Table VI. Initial Screening Design.

INITIAL SCREENING DESIGN

2^4 DESIGN (REQUIRES 16 COMBINATIONS)

FACTORS	LEVELS 0	LEVELS 1
RATE	.7	1.3
FIRST	12, 22 HOURS ETC	18, 34 HOURS ETC
ROUTES	0	2
FUEL TRUCKS	PLAN	PLANNED + 2

graph does not display the expected behavior of a direct relation between closure time and enroute station reliability (intuition suggests that as closure time decreases, departure reliability should also decrease because of increased congestion at enroute bases). It will be seen that closure time is generally independent of enroute station departure reliability because C-130 movement does not increase congestion at enroute bases enough to affect the departure reliability.

Separate ANOVA tables were calculated for each response

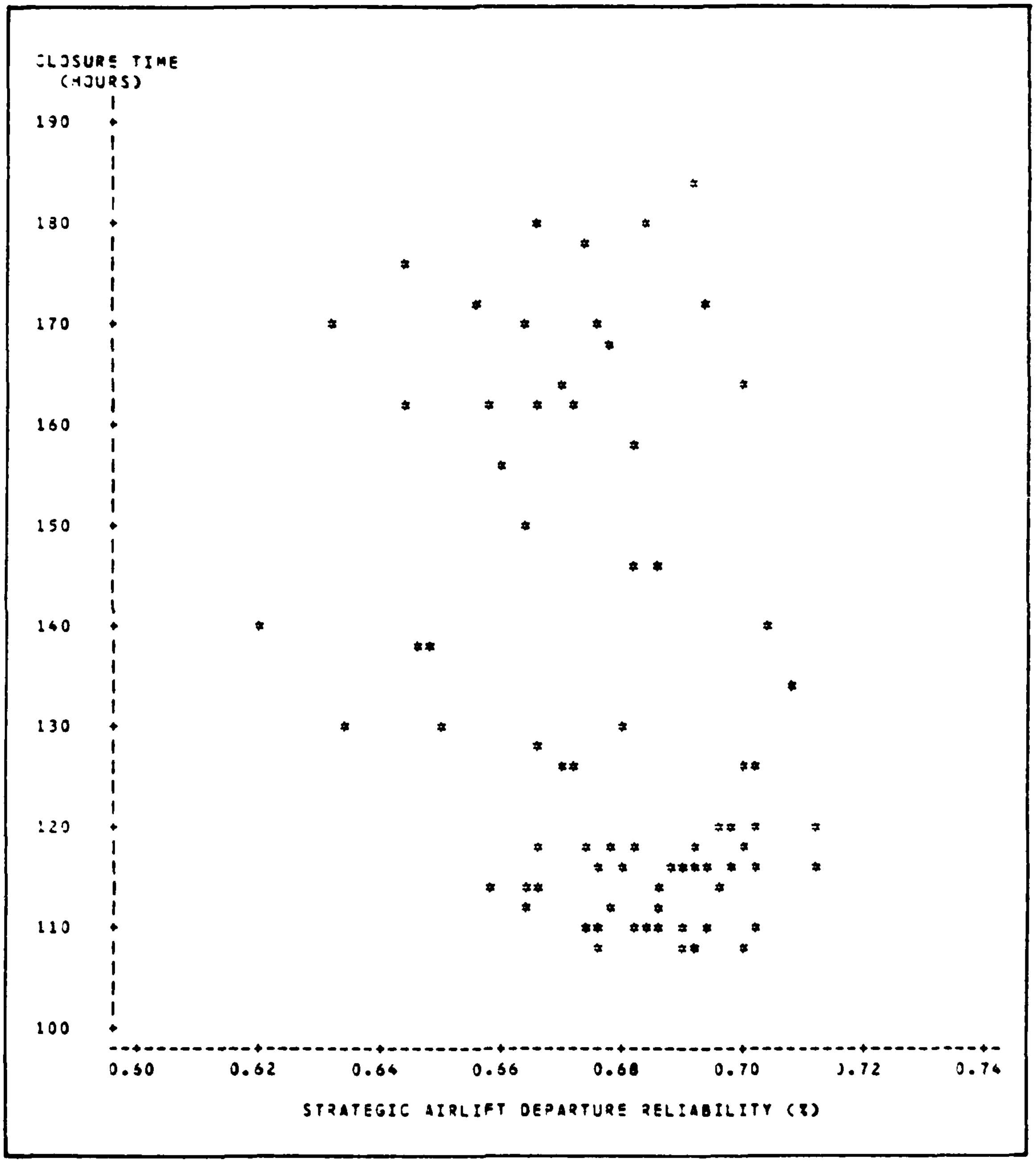

Figure 6. Closure Time vs. Strategic Reliability

variable using Statistical Analysis Software (SAS) (29). Results of the analysis for closure time are displayed in Table VII.

The ANOVA table for closure time displays the following significant effects. Rate (A), First (B), Route (C), and the First*Route (BC) interaction are significant at an alpha of 0.01. Additionally the First*Truck (BD) and Route*Truck (CD) interactions are significant at an alpha of 0.05. The normal probability plot of the residuals and a residual plot, as displayed in Figures 7 and 8, display a random nature, and confirm that the fitted model to the data is correct.

The ANOVA table for the other response variable, strategic aircraft departure reliability, is displayed in Table VIII. Effects and interactions significant at an alpha of 0.01 are Route (C), Trucks (D), and the Route*Truck (CD) interaction. The effect significant at an alpha of 0.05 is First (B). A normal probability plot and a plot of residuals (Figures 9 and 10) do not display evidence that the model is inappropriate.

<u>Final Experimental Design</u>.

Every one of the four factors in the model (Rate, First, Route, and Trucks), as well as several two factor interactions (First*Route, Route*Trucks, and First*Trucks), proved to be significant for at least one response variable in the initial screening design. Therefore, no factors can be abandoned in subsequent designs.

Table VII. ANOVA Table for Closure Time.

DEPENDENT VARIABLE: CLOSURE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	15	40513.05059500	2700.87003967	70.56
ERROR	64	2449.72460000	38.27694687	PR > F
CORRECTED TOTAL	79	42962.77519500		0.0001

R-SQUARE	C.V.	ROOT MSE	CLOSE MEAN
0.942980	4.7137	6.18683658	131.25275000

SOURCE	DF	TYPE I SS	F VALUE	PR > F
RATE	1	708.28802000	18.50	0.0001
FIRST	1	6964.28520500	181.94	0.0001
RATE*FIRST	1	0.42632000	0.01	0.9163
ROUTE	1	24929.56660500	651.29	0.0001
RATE*ROUTE	1	3.57858000	0.09	0.7608
FIRST*ROUTE	1	7179.39724500	187.56	0.0001
RATE*FIRST*ROUTE	1	5.40300000	0.14	0.7082
TRUCKS	1	150.64560500	3.94	0.0516
RATE*TRUCKS	1	21.71528000	0.57	0.4541
FIRST*TRUCKS	1	156.74400500	4.09	0.0472
RATE*FIRST*TRUCKS	1	21.71528000	0.57	0.4541
ROUTE*TRUCKS	1	164.10720500	4.29	0.0424
RATE*ROUTE*TRUCKS	1	56.59248000	1.48	0.2285
FIRST*ROUTE*TRUCKS	1	128.37244500	3.35	0.0717
RATE*FIRS*ROUT*TRUC	1	22.21832000	0.58	0.4489

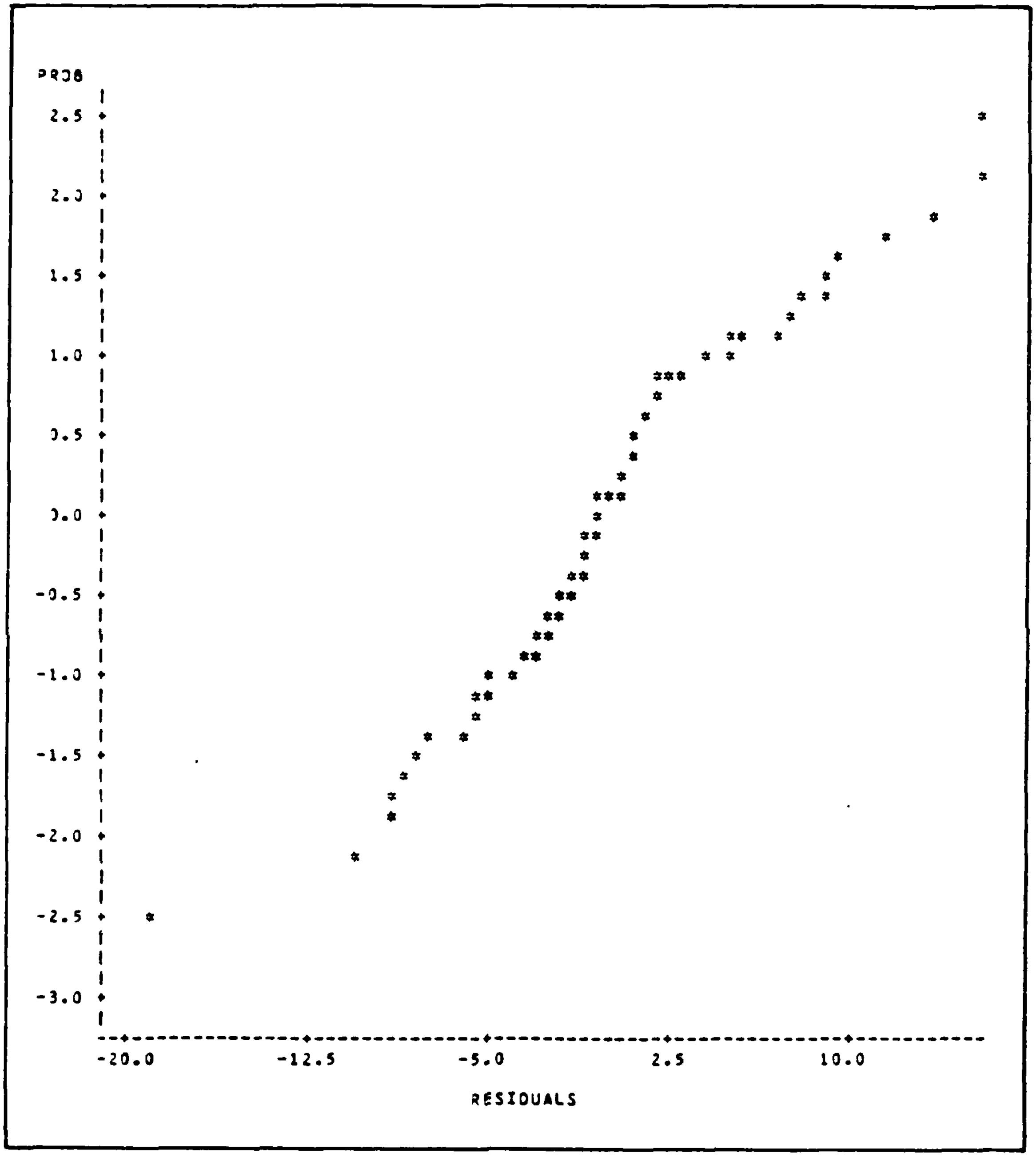

Figure 7. Normal Probability Plot for Closure Time.

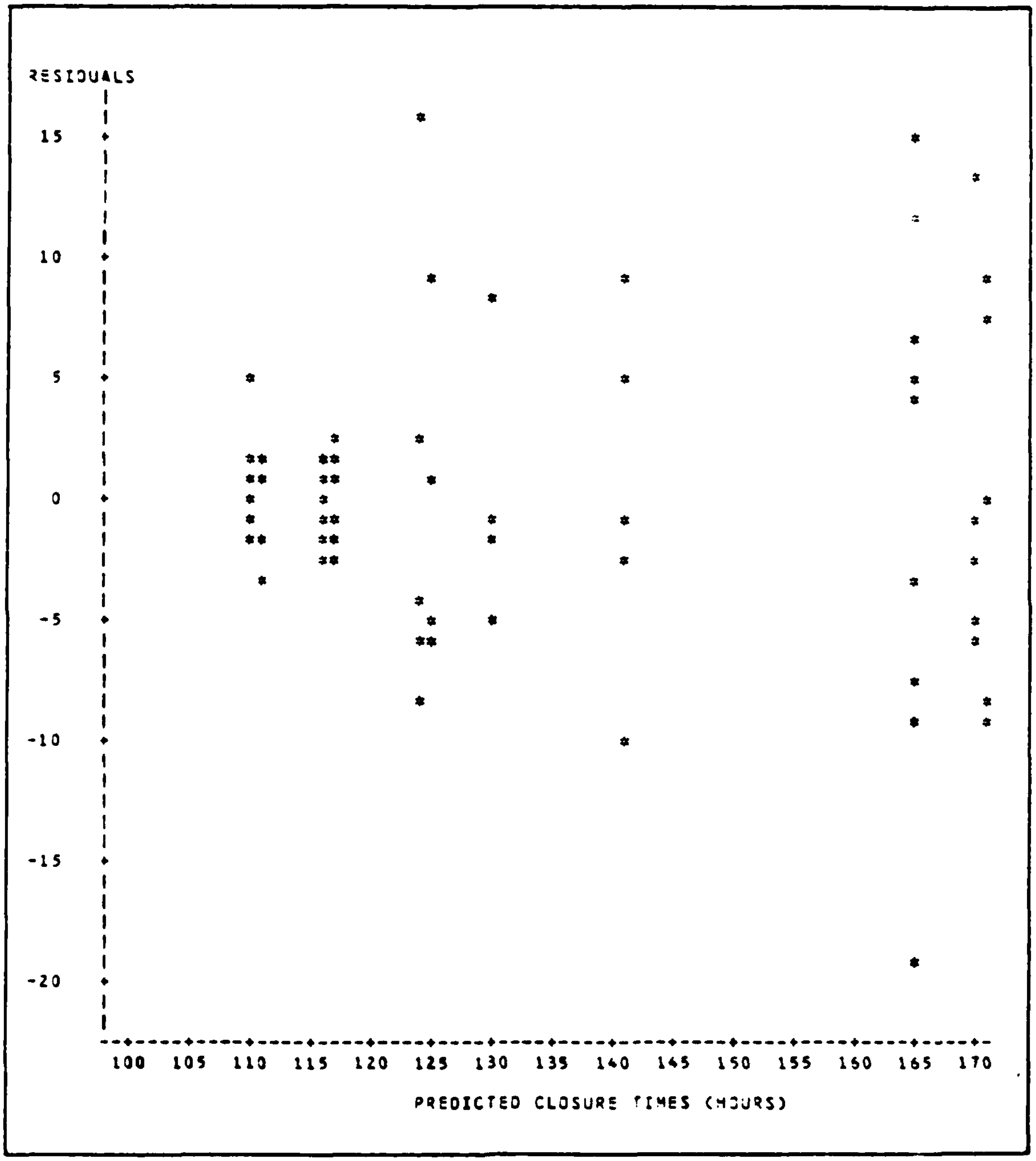

Figure 8. Residuals for Closure Time.

Table VIII. ANOVA Table for Strategic Reliability.

DEPENDENT VARIABLE: RELIABILITY

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	15	0.01998565	0.00133238	8.86
ERROR	64	0.00962947	0.00015046	PR > F
CORRECTED TOTAL	79	0.02961511		0.0001

R-SQUARE	C.V.	ROOT MSE	RELIAB MEAN
0.674846	1.8051	0.01226623	0.67952125

SOURCE	DF	TYPE I SS	F VALUE	PR > F
RATE	1	0.00012375	0.82	0.3679
FIRST	1	0.00067803	4.51	0.0375
RATE*FIRST	1	0.00007163	0.48	0.4927
ROUTE	1	0.00225463	14.98	0.0003
RATE*ROUTE	1	0.00001088	0.07	0.7889
FIRST*ROUTE	1	0.00017199	1.14	0.2890
RATE*FIRST*ROUTE	1	0.00000656	0.04	0.8353
TRUCKS	1	0.01284992	85.40	0.0001
RATE*TRUCKS	1	0.00000009	0.00	0.9806
FIRST*TRUCKS	1	0.00037282	2.48	0.1204
RATE*FIRST*TRUCKS	1	0.00027938	1.86	0.1779
ROUTE*TRUCKS	1	0.00188471	12.53	0.0008
RATE*ROUTE*TRUCKS	1	0.00036937	2.45	0.1221
FIRST*ROUTE*TRUCKS	1	0.00059787	3.97	0.0505
RATE*FIRS*ROUT*TRUC	1	0.00031403	2.09	0.1534

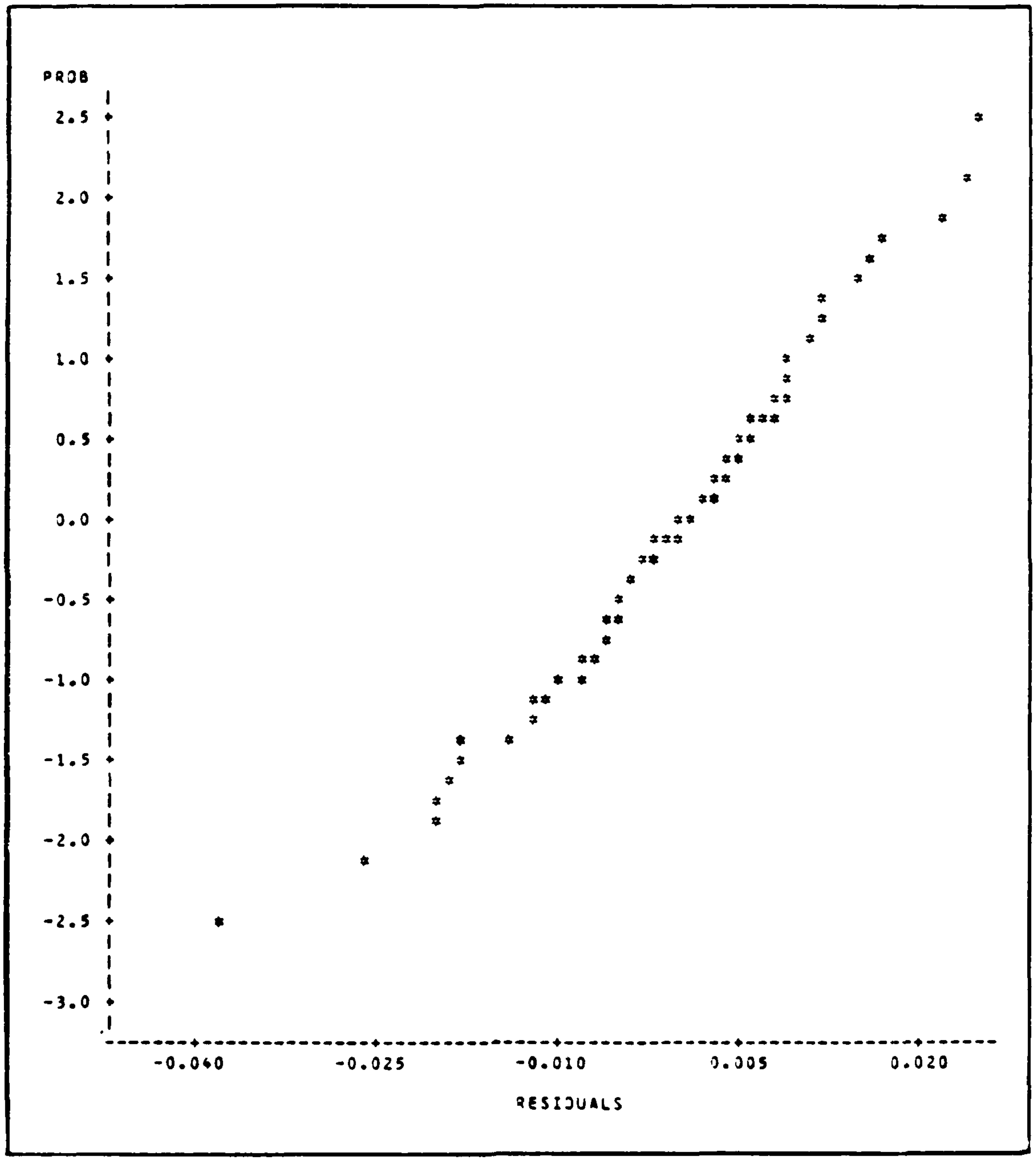

Figure 9. Normal Probability Plot for Strat Reliability.

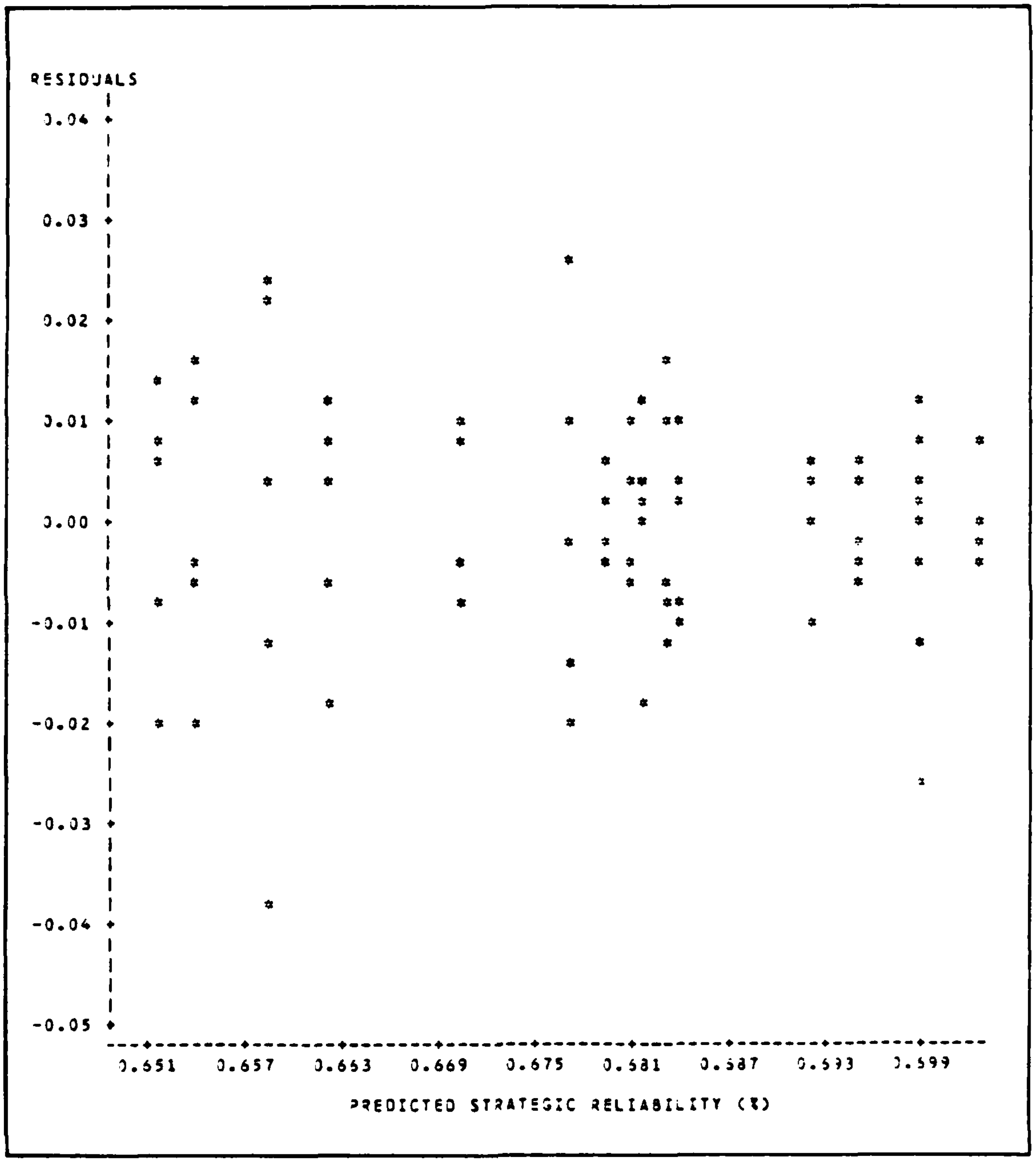

Figure 10. Residuals for Strategic Reliability.

A 3^{4-1} design has a resolution of IV. In a design of resolution IV, no effect is aliased with another main effect or two factor interaction, but some two factor interactions will be aliased with each other (24:329,352). Proper choice of the defining relations will insure that no important two factor interactions will be aliased with each other.

A choice of the defining relation $I = AB^2CD$, also with $I^2 = A^2BC^2D^2$, will produces aliases as shown in Table IX (only two factor interactions are shown).

Table IX. Important Aliases.

$CD = AB^2$
$B^2C = AD$
$BC^2 = AD$
$B^2D = AC$
$BD^2 = AC$
$C^2D^2 = AB^2$

It will be noticed that all of the aliases involve the factor A (Rate), and that Rate was not involved in any of the significant two factor interactions. None of the aliases in the above design are a significant interaction in the problem. Therefore none of the aliases should statistically bias the results. A 3^{4-1} design as described above was selected as the final design.

The 3^{4-1} fractional factorial design used for this analysis required 27 separate combinations of runs, with enough replications to decrease the variance of the output to the desired level. The required levels for the factors are shown in Table X, which was extracted from Montgomery (24:352). The numbers for each combinations represent the appropriate levels for each factor. The first three numbers of each combination form a complete 3^3 design when all 27 combinations are used. The fourth number is derived using the equation below, also extracted from Montgomery (24:352).

$$x_4 = 2x_1 + x_2 + 2x_3$$

The value for the fourth number in Table X is x_4 modulus 3.

Table X. Fractional Factorial Design (24:352)

0000	0012	2221
0101	0110	0021
1100	0211	0122
1002	1011	0220
0202	1112	1020
1201	1210	1121
2001	2010	1222
2102	2111	2022
2200	2212	2121

Sample Size and Reliability

The maximum value of the figure of merit for C-130 closure was 184 hours in the runs of the initial screening design. In the final output runs, the simulation was run for 225 hours to ensure that most C-130s arrive at the beddown bases.

A sufficient number of runs were accomplished to decrease the width of the confidence interval for maximum closure time to within 5% of the mean, and the confidence interval for departure reliability to within 1% of the mean. Not much stochastic variation occurs between runs of the model because the model is large enough to average out much of the randomness. After five replications in the initial screening design, the confidence interval for maximum closure time was 8% of the mean. For departure reliability, the confidence interval was 2%.

Prior to the final design, pilot runs determined that 25 replications were sufficient to reduce the confidence interval for both response variables to within 1% of the mean. Using 25 replications in the output runs, the confidence interval for closure time was measured at 0.7%. For strategic reliability the confidence interval was 0.9%.

Variance Reduction Techniques

Variance reduction techniques were not applied in this analysis. The standard techniques of common random number streams and antithetic variates rely on synchronization of the random number streams (20:186-239). With random numbers required for many activities (fuel load, maintenance times, flying times, arrival rates, taxi times, etc.) and at every departure and enroute base, synchronization would be difficult to obtain and virtually impossible to prove. Since two measures of merit are used, stratified sampling may be suggested. However, with no prior knowledge of the proportion of responses expected in each strata, the stratification after sampling technique would be used (20:110-133). This technique reduces the effectiveness of statified sampling compared to the proportional technique (based on a priori knowledge of proportions in each strata) unless the sample size is large (20:117). Additionally, the stratified sampling technique is most effective when correlation between the response variable is large, a charateristic not realized between the closure time and reliability rate responses (20:114-115).

Fortunately, variance reduction is not necessary in this analysis. The confidence intervals possible using 25 replications for each factor for the final output are adequately narrow. The confidence intervals for both response variables vary no more than 1.0% from the mean value.

V. Analysis of Results

Introduction

The analysis of results will explain both the factorial analysis introduced in the previous chapter and sensitivity analysis of the input parameters. The first section will describe the technical results of the statistical testing. Next, these results will be interpreted with respect to the problem being studied. Later, the input parameters for the model will be evaluated to find the sensitivity of the results to changes or errors. Finally, the collateral result of total C-130 fuel use will be discussed.

In both the airlift system and the model developed for this study the strategic airlifters and C-130s compete for three resources at the enroute stations. This competition for runway use, parking ramp space, and refueling capacity (refueling pits and trucks) is the source of interactions between the two response variables (closure time and strategic airlift reliability) for all combinations of factor levels. This section will focus on both the effects on each response variable and the resulting interactions between the responses.

Technical Description

The 3^{4-1} fractional factorial design described in the previous chapter was run for 25 replications for each combination of factor levels. The resulting group of data, 675 observations of closure time (CLOSURE) and strategic airlift reliability rate (RELIAB), was examined using the SAS statistical language (29). An analysis of variance (ANOVA) was conducted to test the difference between treatment means for the various factors. The model tested included all main effects and the two factor interactions determined to be significant in the screening design described in Chapter IV. The factors in the model were Rate, First, Route, Trucks, and the two factor interactions First*Route, Route*Trucks, and First*Trucks. These ANOVA tables are reproduced in Tables XI and XII.

Table XI. ANOVA for CLOSURE.

DEPENDENT VARIABLE: CLOSURE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	20	107591.81190933	5379.59059547	1393.89
ERROR	654	2524.05209067	3.85940687	PR > F
CORRECTED TOTAL	674	110215.86400000		0.0

R-SQUARE	C.V.	ROOT MSE	CLOSURE MEAN
0.977099	1.9090	1.96453732	102.90800000

SOURCE	DF	TYPE I SS	F VALUE	PR > F
RATE	2	6047.40203022	783.46	0.0
FIRST	2	92344.72937867	11963.59	0.0
ROUTE	2	9112.39075467	1180.54	0.0
TRUCKS	2	1.85991022	0.24	0.7859
FIRST*ROUTE	4	84.71657067	5.49	0.0002
FIRST*TRUCKS	4	87.23212444	5.65	0.0002
ROUTE*TRUCKS	4	13.45114044	0.87	0.4795

Table XII. ANOVA for RELIAB.

DEPENDENT VARIABLE: RELIAB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	20	0.00748528	0.00037426	1.33
ERROR	654	0.18375011	0.00028095	PR > F
CORRECTED TOTAL	674	0.19123540		0.1508

R-SQUARE	C.V.	ROOT MSE	RELIAB MEAN
0.039142	2.4090	0.01676197	0.69580978

SOURCE	DF	TYPE I SS	F VALUE	PR > F
RATE	2	0.00009076	0.16	0.8509
FIRST	2	0.00058965	1.05	0.3508
ROUTE	2	0.00342733	6.10	0.0024
TRUCKS	2	0.00045713	0.81	0.4438
FIRST*ROUTE	4	0.00054930	0.49	0.7440
FIRST*TRUCKS	4	0.00099563	0.89	0.4719
ROUTE*TRUCKS	4	0.00137549	1.22	0.2993

To evaluate the preciseness of the results and to determine the adequacy of the proposed number of replications, confidence interval estimates were constructed about the grand means of closure time and reliability and about the cell means. The confidence intervals (Tables XIII and XIV) are very tight and more than meet the goals stated in Chapter IV.

Table XIII. Confidence Interval Estimates for CLOSURE.

	one-sided width	% of grand mean
Grand Mean	.124 hours	.12 %
Cell Mean	.672 hours	.65 %

The full ANOVA model provided additional information from the individual treatment and interaction effects. Recall the general factorial ANOVA model for a four factor design:

$$Y_{ijklm} = \mu + \tau_i + \beta_j + \gamma_k + \delta_l + (\tau\beta)_{ij} + (\tau\gamma)_{ik} + (\tau\delta)_{il} + (\beta\gamma)_{jk} + (\beta\delta)_{jl} + (\gamma\delta)_{kl} + (\tau\beta\gamma)_{ijk} + (\tau\beta\delta)_{ijl} + (\tau\gamma\delta)_{ikl} + (\beta\gamma\delta)_{jkl} + (\tau\beta\gamma\delta)_{ijkl} + \varepsilon_{ijklm}$$

for $i=1,2,3$
$j=1,2,3$
$k=1,2,3$
$l=1,2,3$
$m=1,2,..,25$ (24:223).

Tables XV and XVI show the effects of the treatments and interactions that were found to be significant in the ANOVAs.

Table XIV. Confidence Interval Estimates for RELIAB.

	one-sided width	% of grand mean
Grand Mean	.00106 %	.15 %
Cell Mean	.00574 %	.82 %

Table XV. Significant Effects for CLOSURE.

Shows parameter estimates for significant effects in general factorial ANOVA model equation.

Factors	Levels	Effect (Hours)
Grand Mean (μ)		102.91
Rate (τ)	0	-3.76
	1	0.19
	2	3.57
First (β)	0	-12.83
	1	-2.62
	2	15.46
Route (γ)	0	-2.96
	1	-2.22
	2	5.18
First*Route	0 0	-0.53
($\beta * \gamma$)	0 1	0.01
	0 2	0.51
	1 0	0.25
	1 1	-0.28
	1 2	0.02
	2 0	0.27
	2 1	0.27
	2 2	-0.55
First*Trucks	0 0	-0.08
($\beta * \delta$)	0 1	0.47
	0 2	-0.40
	1 0	-0.40
	1 1	0.06
	1 2	0.33
	2 0	0.47
	2 1	-0.54
	2 2	0.06

Table XVI. Significant Effects for RELIAB.

Shows parameter estimates for significant effects in general factorial ANOVA model equation.

Factors	Levels	Effect (%)
Grand Mean (μ)		0.6958
Route (γ)	0	0.0002
	1	0.0027
	2	-0.0028

<u>Closure Time</u>. The ANOVA on the dependent variable, CLOSURE (Table XI), showed the first three main effects, Rate, First, and Route, to be significant along with the two interactions First*Route and First*Trucks. The normal probability plot of the residuals (Figure 11) and the plot of residuals versus predicted values (Figure 12) verify the assumptions of normality and constant variance of the residuals necessary to validate the use of ANOVA.

The main effect Trucks and the interaction Route*Trucks were not significant (alpha=0.05). Post hoc analysis (Table XVII), comparing pairs of treatment means by the Least Significant Difference (LSD) method and by Duncan's Multiple Range Test, showed all pairs of treatment means within the three significant main effects to be statistically different (alpha=0.05) (24:64-68 & 199).

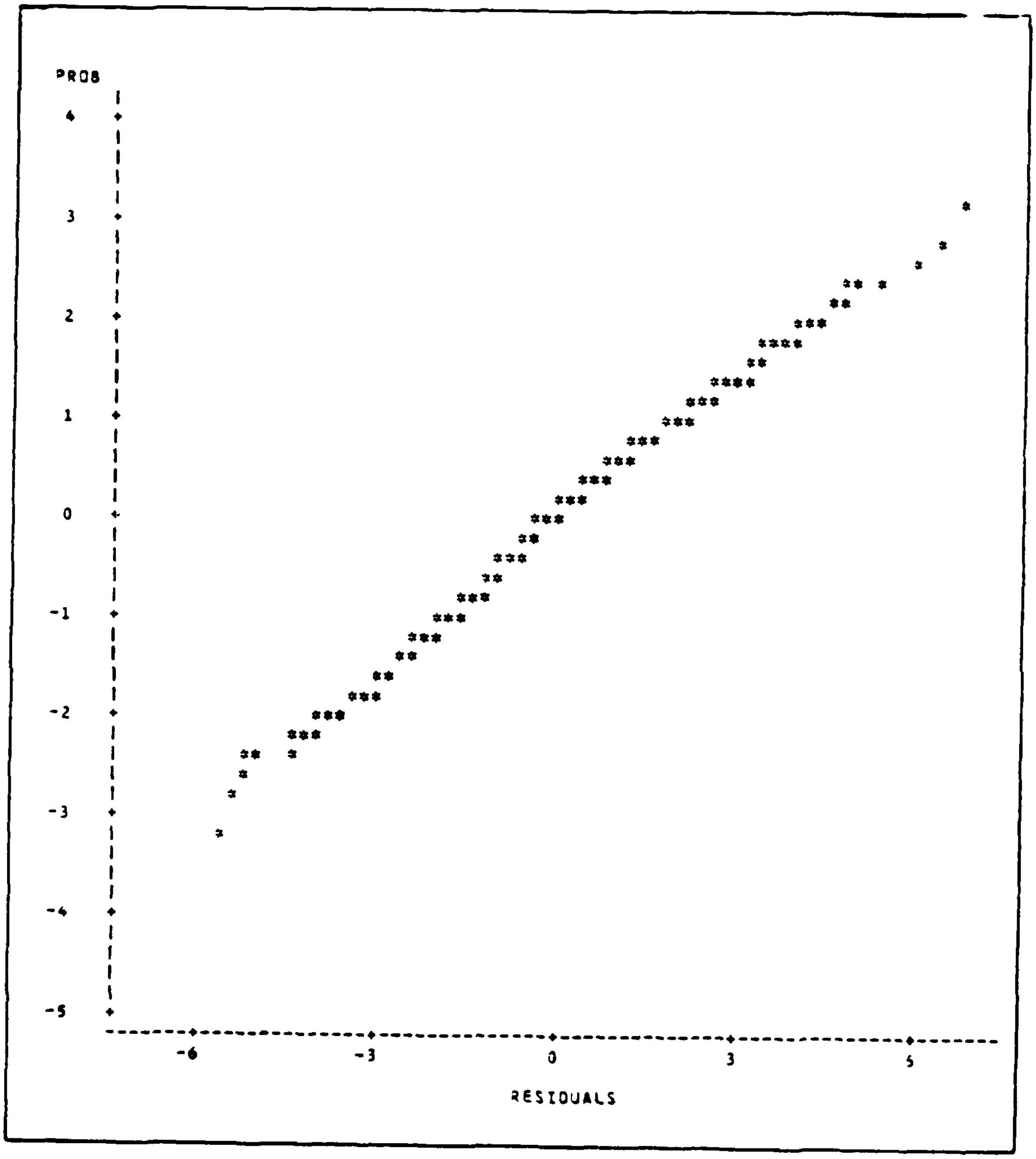

Figure 11. Normal Probability Plot of Residuals

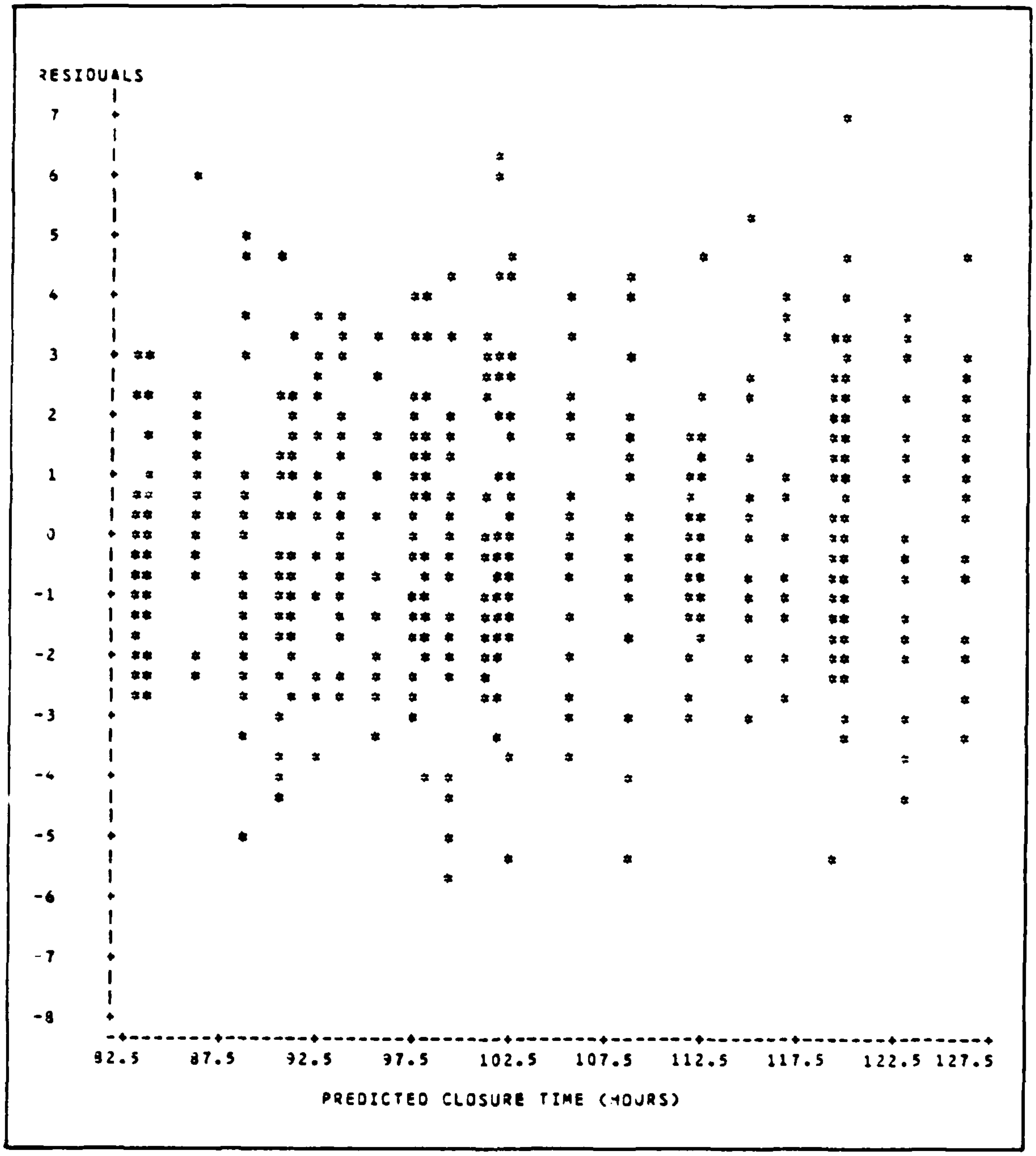

Figure 12. Residuals versus Predicted Values.

Table XVII. Comparison of Pairs of Means for CLOSURE.

Means significantly different at alpha=0.05		
Factor	Level	Mean (Hours)
Rate	2	106.47
	1	103.10
	0	99.15
First	2	118.36
	1	100.29
	0	90.08
Route	2	108.09
	1	100.69
	0	99.95

Strategic Airlift Reliability. The ANOVA on the dependent variable, RELIAB (Table XII), showed only the main effect Route to be significant. Again, the residuals are shown to be normal with constant variance (Figures 13 and 14). None of the other main effects or interactions were significant (alpha=0.05). The LSD and Duncan's tests on Route (Table XVIII) showed a significant difference between levels one and two, but not between zero and one, nor between zero and two (alpha=0.05).

Table XVIII. Comparison of Pairs of Means for RELIAB.

Means significantly different at alpha=0.05		
Factor	Level	Mean (%)
Route	2	.6930
	1	.6985

Interpretation of Results

Closure Time. The significance of the three main factors follows logically. The rate of departure (Rate) levels explain 9.0 hours difference between the 0 level (last aircraft in the squadron launches 10.5 hours after the first aircraft) and the 2 level (last aircraft launches 19.5 hours after the first). This is reasonably close to the difference between the level 0 and level 2 effects shown in Table XV (7.33 hours). The time of first departure (First) levels explain 30 hours difference in CLOSURE, as this is the difference between the times the last squadron departs at levels 0 and 2 (52 and 82 hours, respectively). In fact, the difference between the effects shown in Table XV is 28.3 hours. Finally, the Route factor, while difficult to compare quantitatively, shows an 8.14 hour difference between the 0 and 2 levels resulting from the optimization scheme used to reduce congestion while minimizing enroute time.

The statistical insignificance of the fourth main factor, the number of fuel trucks (Trucks), was initially surprising. Inspection of detailed output from several factor levels showed very little competition for fueling. Only at the most congested bases and factor levels were all the fuel trucks used during the deployment. During the stress testing used for model verification, higher arrival rates showed queuing for fuel trucks causing longer ground

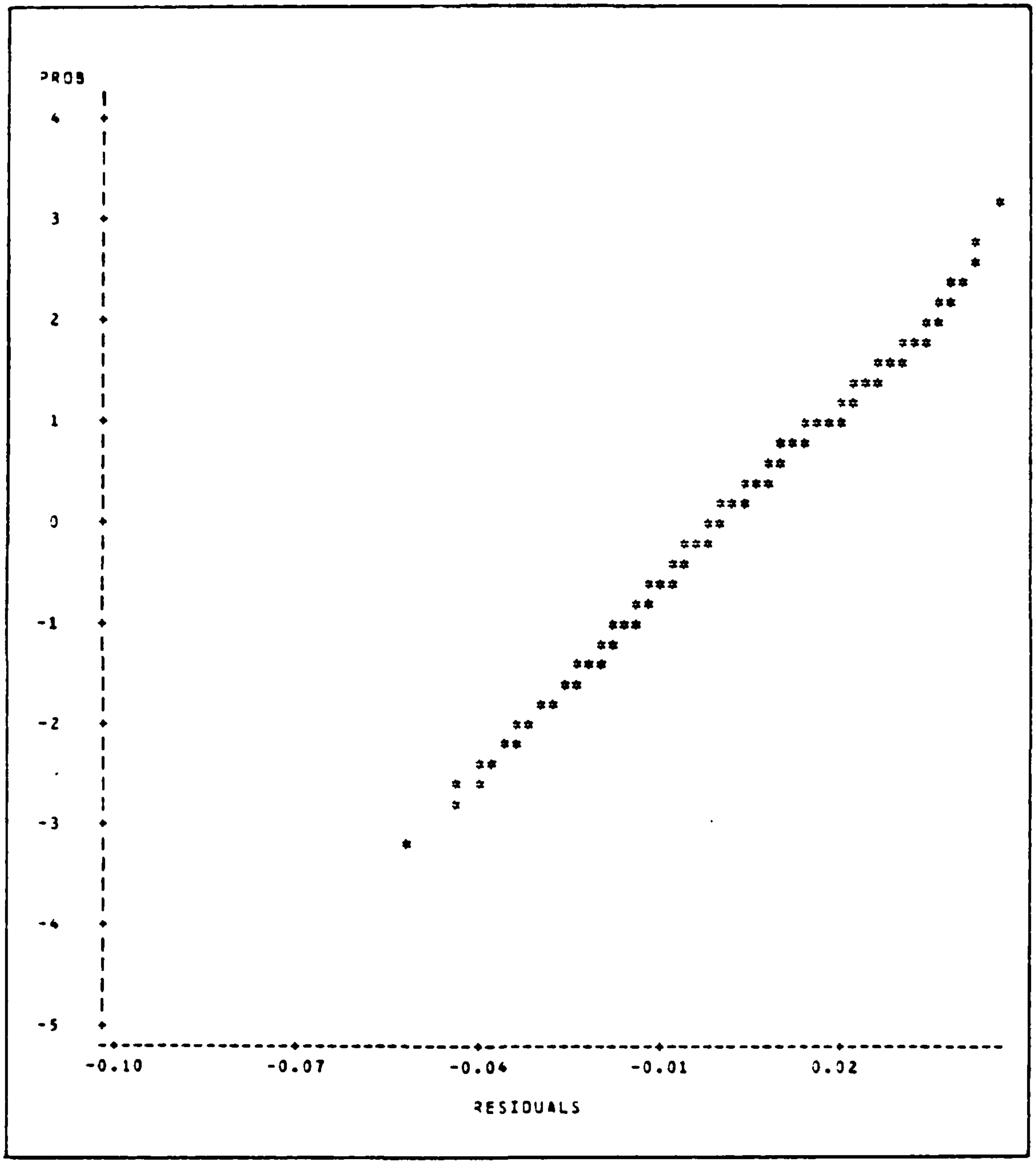

Figure 13. Normal Probability Plot of Residuals

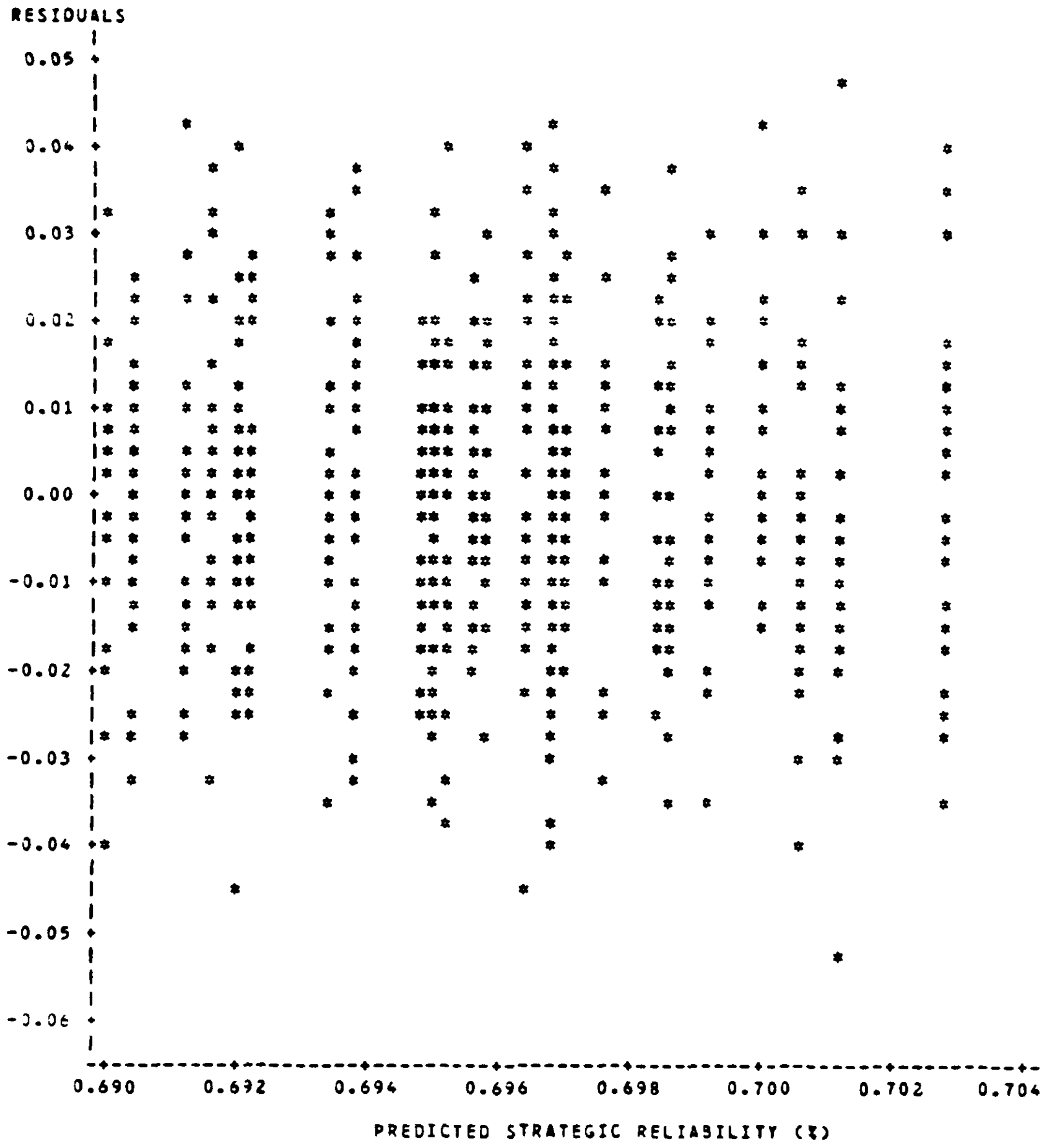

Figure 14. Residuals versus Predicted Values.

times for C-130s and strategic airlifters.

The statistically significant two factor interactions are also easily explained. The First*Route interaction accounts for the fact that when the early launching squadrons use the longer routes and the latest squadrons the shorter routes, overall closure time will be shorter than when the latest squadrons must use the longest routes. Since the planned routes range from 14.7 to 23.3 hours enroute time, scheduling the latest squadrons on short routes could reduce closure time by over 8 hours compared to a plan requiring those squadrons to travel long routes.

The explanation for the First*Trucks interaction stems from the earlier discussion of the insignificance of Trucks. Although Trucks was insignificant overall, different Route levels caused varying amounts of congestion, making the number of fuel trucks more or less important at the stressed station. The competition for refueling assets will be discussed fully in the subsequent section, Interaction Between Aircraft Types.

While the results of the ANOVA for CLOSURE show three main factors and two interactions to be statistically significant, the results in Table XV show the main effects far outweigh the interactions. In fact, the largest interaction terms contribute only 0.5 % of the grand mean closure time to the model. Therefore, the interaction terms, while statistically significant, are negligible for practical purposes and may safely be disregarded.

Strategic Airlift Departure Reliability. The discussion of the response variable RELIAB must start with the caveat that the model was built to analyze the deployment of C-130s to Europe and was calibrated to make the overall departure reliability figures accurate. The simplifying assumptions described in earlier chapters reduce the accuracy of the raw value of this response variable. However, while the actual response may be less accurate than desired (especially reliability rate observations at individual bases, as opposed to overall system reliability), the relative change in the response is still a good indicator of the competition between the strategic airlift and the C-130s.

The only statistically significant factor in explaining variations in RELIAB is the main factor, Route. However, this factor is actually of little value in explaining changes in RELIAB, as the largest effect contributes only 0.4 % of the grand mean to the departure reliability model. As stated earlier, this lack of response to the C-130 deployment occurred because the congestion at the enroute stations was not severe enough to force competition for resources.

Interaction Between Aircraft Types

As explained in the Introduction to this chapter, the source of interactions between the strategic airlifters and the deploying C-130s is the competition for resources at the enroute stations. This competition will only occur when the resources are fully utilized and queuing is occurring. Both the correlation matrix for the factors and responses (Table XIX) and the plot of closure time versus strategic reliability rate (Figure 15) show virtually no correlation between the two response variables. This is mainly due to the lack of stress at the enroute stations. A description of the resources and competition will help explain this lack of correlation.

Table XIX. Correlation Matrix.

	Rate	First	Route	Trucks	Closure	Reliab
Rate	1.000					
First	0.000	1.000				
Route	0.000	0.000	1.000			
Trucks	0.000	0.000	0.000	1.000		
Closure	0.234	0.904	0.260	0.002	1.000	
Reliab	-0.015	0.030	-0.073	0.048	0.004	1.000

<u>Runway</u>. The majority of bases throughout the world use only one runway at a time. All the bases modeled in this study are limited to single runway operation. Recall from earlier chapters, the runway is used for both arrivals and departures with airborne aircraft (arrivals) receiving traffic priority. Queuing for the runway would occur among both the airborne aircraft (aircraft in holding patterns awaiting arrival sequencing) and aircraft on the taxiways leading to the departure runway. The specified traffic priority would force longer queues on the taxiways. Early

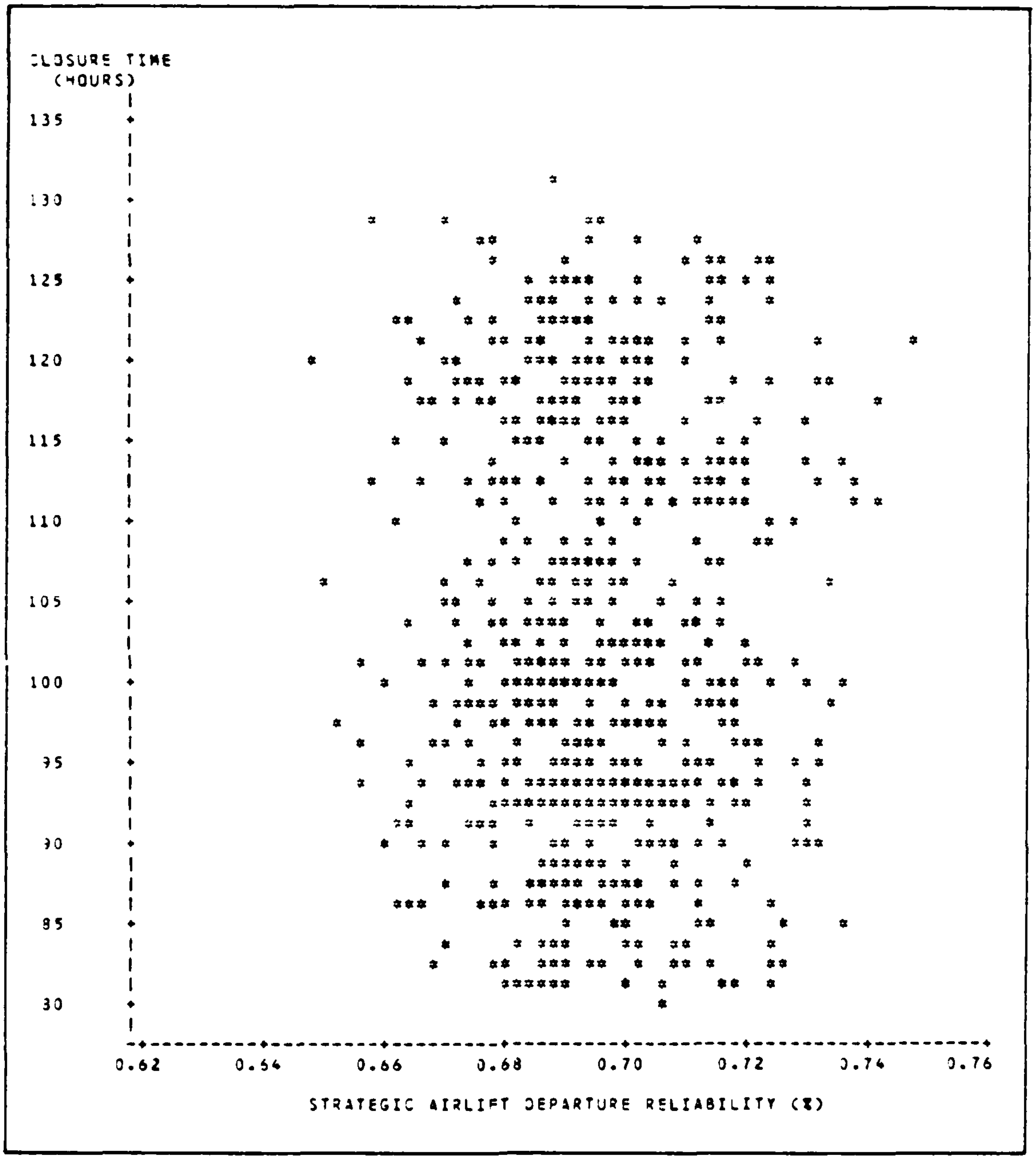

Figure 15. Closure Time vs. Strategic Reliability.

runs of the enroute station portion of the model showed the queuing for runway use to be insignificant until inter-arrival times decreased to less than 12 minutes between arrivals. At greater rates the arrivals, using the runway for 3 to 4 minutes, occasionally queue and begin causing numerous, and sometimes lengthy, queues amoung the departures who need the runway for 1.8 minutes for takeoff. In the factorial analysis none of the stations' average arrival rates increased above two arrivals per hour. While stochastic variations may have created short term surges, and therefore queuing, the runway resource was never heavily taxed.

Parking Ramp Space. Table II, in Chapter 2, shows the number of parking spaces available at each base. The smallest, LEXX, has very little C-130 activity (four squadrons at Route level "2"). At the height of the deployment flow the ramp was fully utilized, but no significant queuing occurred. With no ramp space remaining, a small increase in strategic airlift flow or C-130 deployment rate would cause significant problems, with aircraft unable to park and airborne aircraft requiring diversion. While this model can depict the state of the airlift system up to the point of ramp saturation, beyond that point the model is inadequate. Once aircraft begin queuing for the ramp, in the real world, aircraft may be parked on taxiways and cleared dirt areas or diverted to other bases.

Fuel Trucks and Pits. The stress test runs showed refueling to be a major source of interaction between the strategic airlifters and C-130s. At the highest arrival rates, aircraft were queuing for fuel and sustaining long ground times and late takeoffs. At its worst, this competition caused saturation of ramp space because aircraft could not refuel and release their parking spaces to inbound aircraft.

Under normal operating conditions, the study showed the bases with many fuel pits to underutilize their trucks. These bases rarely needed to use fuel trucks, as the vast majority of their fueling was from the more efficient pits. Average utilization of fuel trucks during the 225 hour period at these bases was at or near 0 for most runs. The bases with no fuel pits occasionally fully utilized their fuel trucks, with minor queuing delays. While these delays were insignificant, the potential for greater congestion with a small increase in arrivals was evident.

Sensitivity Analysis

The preceding discussion of interactions between the strategic airlift flow and the C-130s explained the system's sensitivity to changes in those factors that impact competition for resources at the enroute bases. Two of the input parameters, strategic airlift arrival rate and maintenance time distributions, were obtained from M-14 model output (25). While they are very important to the model, they are based on another stochastic simulation and therefore subject to some suspicion. Although the M-14 model is a highly regarded and very complete model of the strategic airlift system, sensitivity to these input parameters can still be considered worthy of inspection.

Strategic Airlift Arrival Rate. The strategic airlift arrival rates were varied 25 % from the nominal values. The effect on CLOSURE was indistinguishable between the three runs (normal rate, 25 % greater rate, 25 % lesser rate). The response variable RELIAB showed a greater change, varying from 0.6770 at the increased rate to 0.6968 at the slower rate. Competition for resources was only noted at LEXX where the strategic airlifters began queuing for ramp space. No C-130s transited LEXX during these runs. These runs again demonstrated the lack of correlation of response variables when there is no competition for resources.

Maintenance Times. In this series of runs the maintenance time distributions were increased or decreased by 10 % to evaluate the model's sensitivity to the maintenance distributions. As expected, both the strategic airlift reliability increased and the closure time decreased when the maintenance time was decreased (CLOSURE=97.41 and RELIAB=0.7179) versus the nominal case (CLOSURE=98.45 and RELIAB=.7001). Likewise, when maintenance time was increased reliability decreased (RELIAB=0.6858) and the closure time increased (CLOSURE=99.40). CLOSURE, while statistically different (alpha=0.05), was not practically different because of the small change in overall closure time caused by the changes in maintenance time. The impact on RELIAB was more significant, both statistically and practically, with a change in reliability of almost 5 % of the average reliability rate. While the effect on reliability was large, the lack of sensitivity of the closure time to changes in the maintenance rate increase confidence in the validity of closure time results.

Total C-130 Fuel Use.

An additional pr duct of this model is a summary of total C-130 fuel use. The total fuel use was measured at each base and changed only when the routing changed. Both total fuel consumed and fuel used at each base were insensitive to changes in the other three factors. Average fuel figures are displayed in Table XX. The differences between routes are significant at alpha=0.05.

Table XX. Total C-130 Fuel Use.

(in millions of pounds fuel)

Route	KNEX	CYXX	BIXX	LPXX	LEXX	TOTAL
2	7.30	5.98	3.09	1.68	1.64	19.69
1	4.57	4.09	3.03	3.92	0.0	15.60
0	5.23	4.08	2.19	3.92	0.0	15.42

This result is to be expected, as the fuel usage reflects the difference in enroute time on the three routes and follows the mean closure times by Route shown in Table XVII.

Summary

The analysis of results shows that unless the enroute system is congested enough to cause competition for resources there is little interaction between the strategic airlift flow and the C-130 deployment. The methodology envisioned would have the deployment planner determine, using this model, the presence or absence of competition. If no competition is present, the model can be used to adjust the C-130 closure time by changes to the three main factors Rate, First, and Route.

By far the most significant of these factors in terms of the effect on closure time is the time of first departure (First). By generating and launching the squadrons as early as possible, closure time can be decreased measurably. A second factor of significance, but with smaller gains to be achieved, is the time between departures within a squadron (Rate). Gains can be achieved by launching the squadrons in the least amount of time (greatest speed) consistent with departure base resource limitations.

The effects of the first two factors are significant, but predictable. The effects of Route are not as significant as First, but possibly more interesting than the previous two factors. Definite reductions in closure time (up to eight hours) were noted with the use of optimized routing plans (developed using integer programming techniques described in Chapter IV). Of benefit was the decrease in congestion gained by constraining flow through the highly stressed enroute airfields while minimizing total enroute time. Both optimized routing plans (levels "1" and "0") yielded approximately the same benefit (7-8 hours). Level "1" is the prefered plan because it introduces fewer restrictions to the aircraft routing.

A final observation concerns the interaction between the factors First and Route. While not expressly investigated, this interaction shows promise for allowing decreased closure time with decreased enroute congestion. By sending some of the earlier squadrons via longer but less congested routes, the short routes might be left available for the latest starting squadrons. While possibly increasing the average enroute time, this technique may decrease the overall closure time. One important consideration that must be addressed, however, is the need of the combat commander. If he prefered as many C-130s as soon as possible, he would choose the routing plans of this study. If he would rather have the majority of the C-130s closing in the shortest time with the first arriving a few hours later than ultimately possible, he would choose the alternative routing methodology suggested here.

VI. Observations and Recommendations

Introduction

This study simulated the structure of the North Atlantic MAC route system to analyze the deployment of approximately 400 C-130s to Europe during a major contingency. A simulation model of a large complex system such as this must contain some simplifications to reduce the complexity of the model. Simplifying assumptions were made in the construction of this model, as specified in Chapters II and III, primarily in the design of the support system at the enroute bases. These simplifications include: not modeling cargo loading and unloading at enroute bases, only modeling strategic aircraft arrivals at enroute bases (not their movement through the route structure), averaging the maintenance time for the aircraft over all the enroute bases, assuming the maintenance and fuel requirements for CRAF aircraft are the same as for MAC aircraft, not modeling diversion of aircraft when bases become highly congested, and not modeling contingency use of resources (for example, parking aircraft on locations not ordinarily used for ramp space).

Additionally, intentional excursions from reality were included in the model to make it only an approximate representation of the actual route structure and of actual planning for C-130 squadron beddown during contingencies. A more accurate model would have, of necessity, been classified.

These limitations to the model do not prevent analysts from drawing meaningful conclusions from the study. However care must be taken to ensure that the conclusions drawn are not applied indiscriminately to real world planning without consideration of the limitations of the model.

The methodology used in this study is proven. It has been shown that a simulation can identify resource limitations and bottlenecks at enroute stations. Additionally optimization techniques can be used to develop improved routing schemes for C-130 deployment. Lastly the simulation programs can compare quantitatively the effectiveness of the different routing schemes.

Observations

As stated in Chapter V, the model effectively simulates the deployment of C-130 aircraft during those contingencies in which competition for resources at enroute bases is not significant. When competition and queueing for resources does become significant, the model is less accurate. Activities not modeled, such as the diversion of aircraft, detract from the accuracy of the model.

Analysis shown in Chapter V also indicated that three factors were significant to the closure time of C-130s: Rate (the rate at which aircraft of a squadron depart their home base), First (the time the first aircraft of a squadron departs its home station), and Route (the route aircraft fly on their trip to Europe).

The effects of Rate and First correspond well with simple expected value calculations and a logical evaluation. The effect of First is much more significant than the effect of the other factors, with at least four times the influence of any other factor (maximum variation of 28 hours versus a maximum of seven hours).

The effect of the third factor, Route, may be the most interesting and controllable. Analysis indicates that the current route structure could be improved, possibly reducing closure time as much as eight hours.

For none of the factor levels did congestion at the enroute bases appear to be a problem, suggesting that a faster generation of the C-130 squadrons (lower values of First and Rate) could lead to substantial improvement of the closure time of the C-130s. This fact is contrary to the original intuitive expectation that reduced closure time would lead to increased congestion at enroute bases and lower departure reliability for strategic aircraft. Therefore, the limiting factor to rapid deployment appears to be how quickly the C-130s can depart home station.

Competition for the resources of runway and ramp space also did not appear to be significant. In stress tests congestion at enroute bases did not become significant until aircraft arrival rates exceeded five per hour.

In the analysis of strategic airlift departure reliability, Route was statistically significant, but did not have practical importance. C-130 movement apparently did not create enough congestion at enroute bases to significantly affect the departure reliability of the strategic aircraft.

Departure reliability is also statistically independent of closure time, as confirmed by a lack of statistical correlation of the two variables. Because the enroute system was not congested enough to cause competition for the resources at the enroute bases, the movement of strategic aircraft through the enroute bases was not affected by the timely flow of C-130 aircraft. Therefore there was no basis for an interaction of closure time with departure reliability.

The numerical values for closure time produced by the model are most likely more accurate than the values produced for departure reliability. However, since the model was calibrated to produce accurate overall values for departure reliability, these overall values are more accurate than the values at individual bases. The features of the model necessary for an accurate indication of closure time have been used, including an accurate portrayal of enroute times, route structure, and generation pattern of the aircraft over time.

Some of the features necessary for an accurate indication of strategic aircraft departure reliability have not been used, including: cargo loading and unloading at appropriate bases, accurate representation of actual aircraft destinations and enroute times, more accurate indication of

CRAF aircraft maintenance and refueling requirements (not modeled well even in the M-14 model), and a more accurate representation of maintenance distributions at the individual enroute bases.

A corollary benefit of the research was the determination of the fuel requirements for the fleet of C-130s deploying over the North Atlantic. Fuel use was independent of all factors except for Route. For level "2" of Route fuel use by all aircraft was 19.7 million pounds of fuel. For levels "1" and "0" use was approximately 15.5 million pounds, reflecting the use of optimized routing plans (the plans minimized the time enroute). As would be expected, at the individual bases fuel use varied considerably for the different levels of the factor.

Recommendations for Further Study

While this model has proven satisfactory for initial analysis of the deployment of C-130s to Europe, improvements could be made to increase the value of future analysis.

a. Model the movement of strategic aircraft through the route system, including the requirement for the movement of cargo.

b. Model more accurately the maintenance distribution at each enroute base.

c. Model more accurately the maintenance and fuel requirements for CRAF aircraft.

These improvements to the model would simulate much more accurately the movement of strategic aircraft through the North Atlantic route structure. Additionally, more accurate indications of the interactions between strategic aircraft and deploying C-130s would be obtained, especially for scenarios with more congestion at the enroute bases.

Different Contingencies. Other contingencies than NATO conflicts are of interest to operations planners, such as conflicts in Southwest Asia or in the Republic of Korea. Because resource limitations in such contingencies are not as constraining to the movement of aircraft as for a major European conflict, the methodology and model used in this research would be ideally suited for an analysis of C-130 deployment. Therefore, in those cases the application is recommended.

Appendix A. Description of Model

Computer Code.

The SLAM computer code for this model is shown in Appendix B to this thesis. The Fortran computer code is shown in Appendix C.

Output Statistics.

Time persistent statistics are used within the SLAM coding to track the fuel used by the C-130s transiting each of the enroute support bases and to track the number of C-130s delayed at enroute bases because a crew exceeds its crew duty day (16 hours for a basic crew and 18 hours for an augmented crew.) EVENTs 11 - 16 (in the EVENT subroutine) track the arrival of C-130s to beddown bases in Europe (mark the arrival time of every 20th aircraft) and the departure reliability rates for strategic airlift aircraft at enroute bases. The standard ground time for C-141s is 2 hours and 15 minutes, and for C-5s is 3 hours and 15 minutes; an aircraft is late when it takes off more than 14 minutes late. The last two output statistics reflect the measures of merit of the analysis and are written into an output file.

Resources.

Resources needed for landing, takeoff, and servicing operations on the ground are listed for each enroute base, including the runway, ramp space, and refueling facilities. Some bases have only trucks for refueling; some have trucks and refueling pits. Maintenance is treated as an activity, not as a competition for resources. Maintenance times for strategic airlift aircraft are derived from the M-14 model used at Hq MAC (25) and account for the availability (or nonavailability as the case may be) of maintenance personnel. Maintenance times for C-130s are obtained as described in Chapter II. Since the C-130s carry maintenance personnel with them from their home stations, the assumption that personnel necessary for their maintenance are available is satisfactory.

<u>Creation of C-130s</u>.

Twenty five squadrons of 16 aircraft each are created at the three CONUS departure bases, four at KWXX, nine at KCXX, and twelve at KSXX. At each base the first aircraft of one squadron is created at the earliest possible time, and subsequent aircraft are created in a Poisson process with exponential inter-departure times between creations. The Poisson process is appropriate for those situations in which events occur at approximately equal time intervals, but yet are still random in nature. Other squadrons at each base are created beginning at subsequently later times. This creation process is described more fully in Chapter IV, where factors with appropriate levels are fully described. Each aircraft is then assigned a squadron (attribute 3) and routing identifier (attribute 2). A description of the purpose of each attribute of each entity (aircraft) is shown in Table XXI.

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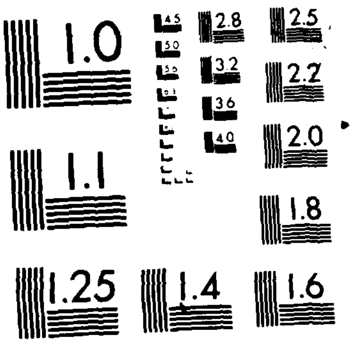

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Table XXI. Description of Attributes.

1 - MARK TIME (TIME OF CREATION)

2 - ROUTE NUMBER (ONLY USED FOR C-130S)

3 - SQUADRON NUMBER (ONLY USED FOR C-130S)

4 - ENROUTE TIME FOR NEXT ROUTE SEGMENT

5 - TIME OF ARRIVAL AT CURRENT ENROUTE BASE

6 - SIZE OF PARKING SPOT REQUIRED FOR TYPE OF AIRCRAFT

7 - TYPE OF AIRCRAFT
    1 - C-130
    2 - C-141
    3 - C-5

8 - USED TO MATCH PAIR OF ENTITIES CREATED DURING CONCURRENT REFUELING AND MAINTENANCE

9 - TIME TO REFUEL AIRCRAFT AT CURRENT ENROUTE STOP

10 - MAINTENANCE TIME FOR AIRCRAFT AT CURRENT ENROUTE STOP

11 - IDENTIFIES WHICH FUELING RESOURCE (PIT OR TRUCK) SELECTED FOR USE BY THE ALLOC SUBROUTINE

   - ALSO IDENTIFIES CREW ENTERING CREW REST (JUST PRIOR TO ENGINE START

   - ALSO USED TO DETERMINE IF ALLOWABLE GROUND TIME IS EXCEEDED

12 - NEXT STOP OF AIRCRAFT ON MISSION (ONLY USED FOR C-130S) (NOTE THAT BASE NAMES ARE NOTIONAL AND REFLECT THE GENERAL LOCATION OF THE BASE USING ICAO NOMENCLATURE)
    1 - CYXX (EASTERN CANADA)
    2 - BIXX (ICELAND)
    3 - LPXX (AZORES)
    4 - LEXX (SPAIN)
    5 - EGXX (GREAT BRITAIN)
    6 - EDXX (GERMANY)
    7 - LGXX (CENTRAL MEDITERRANEAN)

13 - FUEL REQUIRED FOR NEXT ENROUTE SEGMENT

14 - TIME CREW BEGINS DUTY DAY

15 - NUMBER OF RESOURCES USED FOR REFUELING (DETERMINED BY ALLOC ROUTINES)

After the branch to SCHD, the aircraft are assigned the start of the crew duty day (attribute 14), the required amount of parking space (attribute 6), and the aircraft type (attribute 7). EVENT 1 then schedules the aircraft to the proper enroute bases.

Scheduling and Staging.

A staging base is a location where the crew for an aircraft is changed during a minimum ground time. Since Air Reserve Force C-130s are only manned at a 2.0 crew ratio (two crews authorized for every assigned aircraft) (28), only one staging base is planned for every squadron enroute to its beddown location. The transportation of stage crews to the staging bases prior to the beginning of aircraft deployment is not modeled (stage crews are assumed to be in place when the deployment begins).

Staging base, route structure, and route lengths are input to the model from external files, simplifying the process of changing the routing structure of the model. Once input into the model, the data is stored within arrays, with the rows representing the different routes (a maximum of 14) and the six columns representing the different bases (departure base and five enroute bases). EVENTs 1 - 6 read data from the appropriate row and column of the arrays to provide the next destination and route length for the aircraft, and to determine if staging is planned at the current base.

Enroute Bases.

Five enroute bases are used within the model, representing typical bases used by MAC aircraft between the CONUS and Europe. At each base, required service activities are modeled including aircraft landing, taxi, and takeoff, refueling and maintenance activities, and the use of ramp space. Cargo loading and offloading are not modeled; C-130s carry only their own support equipment and will offload only at their beddown bases, and strategic airlift aircraft generally do not offload or onload cargo at enroute bases, only at their final destinations. Because the activities modeled at each base are similar, only one base will be described, with variations between bases noted. Figure 16 summarizes the activities at enroute bases.

At each base, strategic airlift aircraft arrivals are created at rates expected to occur during a NATO contingency. The rates used are obtained from the M-14 simulation model used at Hq MAC (25). C-141 aircraft are combined with narrow body Civil Reserve Air Fleet (CRAF) to form one category of aircraft, and C-5s are combined with wide body CRAF to form a second category of aircraft. For ease of reference, these categories are labeled as narrow body and wide body aircraft. At some bases, a significant number of CRAF aircraft transit, and must therefore be included in the analysis. The strategic airlifters in this model do not travel between bases; after takeoff they are terminated.

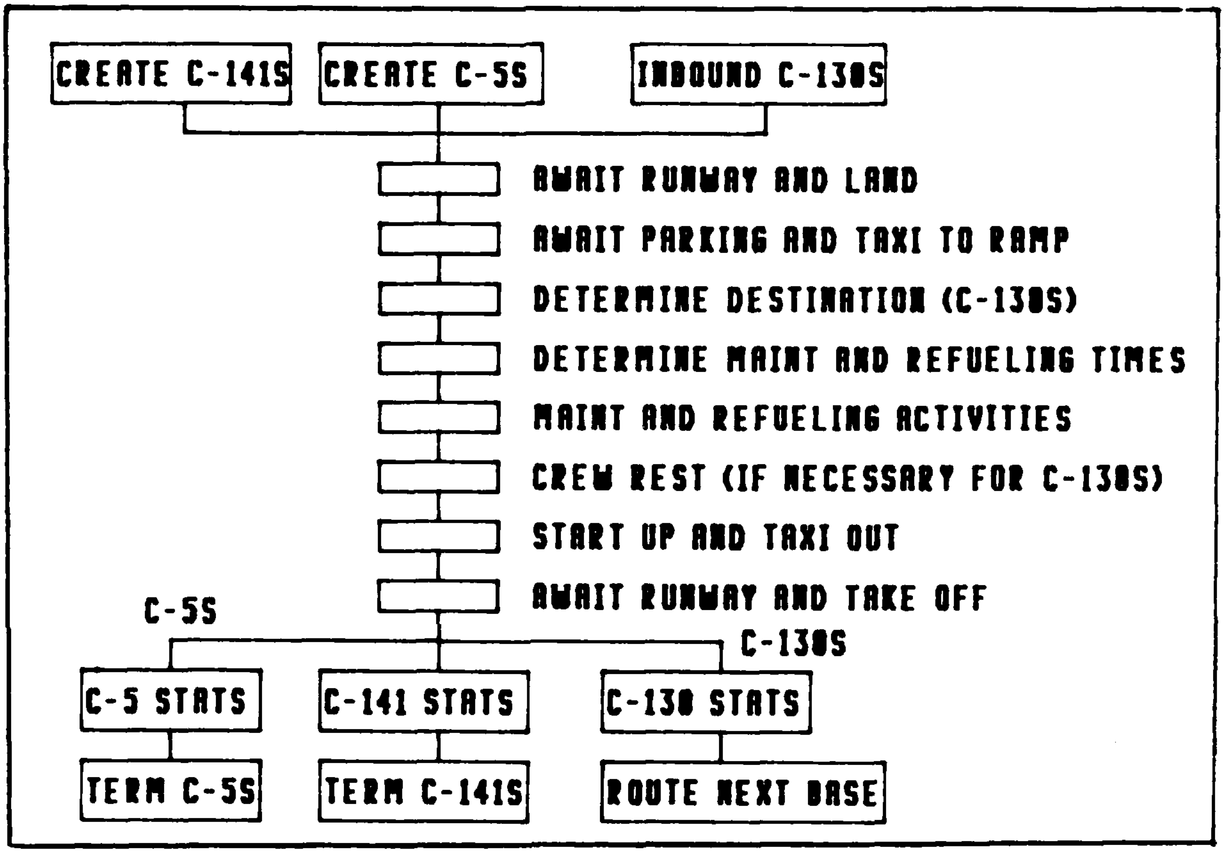

Figure 16. Enroute Base Flow Diagram.

After landing, statistics are collected on the length of time aircraft must wait in a holding pattern for landing clearance. After taxi to the ramp and postflight of the aircraft is complete, the next leg of the mission is scheduled in EVENTs 2-6. In the Fortran coding for the EVENT, destinations and route lengths for C-130s are read from two arrays, and a third array is read to determine if a crew change is scheduled at the base (a one (1) in the proper location in the third array indicates that a crew change, a stage, is planned). Also the enroute time is multiplied by a sample from a normal(1,.02) probability distribution to allow a stochastic variation in enroute times. Strategic airlift aircraft are assigned a flying time anticipated as most likely for aircraft departing the base. Variations are distributed uniformly up to one hour shorter or longer than the mean value to allow for deviations from the mean. These flying times were adjusted in the calibration and validation phase of the research.

Determination of Maintenance and Refueling Times.

Once the aircraft are scheduled for their next leg, the required fuel for the leg is obtained from USERF 1. USERF 1 relies on commonly accepted formulas used by Hq MAC/XOS to determine required fuel in its planning models (19). USERFs 11 - 15, each representing a different base, determine the maintenance time, if required, for the aircraft using probability distributions described in Chapter II.

The type of refueling resource used at a base (pit or truck) is determined by subroutine ALLOC, described later. Subroutine ALLOC also determines the time necessary to refuel the aircraft using regression formulas developed by Hq MAC/XPS which are used in the M-14 model (25).

According to studies conducted by Hq MAC/XPS, aircraft require maintenance 40% of the time at enroute bases for essential maintenance writeups (the Minimum Essential Systems List (MESL), the minimum systems that must work on an aircraft under wartime conditions) (25). Additionally 90% of required maintenance actions can be performed concurrently with refueling of the aircraft; the other maintenance must be performed nonconcurrently (25). Therefore, probabilistic branching is required to determine the category for each aircraft. Figure 17 shows the branching associated with maintenance and refueling.

Entities representing aircraft undergoing concurrent maintenance and refueling split into two parallel branches for the maintenance and refueling actions, and are reunited at a match node. For aircraft with nonconcurrent servicing, a check is made to determine if refueling resources are available. If resources are available, refueling is performed first; otherwise, maintenance is performed first.

Once servicing is complete, EVENTs 7 and 8 determine if C-130s have sufficient crew duty day remaining to fly the next leg of the mission (16 hours for basic crews and 18 hours for augmented crews). An automatic two hour extension to a duty day is assumed under wartime conditions (19). If a crew does not have enough crew duty day remaining, it enters into crew rest for 12 hours. Once crew rest is complete, the crew resumes the mission.

After completing crew rest, if necessary, the aircraft starts engines, taxis to the runway, and waits for the

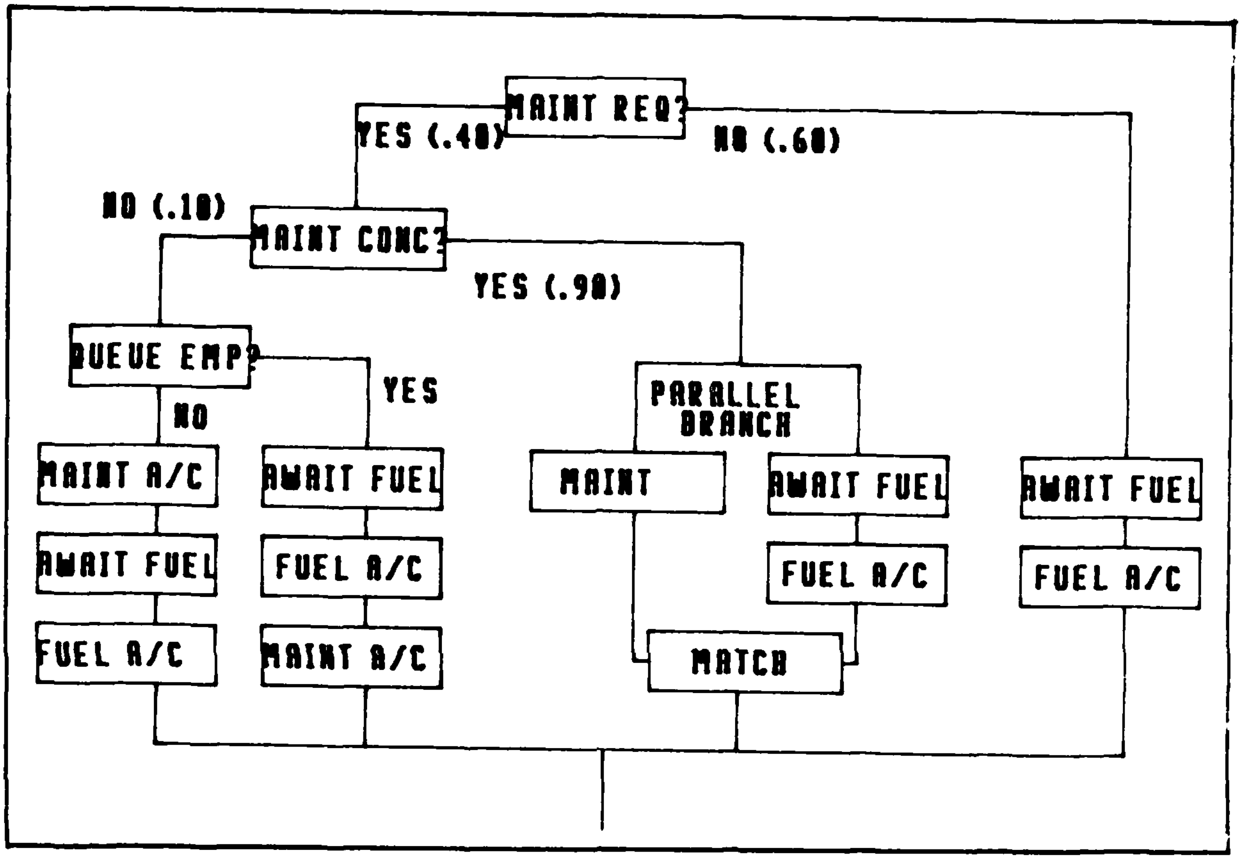

Figure 17. Maintenance and Refueling Activities.

runway to clear of landing traffic. Landing aircraft have priority on use of the runway, a standard Air Traffic Control (ATC) procedure. Aircraft waiting for takeoff must continue to wait until all aircraft holding to land have completed the landing process. Once the aircraft takes off, statistics are collected on the length of the time on the ground.

For strategic aircraft, EVENTs 12-16 determine if the ground time exceeds the authorized ground time (2 hours and 15 minutes for narrow body and 3 hours and 15 minutes for wide body aircraft). Aircraft exceeding these times by more than 14 minutes (the MAC standard for a late takeoff) are registered as an enroute delay. Once collection of statistics is complete, the aircraft are terminated.

Prior to routing the C-130s to their next destination, the toal fuel used at the base by the C-130s is updated by the amount pumped aboard the aircraft. Total fuel use at a base by C-130s is a time persistent output statistic.

Routing for all C-130s is accomplished at node ENR, where branching to the appropriate base takes place.

C-130 Destinations.

Once the C-130s arrive at their destinations, branching takes place to the appropriate squadrons to collect output statistics. Time persistent (XX(I)) variables keep track of the number of aircraft from the squadron arriving at the beddown base. EVENT 11 writes into an output file the time that the 15th (out of 16) aircraft arrives at the base. The time that the 15th aircraft arrives can be used as a measure of merit because the squadron then becomes capable of performing its wartime mission (over 90% of its aircraft are available to fly). Consultation with Hq MAC/XPS confirms this logic (25).

EVENT 11 also writes into the output file the time of arrival of every 20th aircraft at its beddown base. The primary measure of merit used within the model is the time of arrival of the 380th aircraft (95% of the 400 deploying aircraft) to its beddown base. This number displays less variance than the arrival of the 399th aircraft (15th aircraft of the last closing squadron) and is therefore more appropriate as an output measure.

Fortran Subroutines

Most subroutines used by the model are straightforward and self-explanatory, and are not described further in this appendix. However some are worthy of more explanation, which is provided below.

Subroutine Error. EVENTs 1 - 6 read routing information from arrays length, dest, and stage. If a zero is read from arrays length or dest, the arrays have been constructed in error (C-130s always must have a destination from an enroute base). If a zero is detected, subroutine error is called, which prints out the location of the array that was in error and stops the simulation.

Functions MINI, BIG, and JUMBO. USERF 1 calls functions MINI, BIG, and JUMBO to calculate fuel requirements for C-130s, C-141s, and C-5s, respectively, at an enroute base. These functions use rule of thumbs that are commonly used by aircrews and contingency planners at Hq MAC/XOS to calculate fuel requirements for the different aircraft (19).

Subroutine ALLOC. Subroutine ALLOC allocates pit or truck refueling resources at all bases. If no resources are free at the time of the call to the subroutine, the routine returns to the main program with no allocation of resources (the entity continues to wait for a resource to become free). A pit resource is allocated first, if free, because a pit refuels an aircraft faster than a truck. If a pit is not free, a truck is allocated to the aircraft. Once the resource is allocated, the refueling time is computed and the number of the resource used is stored in attribute 11 (this number is used at the free node when refueling is complete). Attribute 15 then stores how many of the resource (one) were used (this number is also used at the free node when refueling is complete to release the resource). Refueling times are calculated using regression equations developed by Hq MAC/XPS for use in the M-14 simulation model. After refueling is complete, the resource in use is released for use at a free node.

Appendix B. SLAM Code

This appendix contains the SLAM code used for the construction of the simulation model. This code is displayed on the following pages.

```
  GEN,HILL & DONNELLY,THESIS MODEL,1/15/86,1,N,N,Y,N,Y;
LIMITS,60,15,750;
;
;         =================================================
;         THE SLAM MODEL FOR THE THESIS OF HILL AND DONNELLY
;         =================================================
;
;
;         THIS MODEL WILL SIMULATE THE MOVEMENT OF 400 C-130S
;         (25 SQUADRONS OF 16 AIRCRAFT) FROM THE CONTINENTAL US
;         (CONUS) THROUGH THE NORTH ATLANTIC ROUTE STRUCTURE TO
;         BEDDOWN BASES IN EUROPE. AT THE ENROUTE BASES THE C-130S
;         WILL COMPETE WITH STRATEGIC AIRLIFT (C-5S ,C-141S, KC-10S,
;         AND CRAF AIRCRAFT) FOR REQUIRED MAINTENANCE AND REFUELING
;         ACTIVITIES.
;
;         EACH SQUADRON HAS AN ASSIGNED ROUTE STRUCTURE, WITH A TOTAL
;         OF 14 POSSIBLE DIFFERENT STRUCTURES. EACH SQUADRON WILL ALSO
;         HAVE ONE STAGING BASE ENROUTE, WHERE THE INCOMING CREW ENTERS
;         CREW REST AND A NEW CREW PICKS UP THE MISSION DURING THE NORMAL
;         1.5 HOUR GROUND TIME. (FURTHER BELOW THE LOCATIONS OF THE BASES
;         ARE DESCRIBED). THE ASSIGNED ROUTE STRUCTURES ARE AS SHOWN BELOW.
;
;        ROUTE      SQUADS          ITINERARY                STAGING BASE
;        -----      ------          ---------                ------- ----
;          1         1,2       KWXX - CYXX - EGXX               CYXX
;          2         3,4       KWXX - KNEX - BIXX - EGXX        KNEX
;          3         5,6       KCXX - KNEX - LEXX - LGXX        LEXX
;                                                   (REQUIRES AUGMENTED CREW)
;          4          7        KCXX - KNEX - LPXX - LGXX        LPXX
;          5         8,9       KCXX - CYXX - BIXX - EDXX        BIXX
;          6         10        KCXX - CYXX - EDXX               CYXX
;          7         11,12     KCXX - KNEX - EGXX               KNEX
;          8          13       KCXX - KNEX - BIXX - EGXX        KNEX
;          9         14,15     KSXX - CYXX - LEXX - LGXX        LEXX
;          10        16,17     KSXX - LPXX - LGXX               LPXX
;          11        18,19     KSXX - CYXX - EDXX               CYXX
;          12        20,21     KSXX - KNEX - BIXX - EDXX        BIXX
;          13        22,23     KSXX - CYXX - EGXX               CYXX
;          14        24,25     KSXX - KNEX - BIXX - EGXX        BIXX
;
;
;         EACH AIRCRAFT FLOWING THROUGH THE NETWORK WILL BE REP-
;         RESENTED AS AN ENTITY. THE ATTRIBUTES FOR EACH ENTITY
;         WILL CONTAIN INFORMATION TO IDENTIFY THE ENTITY.
;         ATTRIBUTES ALSO WILL CONTAIN STOCHASTIC MAINTENANCE
;         AND REFUELING TIMES. A DESCRIPTION OF EACH ATTRIBUTE
;         IS SHOWN BELOW.
;
;
;
;
;
```

```
;          1 - MARK TIME (TIME OF CREATION)
;
;          2 - ROUTE NUMBER (ONLY USED FOR C-130S)
;
;          3 - SQUADRON NUMBER (ONLY USED FOR C-130S)
;
;          4 - ENROUTE TIME FOR NEXT ROUTE SEGMENT
;
;          5 - TIME OF ARRIVAL AT CURRENT ENROUTE BASE
;
;          6 - SIZE OF PARKING SPOT REQUIRED FOR TYPE OF AIRCRAFT
;
;          7 - TYPE OF AIRCRAFT
;                 1 - C-130
;                 2 - C-141
;                 3 - C-5
;
;          8 - USED TO MATCH PAIR OF ENTITIES CREATED DURING CONCURRENT
;              REFUELING AND MAINTENANCE
;
;          9 - TIME TO REFUEL AIRCRAFT AT CURRENT ENROUTE STOP
;
;          10 - MAINTENANCE TIME FOR AIRCRAFT AT CURRENT ENROUTE STOP
;
;          11 - IDENTIFIES WHICH FUELING RESOURCE (PIT OR TRUCK) SELECTED
;               FOR USE BY THE ALLOC SUBROUTINE
;
;             - ALSO IDENTIFIES CREW ENTERING CREW REST (JUST PRIOR
;               TO ENGINE START
;
;             - ALSO USED TO DETERMINE IF ALLOWABLE GROUND TIME IS EXCEEDED
;
;          12 - NEXT STOP OF AIRCRAFT ON MISSION (ONLY USED FOR C-130S)
;               (NOTE THAT BASE NAMES ARE NOTIONAL AND REFLECT THE GENERAL
;               LOCATION OF THE BASE USING ICAO NOMENCLATURE)
;               1 - CYXX  (EASTERN CANADA)
;               2 - BIXX  (ICELAND)
;               3 - LPXX  (AZORES)
;               4 - LEXX  (SPAIN)
;               5 - EGXX  (GREAT BRITAIN)
;               6 - EDXX  (GERMANY)
;               7 - LGXX  (CENTRAL MEDITERRANEAN)
;
;          13 - FUEL REQUIRED FOR NEXT ENROUTE SEGMENT
;
;          14 - TIME CREW BEGINS DUTY DAY
;
;          15 - NUMBER OF RESOURCES USED FOR REFUELING (DETERMINED
;               BY ALLOC ROUTINES)
;
;
;
;
```

```
;                STATISTICS COLLECTED OVER TIME
;                ---------- --------- ---- ----
;
;                FUEL REQUIRED AT ENROUTE BASES
;
TIMST,XX(2),FUEL REQ AT KNEX;
TIMST,XX(3),FUEL REQ AT CYXX;
TIMST,XX(4),FUEL REQ AT BIXX;
TIMST,XX(5),FUEL REQ AT LPXX;
TIMST,XX(6),FUEL REQ AT LEXX;
;
;              NUMBER OF CREWS ENTERING CREW REST OTHER
;                    THAN AT STAGE LOCATIONS
;
TIMST,XX(32),NET 1 CREW REST;
TIMST,XX(33),NET 2 CREW REST;
TIMST,XX(34),NET 3 CREW REST;
TIMST,XX(35),NET 4 CREW REST;
TIMST,XX(36),NET 5 CREW REST;
TIMST,XX(37),NET 6 CREW REST;
TIMST,XX(38),NET 7 CREW REST;
TIMST,XX(39),NET 8 CREW REST;
TIMST,XX(40),NET 9 CREW REST;
TIMST,XX(41),NET 10 CREW REST;
TIMST,XX(42),NET 11 CREW REST;
TIMST,XX(43),NET 12 CREW REST;
TIMST,XX(44),NET 13 CREW REST;
TIMST,XX(45),NET 14 CREW REST;
;
NETWORK;
;
;             =======================
;             RESOURCES FOR ALL BASES
;             =======================
;
;                                     RESOURCE NUMBER
;                                     -------- ------
;                FOR BASE KNEX
;
        RESOURCE/RUNWAY1(1),11,12;          1
        RESOURCE/PARK1(630),13;             2
        RESOURCE/TRUCK1(12),14;             3
;
;                FOR BASE CYXX
;
        RESOURCE/RUNWAY2(1),21,22;          4
        RESOURCE/PARK2(840),23;             5
        RESOURCE/PIT2(11),24;               6
        RESOURCE/TRUCK2(2),24;              7
;
;
;
;
```

```
;                FOR BASE BIXX
;
        RESOURCE/RUNWAY3(1),31,32;        8
        RESOURCE/PARK3(462),33;           9
        RESOURCE/TRUCK3(10),34;           10
;
;                FOR BASE LPXX
;
        RESOURCE/RUNWAY4(1),41,42;        11
        RESOURCE/PARK4(830),43;           12
        RESOURCE/PIT4(29).44;             13
        RESOURCE/TRUCK4(6),44;           14
;
;                FOR BASE LEXX
;
        RESOURCE/RUNWAY5(1),51,52;        15
        RESOURCE/PARK5(144),53;           16
        RESOURCE/PIT5(27),54;             17
        RESOURCE/TRUCK5(7),54;           18
;
;            =========================
;            CREATION OF ALL SQUADRONS
;            =========================
;
;         (SIXTEEN AIRCRAFT PER SQUADRON)
;
;
;            AT CONUS BASE KWXX
;            -- ----- ---- ----
:
;               SQUADRON ONE
;
KWXX    CREATE,EXPON(1.0),15.1.16:
        ASSIGN,ATRIB(2) = 1,ATRIB(3) = 1;
        ACT,,,SCHD;
;
;              SQUADRON TWO
;
        CREATE.EXPON(1.0),27,1,16:
        ASSIGN,ATRIB(2)=1,ATRIB(3)=2;
        ACT,,,SCHD;
;
;            SQUADRON THREE
;
        CREATE,EXPON(1.0),39,1,16;
        ASSIGN,ATRIB(2)=2,ATRIB(3)=3;
        ACT,,,SCHD;
;
;            SQUADRON FOUR
;
        CREATE,EXPON(1.0),51,1,16;
        ASSIGN,ATRIB(2)=2,ATRIB(3)=4;
        ACT,,,SCHD;
```

```
;
;
;          AT CONUS BASE KCXX
;          -- ----- ---- ----
;
;         CREATE SQUADRON FIVE
;
KCXX    CREATE,EXPON(1.0),15,1,16;
        ASSIGN,ATRIB(2)=3,ATRIB(3)= 5;
        ACT,,,SCHD;
;
;            SQUADRON SIX
;
        CREATE,EXPON(1.0),27,1,16;
        ASSIGN,ATRIB(2)=3,ATRIB(3)=6;
        ACT,,,SCHD;
;
;            SQUADRON SEVEN
;
        CREATE,EXPON(1.0),39,1,16;
        ASSIGN,ATRIB(2)=4,ATRIB(3)=7;
        ACT,,,SCHD;
;
;            SQUADRON EIGHT
;
        CREATE,EXPON(1.0),51,1,16;
        ASSIGN,ATRIB(2)=5,ATRIB(3)=8;
        ACT,,,SCHD;
;
;            SQUADRON NINE
;
        CREATE,EXPON(1.0),63,1,16;
        ASSIGN,ATRIB(2)=5,ATRIB(3)=9;
        ACT,,,SCHD;
;
;            SQUADRON TEN
;
        CREATE,EXPON(1.0),51,1,16;
        ASSIGN,ATRIB(2)=6,ATRIB(3)=10;
        ACT,,,SCHD;
;
;            SQUADRON ELEVEN
;
        CREATE,EXPON(1.0),63,1,16;
        ASSIGN,ATRIB(2)=7,ATRIB(3)=11;
        ACT,,,SCHD;
;
;            SQUADRON TWELVE
;
        CREATE,EXPON(1.0),51,1,16;
        ASSIGN,ATRIB(2)=7,ATRIB(3)=12;
        ACT,,,SCHD;
;
```

```
;           SQUADRON THIRTEEN
;
        CREATE,EXPON(1.0),63,1,16;
        ASSIGN,ATRIB(2)=8,ATRIB(3)=13;
        ACT,,,SCHD;
;
;
;          AT CONUS BASE KSXX
;
;          -- ----- ---- ----
;
;        CREATE SQUADRON FOURTEEN
;
KSXX    CREATE,EXPON(1.0),63,1,16;
        ASSIGN,ATRIB(2)=9,ATRIB(3)=14;
        ACT,,,SCHD;
;
;           SQUADRON FIFTEEN
;
        CREATE,EXPON(1.0),51,1,16;
        ASSIGN,ATRIB(2)=9,ATRIB(3)=15;
        ACT,,,SCHD;
;
;           SQUADRON SIXTEEN
;
        CREATE,EXPON(1.0),63,1,16;
        ASSIGN,ATRIB(2)=10,ATRIB(3)=16;
        ACT,,,SCHD;
;
;           SQUADRON SEVENTEEN
;
        CREATE,EXPON(1.0),51,1,16;
        ASSIGN,ATRIB(2)=10,ATRIB(3)=17;
        ACT,,,SCHD;
;
;           SQUADRON EIGHTEEN
;
        CREATE,EXPON(1.0),63,1,16;
        ASSIGN,ATRIB(2)=11,ATRIB(3)=18;
        ACT,,,SCHD;
;
;           SQUADRON NINETEEN
;
        CREATE.EXPON(1.0),51,1,16:
        ASSIGN,ATRIB(2)=11,ATRIB(3)=19;
        ACT,,,SCHD:
;
;           SQUADRON TWENTY
;
        CREATE,EXPON(1.0),63,1,16;
        ASSIGN,ATRIB(2)=12,ATRIB(3)=20;
        ACT,,,SCHD;
;
;
```

```
;            SQUADRON TWENTY-ONE
;
        CREATE,EXPON(1.0),51,1.16:
        ASSIGN,ATRIB(2)=12,ATRIB(3)=21;
        ACT,,,SCHD:
;
;            SQUADRON TWENTY-TWO
;
        CREATE,EXPON(1.0).15,1,16;
        ASSIGN,ATRIB(2)=13,ATRIB(3)=22;
        ACT,,,SCHD;
;
;            SQUADRON TWENTY-THREE
;
        CREATE,EXPON(1.0),27,1,16;
        ASSIGN,ATRIB(2)=13,ATRIB(3)=23;
        ACT,,,SCHD;
;
;            SQUADRON TWENTY-FOUR
;
        CREATE,EXPON(1.0).39,1,16;
        ASSIGN,ATRIB(2)=14,ATRIB(3)=24;
        ACT,,,SCHD;
;
;            SQUADRON TWENTY-FIVE
;
        CREATE,EXPON(1.0),51,1,16:
        ASSIGN,ATRIB(2)=14,ATRIB(3)=25:
        ACT,.,SCHD;
;
;          ===========================
;          BRANCH C-130S TO PROPER BASE
;          ===========================
;
;        FIRST ASSIGN PARKING SPOTS REQUIRED, A/C TYPE, AND
;             MARK START OF DUTY DAY
;
SCHD    ASSIGN,ATRIB(6)=10,ATRIB(7)=1,ATRIB(14)=TNOW - 1.5:
;
;              THEN SCHEDULE THE C-130S TO THE PROPER BASE
;
        EVENT,1;
;
;
;
;
;
;
;
;
;
;
;
```

```
;               ==============================================
;               BRANCHING OF ALL C-130S FROM ALL ENROUTE BASES
;               ==============================================
;
ENR      GOON,1;
         ACT,ATRIB(4),ATRIB(12).EQ.1,CYXX;
         ACT,ATRIB(4),ATRIB(12).EQ.2,BIXX;
         ACT,ATRIB(4),ATRIB(12).EQ.3,LPXX;
         ACT,ATRIB(4),ATRIB(12).EQ.4,LEXX;
         ACT,ATRIB(4),ATRIB(12).EQ.5,EGXX;
         ACT,ATRIB(4),ATRIB(12).EQ.6,EDXX;
         ACT,ATRIB(4),ATRIB(12).EQ.7,LGXX;
         ACT,ATRIB(4),ATRIB(12).EQ.8,KNEX;
;
;       ============================================
;       STATION MODELS FOR GROUND SERVICE ACTIVITIES
;       ============================================
;
;
;
;              ============
;              STATION KNEX
;              ============
;
;        ONLY TRUCKS ARE AVAILABLE FOR REFUELING AT KNEX
;        ---- ------ --- --------- --- --------- -- ----
;
;         CREATE STRAT AIRLIFT ARRIVALS
;
         CREATE,EXPON(3.712),,1;      C-141 AIRCRAFT
         ASSIGN,ATRIB(6)=30,ATRIB(7)=2;
         ACT,,,KNEX;
;
         CREATE,EXPON(7.779),,1;      C-5   AIRCRAFT
         ASSIGN,ATRIB(6)=90,ATRIB(7)=3;
         ACT,,,KNEX;
;
;         GROUND ACTIVITIES AT BASE KNEX
;
KNEX     ASSIGN,ATRIB(5)=TNOW;
;
;         LAND AIRCRAFT
;
         AWAIT(11),RUNWAY1/1;
         ACT(1)/11,USERF(5);        TIME TO LAND
         FREE,RUNWAY1/1;
         COLCT,INT(5),HOLDING AT KNEX;
;
;        TAXI AND PARK
;
         ASSIGN,ATRIB(5)=TNOW;
         AWAIT(13),PARK1/ATRIB(6);
         ACT,USERF(6);     TIME TO TAXI TO RAMP
         GOON;
```

```
        ACT,TRIAG(.1,.2,.4);   POSTFLIGHT
;
;       SCHEDULE NEXT LEG
;       -------- ---- ---
;
        EVENT,2,1;
;
;      DETERMINE MAINT AND REFUELING TIMES,AND REQUIRED FUEL
;
        ASSIGN,ATRIB(13) = USERF(1);
        ASSIGN,ATRIB(10) = USERF(11);
;
;
;      DETERMINE IF MAINTENANCE IS CONCURRENT
;      --------- -- ----------- -- ----------
;
        GOON,1;
        ACT/17,,.60,FUE1;           NO MAINTENANCE REQUIRED
        ACT/18,,.35,CON1;           CONCURRENT MAINTENANCE
        ACT/19,,.05,NON1;          NONCONCURRENT MAINTENANCE
;
;
;               CONCURRENT SERVICE
;               ---------- -------
;
;     (PARALLEL BRANCHING - CREATE TWO ENTITIES)
;
CON1    ASSIGN,XX(1)=XX(1)+1,ATRIB(8)=XX(1);
        ACT,,,GAS1;
        ACT,,,FIX1;
;
;       FUEL CONCURRENTLY
;
GAS1    AWAIT(14),ALLOC(1);
        ACT/14,ATRIB(9);
        FREE,ATRIB(11)/ATRIB(15);
ONE1    QUEUE(15),,,,GO1;
;
;       CONCURRENT MAINTENANCE
;
FIX1    GOON;
        ACT/15,ATRIB(10);
TWO1    QUEUE(16),,,,GO1;
;
;       MATCH ENTITIES BACK TOGETHER
;
GO1     MATCH,8,ONE1/TOG1,TWO1;
;
;
;
;
;
;
```

```
;         NONCURRENT SERVICE
;         ---------- -------
;
;
;    IF AIRCRAFT ARE IN REFUELING QUEUE, PERFORM MAINTENANCE
;    FIRST, OTHERWISE FUEL FIRST
;
NON1      GOON,1;
          ACT,,NNQ(14).GT.0,NMN1;
          ACT;
;
;        FUEL FIRST
;
          AWAIT(14),ALLOC(1);
          ACT/14,ATRIB(9);    FUEL
          FREE,ATRIB(11)/ATRIB(15);
;
          ACT/15,ATRIB(10),,TOG1;          MAINTENANCE
;
;         MAINTENANCE FIRST
;
NMN1      GOON;
          ACT/15,ATRIB(10);      MAINTENANCE
;
FUE1      AWAIT(14),ALLOC(1);
          ACT/14,ATRIB(9):    FUEL
          FREE,ATRIB(11)/ATRIB(15);
;
:
;          SERVICING IS NOW COMPLETE
;          --------- -- --- --------
;
;        ALL ENTITIES ARE NOW BACK TOGETHER
;       (ALL BRANCHES ARE COMBINED AT TOG1)
;
;       ALSO SCHEDULE CREW REST, IF NECESSARY
;       ---- -------- ---- ----- -- ---------
;
:
TOG1      EVENT,7,1;
;
;          DELAY IF CREW IS IN CREW REST
;          ----- -- ---- -- -- ---- ----
;   (ATRIB(11) INDICATES THAT CREW ENTERS CREW REST)
;
          GOON,1;
          ACT,14,ATRIB(11).EQ.1;
          ACT:
;
BAC1      FREE,PARK1/ATRIB(6);
;
:    START AND TAXI OUT
;
          ACT,RLOGN(.4,.1);
```

```
;
;     TAKEOFF
;
;
         AWAIT(12),RUNWAY1/1;
         ACT,.03;
         FREE,RUNWAY1/1;
         ASSIGN,ATRIB(5) = ATRIB(5) + .03;
;
;
;     COLLECT STATISTICS FOR KNEX
;     ------- ---------- --- ----
;
         GOON,1;
         ACT,,ATRIB(7).EQ.2,BIG1;
         ACT,,ATRIB(7).EQ.3,JUM1;
         ACT;
;
;     COLLECT C-130 STATISTICS AND ROUTE TO NEXT BASE
;     ------- ----- ---------- --- ----- -- ---- ----
;
         COLCT,INT(5),C130 GRD KNEX;
         ASSIGN,XX(2) = XX(2) + ATRIB(13);
         ACT,,,ENR;
;
;      C-141 STATISTICS
;
BIG1     COLCT,INT(5),C141 GRD KNEX;
         ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
         EVENT,12;          COLLECT DATA ON STRAT DELAYS
         TERM;
;
;      C-5 STATISTICS
;
JUM1     COLCT,INT(5),C5 GRD TIME KNEX;
         ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
         EVENT,12;          COLLECT DATA ON STRAT DELAYS
         TERM;
;
;              ============
;              STATION CYXX
;              ============
;
;     BOTH TRUCKS AND PITS ARE AVAILABLE FOR REFUELING AT CYXX
;     ---- ------ --- ---- --- --------- --- --------- -- ----
;
;         CREATE STRAT AIRLIFT ARRIVALS
;
         CREATE,EXPON(7.558),,1;      C-141 AIRCRAFT
         ASSIGN,ATRIB(6)=20,ATRIB(7)=2;
         ACT,,,CYXX;
```

```
;
        CREATE,EXPON(2.704),,1;     C-5   AIRCRAFT
        ASSIGN,ATRIB(6)=35,ATRIB(7)=3;
        ACT,,,CYXX;
;
;        GROUND ACTIVITIES AT BASE CYXX
;
CYXX    ASSIGN,ATRIB(5)=TNOW;
;
;        LAND AIRCRAFT
;
        AWAIT(21),RUNWAY2/1;
        ACT(1)/21,USERF(5);     TIME TO LAND
        FREE,RUNWAY2/1;
        COLCT,INT(5),HOLDING AT CYXX;
;
;       TAXI AND PARK
;
        ASSIGN,ATRIB(5)=TNOW;
        AWAIT(23),PARK2/ATRIB(6);
        ACT,USERF(6);     TIME TO TAXI TO RAMP
        GOON;
        ACT,TRIAG(.1,.2..4);   POSTFLIGHT
;
;       SCHEDULE NEXT LEG
;       -------- ---- ---
;
        EVENT,3,1;
;
;      DETERMINE MAINT TIME AND REQUIRED FUEL
;
        ASSIGN,ATRIB(13) = USERF(1);
        ASSIGN,ATRIB(10) = USERF(12);
;
;
;      DETERMINE IF MAINTENANCE IS CONCURRENT
;
;      --------- -- ----------- -- ----------
;
        GOON,1;
        ACT/27,,.60,FUE2;          NO MAINTENANCE REQUIRED
        ACT/28,,.35,CON2;          CONCURRENT MAINTENANCE
        ACT/29,,.05,NON2;         NONCONCURRENT MAINTENANCE
;
;
;              CONCURRENT SERVICE
;              ---------- -------
;
;     (PARALLEL BRANCHING - CREATE TWO ENTITIES)
;
CON2    ASSIGN,XX(1)=XX(1)+1,ATRIB(8)=XX(1);
        ACT,,,GAS2;
        ACT,,,FIX2;
;
```

```
;         FUEL CONCURRENTLY
;
;    ALLOC(2) DETERMINES IF PIT OR TRUCK RESOURCE, PREFERABLY
;    -------
;              PIT, IS AVAILABLE
;
GAS2      AWAIT(24),ALLOC(2):
          ACT/24,ATRIB(9);
          GOON,1;
          ACT,,ATRIB(11).EQ.6,ONE2;
          ACT:
          FREE,ATRIB(11)/ATRIB(15);
ONE2      QUEUE(25),,,,GO2;
;
;         CONCURRENT MAINTENANCE
;
FIX2      GOON:
          ACT/25,ATRIB(10);
TWO2      QUEUE(26),,,,GO2;
;
;         MATCH ENTITIES BACK TOGETHER
;
GO2       MATCH,8,ONE2/TOG2,TWO2:
;
;
;         NONCURRENT SERVICE
;         ---------- -------
;
;    IF AIRCRAFT ARE IN REFUELING QUEUE, PERFORM MAINTENANCE
;    FIRST, OTHERWISE FUEL FIRST
;
NON2      GOON,1;
          ACT,,NNQ(24).GT.0,NMN2;
          ACT;
;
;        FUEL FIRST
;
          AWAIT(24),ALLOC(2);
          ACT/24,ATRIB(9);    FUEL
          GOON,1:
          ACT,,ATRIB(11).EQ.6,HEL2;
          ACT:
          FREE,ATRIB(11)/ATRIB(15):
;
HEL2      GOON,1:
          ACT/25,ATRIB(10),,TOG2;      MAINTENANCE
;
;         MAINTENANCE FIRST
;
NMN2      GOON;
          ACT/25,ATRIB(10);      MAINTENANCE
;
;
```

```
FUE2     AWAIT(24),ALLOC(2);
         ACT/24,ATRIB(9);    FUEL
         GOON,1;
         ACT,,ATRIB(11).EQ.6,TOG2;
         ACT;
         FREE,ATRIB(11)/ATRIB(15);
;
;
;         SERVICING IS NOW COMPLETE
;         --------- -- --- --------
;
;       ALL ENTITIES ARE NOW BACK TOGETHER
;      (ALL BRANCHES ARE COMBINED AT TOG2)
;
;      ALSO SCHEDULE CREW REST IF NECESSARY
;      ---- -------- ---- ---- -- ---------
;
TOG2     GOON,1;
         ACT,,ATRIB(11).EQ.6,REL2;
         ACT;
;
HUR2     EVENT,8,1
;
;         DELAY IF CREW IS IN CREW REST
;         ----- -- ---- -- -- ---- ----
;
;    (ATRIB(11) INDICATES THAT CREW ENTERS CREW REST)
;
         GOON,1;
         ACT,14,ATRIB(11).EQ.1;
         ACT;
;
BAC2     FREE,PARK2/ATRIB(6);
;
;     START AND TAXI OUT
;
         ACT,RLOGN(.4,.1);
;
;     TAKEOFF
;
         AWAIT(22),RUNWAY2/1;
         ACT,.03;
         FREE,RUNWAY2/1;
         ASSIGN,ATRIB(5) = ATRIB(5) + .03;
;
;
;     COLLECT STATISTICS FOR CYXX
;     ------- ---------- --- ----
;
         GOON,1;
         ACT,,ATRIB(7).EQ.2,BIG2;
         ACT,,ATRIB(7).EQ.3,JUM2;
         ACT;
```

```
;
;     COLLECT C-130 STATISTICS AND ROUTE TO NEXT BASE
;     ------- ----- ---------- --- ----- -- ---- ----
;
        COLCT,INT(5),C130 GRD CYXX;
        ASSIGN,XX(3) = XX(3) + ATRIB(13);
        ACT,,,ENR;
;
;      C-141 STATISTICS
;
BIG2    COLCT,INT(5),C141 GROUND CYXX;
        ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
        EVENT,13;            COLLECT DATA ON STRAT DELAYS
        TERM;
;
;      C-5 STATISTICS
;
JUM2    COLCT,INT(5),C5 GROUND CYXX:
        ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
        EVENT,13;             COLLECT DATA ON STRAT DELAYS
        TERM;
;
REL2    FREE,ATRIB(11)/ATRIB(15);
        ACT,,,HUR2;

;              ============
;              STATION BIXX
;              ============
;
;      ONLY TRUCKS ARE AVAILABLE FOR REFUELING AT BIXX
;      ---- ------ --- --------- --- --------- -- ----
;
;         CREATE STRAT AIRLIFT ARRIVALS
;
        CREATE,EXPON(1.075),,1;     C-141 AIRCRAFT AND NARROW BODY CRAF
        ASSIGN,ATRIB(6)=21,ATRIB(7)=2;
        ACT,,,BIXX;
;
        CREATE,EXPON(3.453),,1;     C-5 AIRCRAFT AND WIDE BODY CRAF
        ASSIGN,ATRIB(6)=42,ATRIB(7)=3;
        ACT,,,BIXX;
;
;         GROUND ACTIVITIES AT BASE BIXX
;
BIXX    ASSIGN,ATRIB(5)=TNOW;
;
;
;
;
;
;
```

```
;        LAND AIRCRAFT
;
         AWAIT(31),RUNWAY3/1;
         ACT(1)/31,USERF(5);    TIME TO LAND
         FREE,RUNWAY3/1;
         COLCT,INT(5),HOLDING AT BIXX;
;
;        TAXI AND PARK
;
         ASSIGN,ATRIB(5)=TNOW;
         AWAIT(33),PARK3/ATRIB(6);
         ACT,USERF(6);       TIME TO TAXI TO RAMP
         GOON;
         ACT,TRIAG(.1,.2,.4);   POSTFLIGHT
;
;        SCHEDULE NEXT LEG
;        -------- ---- ---
;
         EVENT,4,1;
;
;       DETERMINE MAINT TIME AND FUEL REQUIRED
;
         ASSIGN,ATRIB(13) = USERF(1);
         ASSIGN,ATRIB(10) = USERF(13);
;
;
;       DETERMINE IF MAINTENANCE IS CONCURRENT
;       --------- -- ----------- -- ----------
;
         GOON,1;
         ACT/37,,.60,FUE3;       NO MAINTENANCE REQUIRED
         ACT/38,,.35,CON3;       CONCURRENT MAINTENANCE
         ACT/39,,.05,NON3;      NONCONCURRENT MAINTENANCE
;
;
;               CONCURRENT SERVICE
;               ---------- -------
;
;      (PARALLEL BRANCHING - CREATE TWO ENTITIES)
;
CON3     ASSIGN,XX(1)=XX(1)+1,ATRIB(8)=XX(1);
         ACT,,,GAS3;
         ACT,,,FIX3;
;
;        FUEL CONCURRENTLY
;
GAS3     AWAIT(34),ALLOC(3);
         ACT/34,ATRIB(9);
         FREE,ATRIB(11)/ATRIB(15);
ONE3     QUEUE(35),,,,GO3;
;
;
;
```

```
;        CONCURRENT MAINTENANCE
:
FIX3     GOON;
         ACT/35,ATRIB(10);
TWO3     QUEUE(36),,,,GO3;
:
;        MATCH ENTITIES BACK TOGETHER
;
GO3      MATCH,8,ONE3/TOG3,TWO3;
;
;
:        NONCURRENT SERVICE
;        ---------- -------
;
:     IF AIRCRAFT ARE IN REFUELING QUEUE. PERFORM MAINTENANCE
;     FIRST, OTHERWISE FUEL FIRST
;
NON3     GOON,1:
         ACT,.NNQ(34).GT.0,NMN3:
         ACT;
;
;       FUEL FIRST
;
         AWAIT(34).ALLOC(3);
         ACT/34,ATRIB(9);    FUEL
         FREE.ATRIB(11)/ATRIB(15):
;
         ACT/35.ATRIB(10),,TOG3;     MAINTENANCE
;
;        MAINTENANCE FIRST
;
NMN3     GOON;
         ACT/35,ATRIB(10);      MAINTENANCE
;
FUE3     AWAIT(34),ALLOC(3);
         ACT/34,ATRIB(9):    FUEL
         FREE.ATRIB(11)/ATRIB(15):
;
:
:         SERVICING IS NOW COMPLETE
;         --------- -- --- --------
:
:       ALL ENTITIES ARE NOW BACK TOGETHER
:      (ALL BRANCHES ARE COMBINED AT TOG3)
:
;         ALSO SCHEDULE CREW REST, IF NECESSARY
;         ---- -------- ---- ----- -- ---------
;
TOG3     EVENT,8,1;
;
;
;
;
```

```
;         DELAY IF CREW IS IN CREW REST
;         ----- -- ---- -- -- ---- ----
;    (ATRIB(11) INDICATES THAT CREW ENTERS CREW REST)
;
        GOON,1;
        ACT,14,ATRIB(11).EQ.1;
        ACT;
;
BAC3    FREE,PARK3/ATRIB(6);
;
;     START AND TAXI OUT
;
        ACT,RLOGN(.4,.1);
;
;     TAKEOFF
;
        AWAIT(32),RUNWAY3/1;
        ACT,.03;
        FREE,RUNWAY3/1;
        ASSIGN,ATRIB(5) = ATRIB(5) + .03;
;
;
;     COLLECT STATISTICS FOR BIXX
;     ------- ---------- --- ----
;
        GOON,1;
        ACT,,ATRIB(7).EQ.2,BIG3;
        ACT,,ATRIB(7).EQ.3,JUM3;
        ACT;
;
;
;     COLLECT C-130 STATISTICS AND ROUTE TO NEXT BASE
;     ------- ----- ---------- --- ----- -- ---- ----
;
        COLCT,INT(5),C130 GRD BIXX;
        ASSIGN,XX(4) = XX(4) + ATRIB(13);
        ACT,,,ENR;
;
;      C-141 STATISTICS
;
BIG3    COLCT,INT(5),C141 GROUND BIXX;
        ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
        EVENT,14;            COLLECT DATA ON STRAT DELAYS
        TERM;
;
;      C-5 STATISTICS
;
JUM3    COLCT,INT(5),C5 GROUND BIXX;
        ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
        EVENT,14;            COLLECT DATA ON STRAT DELAYS
        TERM;
```

```
;
;              ===========
;              STATION LPXX
;              ===========
;
;     BOTH TRUCKS AND PITS ARE AVAILABLE FOR REFUELING AT LPXX
;     ---- ------ --- ---- --- --------- --- --------- -- ----
;
;        CREATE STRAT AIRLIFT ARRIVALS
;
        CREATE,EXPON(1.476),,1;    C-141 AIRCRAFT AND NARROW BODY CRAF
        ASSIGN,ATRIB(6)= 16,ATRIB(7)=2;
        ACT,,,LPXX;
;
        CREATE,EXPON(33.572),,1;    C-5 AIRCRAFT AND WIDE BODY CRAF
        ASSIGN,ATRIB(6)=30,ATRIB(7)=3;
        ACT,,.LPXX;
;
;        GROUND ACTIVITIES AT BASE LPXX
;
LPXX    ASSIGN,ATRIB(5)=TNOW:
;
;        LAND AIRCRAFT
;
        AWAIT(41),RUNWAY4/1:
        ACT(1)/41,USERF(5);       TIME TO LAND
        FREE,RUNWAY4/1:
        COLCT,INT(5),HOLDING AT LPXX;
;
;       TAXI AND PARK
;
        ASSIGN,ATRIB(5)=TNOW:
        AWAIT(43),PARK4/ATRIB(6);
        ACT,USERF(6);      TIME TO TAXI TO RAMP
        GOON;
        ACT,TRIAG(.1,.2,.4);    POSTFLIGHT
;
;       SCHEDULE NEXT LEG
;       -------- ---- ---
;
        EVENT,5,1;
;
;      DETERMINE MAINT TIME AND REQUIRED FUEL
;
        ASSIGN,ATRIB(13) = USERF(1);
        ASSIGN,ATRIB(10) = USERF(14);
;
;
;
;
;
;
;
```

```
;       DETERMINE IF MAINTENANCE IS CONCURRENT
;       --------- -- ----------- -- ----------
;
         GOON,1;
         ACT/47,,.60,FUE4;       NO MAINTENANCE REQUIRED
         ACT/48,,.35,CON4;       CONCURRENT MAINTENANCE
         ACT/49,,.05,NON4;      NONCONCURRENT MAINTENANCE
;
;
;               CONCURRENT SERVICE
;               ---------- -------
;
;      (PARALLEL BRANCHING - CREATE TWO ENTITIES)
;
CON4     ASSIGN,XX(1)=XX(1)+1,ATRIB(8)=XX(1);
         ACT,,,GAS4;
         ACT,,,FIX4;
;
;        FUEL CONCURRENTLY
;
;     ALLOC(4) DETERMINES IF PIT OR TRUCK RESOURCE,
;     --------
;           PREFERABLY PIT, IS AVAILABLE
;
GAS4     AWAIT(44),ALLOC(4);
         ACT/44,ATRIB(9);
         GOON,1;
         ACT,,ATRIB(11).EQ.13,ONE4;
         ACT;
         FREE,ATRIB(11)/ATRIB(15);
ONE4     QUEUE(45),,,,GO4;
;
;        CONCURRENT MAINTENANCE
;
FIX4     GOON;
         ACT/45,ATRIB(10);
TWO4     QUEUE(46),,,,GO4;
;
;        MATCH ENTITIES BACK TOGETHER
;
GO4      MATCH,8,ONE4/TOG4,TWO4;
;
;
;        NONCURRENT SERVICE
;        ---------- -------
;
;     IF AIRCRAFT ARE IN REFUELING QUEUE, PERFORM MAINTENANCE
;     FIRST, OTHERWISE FUEL FIRST
;
NON4     GOON,1;
         ACT,,NNQ(44).GT.0,NMN4;
         ACT;
;
```

```
;       FUEL FIRST
;
         AWAIT(44),ALLOC(4);
         ACT/44,ATRIB(9);   FUEL
         GOON,1;
         ACT,,ATRIB(11).EQ.13,HEL4:
         ACT:
         FREE,ATRIB(11)/ATRIB(15);
;
HEL4     GOON,1;
         ACT/45,ATRIB(10),,TOG4:     MAINTENANCE
;
;        MAINTENANCE FIRST
;
NMN4     GOON;
         ACT/45,ATRIB(10);     MAINTENANCE
;
FUE4     AWAIT(44),ALLOC(4):
         ACT/44,ATRIB(9);   FUEL
         GOON,1:
         ACT,,ATRIB(11).EQ.13,TOG4:
         ACT;
         FREE,ATRIB(11)/ATRIB(15);
;
;
;         SERVICING IS NOW COMPLETE
;         --------- -- --- --------
;
;       ALL ENTITIES ARE NOW BACK TOGETHER
;      (ALL BRANCHES ARE COMBINED AT TOG4)
;
;       ALSO SCHEDULE CREW REST IF NECESSARY
;       ---- -------- ---- ---- -- ---------
;
;         THIS BRANCH WILL RELEASE THE FUEL PIT.
;                 IF USED
;
TOG4     GOON,1;
         ACT,,ATRIB(11).EQ.13,REL4;
         ACT:
;
HUR4     EVENT,8,1;
;
;         DELAY IF CREW IS IN CREW REST
;         ----- -- ---- -- -- ---- ----
;    (ATRIB(11) INDICATES THAT CREW ENTERS CREW REST)
;
         GOON,1;
         ACT,14,ATRIB(11).EQ.1;
         ACT;
;
BAC4     FREE,PARK4/ATRIB(6);
;
```

```
;     START AND TAXI OUT
;
         ACT,RLOGN(.4,.1);
;
;     TAKEOFF
;
         AWAIT(42),RUNWAY4/1;
         ACT,.03;
         FREE,RUNWAY4/1;
         ASSIGN,ATRIB(5) = ATRIB(5) + .03;
;
;
;     COLLECT STATISTICS FOR LPXX
;     ------- ---------- --- ----
;
         GOON,1;
         ACT,,ATRIB(7).EQ.2,BIG4;
         ACT,,ATRIB(7).EQ.3,JUM4;
         ACT;
;
;     COLLECT C-130 STATISTICS AND ROUTE TO NEXT BASE
;
         COLCT,INT(5),C130 GRD LPXX;
         ASSIGN,XX(5) = XX(5) + ATRIB(13);
         ACT,,,ENR;
;
;      C-141 STATISTICS
;
BIG4     COLCT,INT(5),C141 GROUND LPXX;
         ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
         EVENT,15;           COLLECT DATA ON STRAT DELAYS
         TERM;
;
;      C-5 STATISTICS
;
JUM4     COLCT,INT(5),C5 GROUND LPXX;
         ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
         EVENT,15;           COLLECT DATA ON STRAT DELAYS
         TERM;
;
REL4     FREE,ATRIB(11)/ATRIB(15);
         ACT,,,HUR4;
;
;              ============
;              STATION LEXX
;              ============
;
;     BOTH TRUCKS AND PITS ARE AVAILABLE FOR REFUELING AT LEXX
;     ---- ------ --- ---- --- --------- --- --------- -- ----
;
;
```

```
;        CREATE STRAT AIRLIFT ARRIVALS
;
        CREATE,EXPON(1.432),,1:  C-141 AIRCRAFT AND NARROW BODY CRAF
        ASSIGN,ATRIB(6)=12,ATRIB(7)=2:
        ACT,,,LEXX:
;
        CREATE,EXPON(3.994),,1:     C-5 AIRCRAFT AND WIDE BODY CRAF
        ASSIGN,ATRIB(6)=36,ATRIB(7)=3;
        ACT,,,LEXX:
;
;        GROUND ACTIVITIES AT BASE LEXX
;
LEXX    ASSIGN,ATRIB(5)=TNOW;
;
;        LAND AIRCRAFT
;
        AWAIT(51),RUNWAY5/1;
        ACT(1)/51,USERF(5);
        FREE,RUNWAY5/1:
        COLCT,INT(5),HOLDING AT LEXX;
;
;       TAXI AND PARK
;
        ASSIGN,ATRIB(5)=TNOW;
        AWAIT(53),PARK5/ATRIB(6);
        ACT,USERF(6):       TIME TO TAXI TO RAMP
        GOON;
        ACT,TRIAG(.1,.2,.4):   POSTFLIGHT
;
;       SCHEDULE NEXT LEG
;
        EVENT,6,1:
;
;      DETERMINE MAINT TIME AND REQUIRED FUEL
;
        ASSIGN,ATRIB(13) = USERF(1):
        ASSIGN,ATRIB(10) = USERF(15);
;
;
;      DETERMINE IF MAINTENANCE IS CONCURRENT
;      --------- -- ----------- -- ----------
;
        GOON,1;
        ACT/57,,.60,FUE5:     NO MAINTENANCE REQUIRED
        ACT/58,,.35,CON5;     CONCURRENT MAINTENANCE
        ACT/59,,.05,NON5;    NONCONCURRENT MAINTENANCE
;
;
;
;
;
;
;
```

```
;              CONCURRENT SERVICE
;              ---------- -------
;
;     (PARALLEL BRANCHING - CREATE TWO ENTITIES)
;
CONS      ASSIGN,XX(1)=XX(1)+1,ATRIB(9)=XX(1);
          ACT,,,GAS5;
          ACT,,,FIX5;
;
;         FUEL CONCURRENTLY
;
;    ALLOC(5) DETERMINES IF PIT OR TRUCK RESOURCE, PREFERABLY
;    --------
;                   PIT, IS AVAILABLE
;
GAS5      AWAIT(54),ALLOC(5);
          ACT/54,ATRIB(9);
          GOON,1;
          ACT,,ATRIB(11).EQ.17,ONE5;
          ACT;
          FREE,ATRIB(11)/ATRIB(15);
ONE5      QUEUE(55),,,,GO5;
;
;         CONCURRENT MAINTENANCE
;
FIX5      GOON;
          ACT/55,ATRIB(10);
TWO5      QUEUE(56),,,,GO5;
;
;         MATCH ENTITIES BACK TOGETHER
;
GO5       MATCH,8,ONE5/TOG5,TWO5;
;
;
;         NONCURRENT SERVICE
;         ---------- -------
;
;    IF AIRCRAFT ARE IN REFUELING QUEUE, PERFORM MAINTENANCE
;    FIRST, OTHERWISE FUEL FIRST
;
NON5      GOON,1;
          ACT,,NNQ(54).GT.0,NMN5;
          ACT;
;
;        FUEL FIRST
;
          AWAIT(54),ALLOC(5);
          ACT/54,ATRIB(9);   FUEL
          GOON,1;
          ACT,,ATRIB(11).EQ.17,HEL5;
          ACT;
          FREE,ATRIB(11)/ATRIB(15);
;
```

```
HEL5     GOON,1:
         ACT/55,ATRIB(10),,TOG5;      MAINTENANCE
;
;        MAINTENANCE FIRST
;
NMN5     GOON;
         ACT/55,ATRIB(10);      MAINTENANCE
;
FUE5     AWAIT(54),ALLOC(5):
         ACT/54,ATRIB(9);    FUEL
         GOON,1:
         ACT,,ATRIB(11).EQ.17,TOG5;
         ACT:
         FREE,ATRIB(11)/ATRIB(15):
;
;
;         SERVICING IS NOW COMPLETE
;         --------- -- --- --------
;
;       ALL ENTITIES ARE NOW BACK TOGETHER
;      (ALL BRANCHES ARE COMBINED AT TOG5)
;
;       ALSO SCHEDULE CREW REST, IF NECESSARY
;       ---- -------- ---- -----  -- ---------
;
TOG5     GOON,1:
         ACT,,ATRIB(11).EQ.17,REL5;
         ACT;
;
HUR5     EVENT,8,1;
;
;         DELAY IF CREW IS IN CREW REST
;         ----- -- ---- -- -- ---- ----
;   (ATRIB(11) INDICATES THAT CREW ENTERS CREW REST)
;
         GOON,1;
         ACT,14,ATRIB(11).EQ.1;
         ACT:
;
BAC5     FREE,PARK5/ATRIB(6);
;
;    START AND TAXI OUT
;
         ACT,RLOGN(.4,.1);
;
;    TAKEOFF
;
         AWAIT(52),RUNWAY5/1;
         ACT,.03;
         FREE,RUNWAY5/1:
         ASSIGN,ATRIB(5) = ATRIB(5) + .03;
;
;
```

```
;     COLLECT STATISTICS FOR LEXX
;     ------- ---------- --- ----
;
         GOON,1;
         ACT,,ATRIB(7).EQ.2,BIG5;
         ACT.,ATRIB(7).EQ.3,JUM5;
         ACT;
;
:     COLLECT C-130 STATISTICS AND ROUTE TO NEXT BASE
;     ------- ----- ---------- --- ----- -- ---- ----
:
         COLCT,INT(5),C130 GRD LEXX;
         ASSIGN,XX(6) = XX(6) + ATRIB(13);
         ACT,,,ENR;
;
;      C-141 STATISTICS
;
BIG5     COLCT,INT(5),C141 GROUND LEXX;
         ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
:
         EVENT,16;          COLLECT DATA ON STRAT DELAYS
         TERM;
;
:      C-5 STATISTICS
;
JUM5     COLCT,INT(5),C5 GROUND LEXX;
         ASSIGN,ATRIB(11)=TNOW-ATRIB(5);
;
         EVENT,16;           COLLECT DATA ON STRAT DELAYS
         TERM;
;
REL5     FREE,ATRIB(11)/ATRIB(15);
         ACT,,,HUR5;
;
:              ================
;              C-130 DESTINATIONS
;              ================
;
;
;         SQUADRONS ARE NOT BROKEN DOWN BY BASE BECAUSE
;         ROUTINGS CHANGE BETWEEN DIFFERENT RUNS OF THE
;         MODEL.
;
EGXX     GOON,1;
EDXX     GOON,1;
LGXX     GOON,1;
;
:
;
:
;
:
;
;
```

```
        ACT,,ATRIB(3).EQ.1,SQ1;
        ACT,,ATRIB(3).EQ.2,SQ2;
        ACT,,ATRIB(3).EQ.11,SQ11:
        ACT,,ATRIB(3).EQ.12,SQ12:
        ACT,,ATRIB(3).EQ.13,SQ13;
        ACT,,ATRIB(3).EQ.22,SQ22:
        ACT,,ATRIB(3).EQ.23,SQ23;
        ACT,,ATRIB(3).EQ.24,SQ24:
        ACT,,ATRIB(3).EQ.25,SQ25;
;
;
        ACT,,ATRIB(3).EQ.3,SQ3:
        ACT,,ATRIB(3).EQ.4,SQ4;
        ACT,,ATRIB(3).EQ.8,SQ8;
        ACT,,ATRIB(3).EQ.9,SQ9:
        ACT,,ATRIB(3).EQ.10,SQ10:
        ACT,,ATRIB(3).EQ.18,SQ18:
        ACT,,ATRIB(3).EQ.19,SQ19:
        ACT,,ATRIB(3).EQ.20,SQ20;
        ACT,,ATRIB(3).EQ.21,SQ21;
;
;
        ACT,,ATRIB(3).EQ.5,SQ5:
        ACT,,ATRIB(3).EQ.6,SQ6:
        ACT,,ATRIB(3).EQ.7,SQ7;
        ACT,,ATRIB(3).EQ.14,SQ14:
        ACT,,ATRIB(3).EQ.15,SQ15;
        ACT,,ATRIB(3).EQ.16,SQ16:
        ACT,,ATRIB(3).EQ.17,SQ17;
;
;
;       ==================================
;       COLLECT DATA AND TERMINATE AIRCRAFT
;
;              FOR EACH SQUADRON
;              ================
;
;
;                SQUADRON ONE
;
SQ1     COLCT,INT(1),SQD 1 ENROUTE TIME:
        ASSIGN,XX(7)=XX(7)+1;
        EVENT,11;          OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
;
;                SQUADRON TWO
;
SQ2     COLCT,INT(1),SQD 2 ENROUTE TIME:
        ASSIGN,XX(8)=XX(8)+1;
        EVENT,11;         OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
```

```
;
;               SQUADRON THREE
;
SQ3     COLCT,INT(1),SQD 3 ENROUTE TIME:
        ASSIGN,XX(9)=XX(9)+1;
        EVENT,11;       OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
;
;               SQUADRON FOUR
;
SQ4     COLCT.INT(1).SQD 4 ENROUTE TIME:
        ASSIGN,XX(10)=XX(10)+1;
        EVENT,11;       OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
;
;               SQUADRON FIVE
;
SQ5     COLCT,INT(1).SQD 5 ENROUTE TIME:
        ASSIGN,XX(11)=XX(11)+1;
        EVENT,11;         OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
;
;               SQUADRON SIX
;
SQ6     COLCT,INT(1),SQD 6 ENROUTE TIME;
        ASSIGN,XX(12)=XX(12)+1;
        EVENT,11;         OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
;
;               SQUADRON SEVEN
;
SQ7     COLCT.INT(1),SQD 7 ENROUTE TIME;
        ASSIGN,XX(13)=XX(13)+1;
        EVENT,11;         OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
;
;               SQUADRON EIGHT
;
SQ8     COLCT,INT(1),SQD 8 ENROUTE TIME:
        ASSIGN,XX(14)=XX(14)+1;
        EVENT,11;         OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
;
;
;
;
;
```

```
;                   SQUADRON NINE
;
SQ9     COLCT,INT(1),SQD 9 ENROUTE TIME:
        ASSIGN,XX(15)=XX(15)+1;
        EVENT,11;           OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
;
;                   SQUADRON TEN
;
SQ10    COLCT,INT(1),SQD 10 ENROUTE TIME:
        ASSIGN,XX(16)=XX(16)+1;
        EVENT,11;           OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
:
:                   SQUADRON ELEVEN
;
SQ11    COLCT,INT(1),SQD 11 ENROUTE TIME;
        ASSIGN,XX(17)=XX(17)+1:
        EVENT,11;           OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
:
;                   SQUADRON TWELVE
;
SQ12    COLCT,INT(1),SQD 12 ENROUTE TIME;
        ASSIGN,XX(18)=XX(18)+1;
        EVENT,11;           OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
:
:                   SQUADRON THIRTEEN;
;
SQ13    COLCT,INT(1),SQD 13 ENROUTE TIME;
        ASSIGN,XX(19)=XX(19)+1;
        EVENT,11;           OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
:
:                   SQUADRON FOURTEEN
:
SQ14    COLCT,INT(1),SQD 14 ENROUTE TIME:
        ASSIGN,XX(20)=XX(20)+1;
        EVENT,11;           OUTPUT STATISTICS ON CLOSURE TIME
        TERM;
;
:
;
;
;
;
;
```

```
;                    SQUADRON FIFTEEN
;
SQ15     COLCT,INT(1),SQD 15 ENROUTE TIME:
         ASSIGN,XX(21)=XX(21)+1;
         EVENT,11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                    SQUADRON SIXTEEN
;
SQ16     COLCT,INT(1),SQD 16 ENROUTE TIME:
         ASSIGN,XX(22)=XX(22)+1;
         EVENT,11:             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                    SQUADRON SEVENTEEN
;
SQ17     COLCT,INT(1).SQD 17 ENROUTE TIME:
         ASSIGN,XX(23)=XX(23)+1;
         EVENT.11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                    SQUADRON EIGHTEEN
;
SQ18     COLCT,INT(1),SQD 18 ENROUTE TIME:
         ASSIGN,XX(24)=XX(24)+1;
         EVENT.11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                    SQUADRON NINETEEN
;
SQ19     COLCT,INT(1).SQD 19 ENROUTE TIME:
         ASSIGN,XX(25)=XX(25)+1;
         EVENT,11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                    SQUADRON TWENTY
;
SQ20     COLCT.INT(1),SQD 20 ENROUTE TIME:
         ASSIGN,XX(26)=XX(26)+1;
         EVENT,11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;
;
;
;
;
```

```
;                   SQUADRON TWENTY ONE
;
SQ21     COLCT,INT(1),SQD 21 ENROUTE TIME:
         ASSIGN,XX(27)=XX(27)+1;
         EVENT,11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                   SQUADRON TWENTY TWO
;
SQ22     COLCT,INT(1),SQD 22 ENROUTE TIME:
         ASSIGN,XX(28)=XX(28)+1;
         EVENT,11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                   SQUADRON TWENTY THREE
;
SQ23     COLCT,INT(1),SQD 23 ENROUTE TIME:
         ASSIGN,XX(29)=XX(29)+1;
         EVENT,11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                   SQUADRON TWENTY FOUR
;
SQ24     COLCT,INT(1),SQD 24 ENROUTE TIME:
         ASSIGN,XX(30)=XX(30)+1;
         EVENT,11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
;
;                   SQUADRON TWENTY FIVE
;
SQ25     COLCT,INT(1),SQD 25 ENROUTE TIME:
         ASSIGN,XX(31)=XX(31)+1;
         EVENT,11;             OUTPUT STATISTICS ON CLOSURE TIME
         TERM;
;
         ENDNET;
;
INIT,0,225;
;
RECORD,TNOW,TIME,0,P,2.5,0,200;
VAR,XX(46),A,TOTAL AC,0,225;
;
FIN;
```

Appendix C. Fortran Code

This appendix contains the Fortran code necessary for the development of the simulation model of this thesis. The Fortran code includes EVENT, USERF, ALLOC, and OUTPUT subroutines, as defined by SLAM, and several other user developed subroutines. The code is displayed on the following pages.

```
      PROGRAM MODEL
C     =============
C
C        Fortran subroutines for use in thesis model.
C
C               by  HILL & DONNELLY
C
      DIMENSION NSET(40000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(40000)
C
      EQUIVALENCE(NSET(1),QSET(1))
C
      REAL LENGTH(14,6),DEST(14,6),STAGE(14,6)
      COMMON/ROUTE/LENGTH,DEST,STAGE
C
      OPEN (10, FILE='[JHILL.THESIS]HOPE2.OUT', STATUS='NEW')
      OPEN (20, FILE='[JHILL.THESIS]LENGTH2.DAT',STATUS='OLD')
      OPEN (30, FILE='[JHILL.THESIS]DEST2.DAT',STATUS='OLD')
      OPEN (40, FILE='[JHILL.THESIS]STAGE2.DAT',STATUS='OLD')
      OPEN (50, FILE='[JHILL.THESIS]RESULTS2.OUT',STATUS='NEW')
C
      NNSET=40000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
C
      DO 10 I = 1,14
           READ (20,*)LENGTH(I,1),LENGTH(I,2),LENGTH(I,3),
     1LENGTH(I,4),LENGTH(I,5),LENGTH(I,6)
           READ (30,*)DEST(I,1),DEST(I,2),DEST(I,3),
     1DEST(I,4),DEST(I,5),DEST(I,6)
           READ (40,*)STAGE(I,1),STAGE(I,2),STAGE(I,3),
     1STAGE(I,4),STAGE(I,5),STAGE(I,6)
10    CONTINUE
C
      CALL SLAM
      STOP
      END
C
C
C
C
C
C
C
C
C
C
C
C
```

```
C              ================
C              EVENT SUBROUTINES
C              ================
C
      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW.II,MFA,MSTOP.NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
C
      REAL LENGTH(14,6),DEST(14,6),STAGE(14,6)
      COMMON/ROUTE/LENGTH,DEST,STAGE
C
C         ===============================================
C         EVENTS 1 - 6 ARE USED TO SCHEDULE THE AIRCRAFT AT
C         AN ENROUTE BASE TO THE NEXT STOP ON THEIR SCHEDULED
C         ITINERARY. EACH C-130 SQUADRON HAS A SCHEDULED ROUTE
C         STRUCTURE.
C
C         EVENTS 1 - 5 WILL ALSO BE USED TO EFFECT CREW CHANGES
C         AT THOSE ENROUTE BASES WHERE A CREW CHANGE (STAGE) IS
C         SCHEDULED.
C         ===================================================
C
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16).I
C
C               ====================
C               EVENT 1 - AT CREATION
C               ====================
C
C        DETERMINE NEW DESTINATION FOR C-130
C        --------- --- ----------- --- -----
C
1     ATRIB(12) = DEST(ATRIB(2),I)
C
C      A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
      IF (ATRIB(12).EQ.0) THEN
            ATRIB(12) = 10
            CALL ERROR(I)
            ENDIF
C
C         DETERMINE LENGTH OF NEXT LEG FOR C-130S
C         --------- ------ -- ---- --- --- ------
C
      ATRIB(4) = LENGTH(ATRIB(2),I)
C
C     A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
      IF (ATRIB(4).EQ.0) THEN
           ATRIB(12) = 20
           CALL ERROR(I)
           ENDIF
C
C
```

```
      ATRIB(4) = ATRIB(4) * RNORM(1.0,0.02,2)
C
      RETURN
C
C                ================
C                EVENT 2 - AT KNEX
C                ================
C
2     IF (ATRIB(7).EQ.2) THEN
              ATRIB(4) = 4.5 + UNFRM(0.0,2.0,1)
              RETURN
              ENDIF
C
      IF (ATRIB(7).EQ.3) THEN
              ATRIB(4) = 4.8 + UNFRM(0.0,2.0,1)
              RETURN
              ENDIF
C
C       DETERMINE NEW DESTINATION FOR C-130
C       --------- --- ----------- --- -----
C
      ATRIB(12) = DEST(ATRIB(2),I)
C
C      A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
      IF (ATRIB(12).EQ.0) THEN
           ATRIB(12) = 10
           CALL ERROR(I)
           ENDIF
C
C        DETERMINE LENGTH OF NEXT LEG FOR C-130S
C        --------- ------ -- ---- --- --- ------
C
      ATRIB(4) = LENGTH(ATRIB(2),I)
C
C     A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
      IF (ATRIB(4).EQ.0) THEN
          ATRIB(12) = 20
          CALL ERROR(I)
          ENDIF
C
      ATRIB(4) = ATRIB(4) * RNORM(1.0,0.02,2)
C
C         DETERMINE IF THE CREW STAGES AT THIS LOCATION
C         --------- -- --- ---- ------ -- ---- --------
C
      IF (STAGE(ATRIB(2),I).EQ.1) THEN
          ATRIB(14) = TNOW
          ENDIF
C
      RETURN
C
```

```
C               ================
C               EVENT 3 - AT CYXX
C               ================
C
C             FIRST ASSIGN AN EXPECTED FLYING TIME
C                FOR THE STRAT AIRLIFTERS
C
3      IF (ATRIB(7).EQ.2) THEN
               ATRIB(4) = 7.9 + UNFRM(0.0,2.0,1)
               RETURN
               ENDIF
C
       IF (ATRIB(7).EQ.3) THEN
               ATRIB(4) = 8.9 + UNFRM(0.0,2.0,1)
               RETURN
               ENDIF
C
C        DETERMINE NEW DESTINATION FOR C-130
C        --------- --- ----------- --- -----
C
       ATRIB(12) = DEST(ATRIB(2),I)
C
C       A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
       IF (ATRIB(12).EQ.0) THEN
            ATRIB(12) = 10
            CALL ERROR(I)
            ENDIF
C
C         DETERMINE LENGTH OF NEXT LEG FOR C-130S
C         --------- ------ -- ---- --- --- ------
C
       ATRIB(4) = LENGTH(ATRIB(2),I)
C
C      A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
       IF (ATRIB(4).EQ.0) THEN
           ATRIB(12) = 20
           CALL ERROR(I)
           ENDIF
C
       ATRIB(4) = ATRIB(4) * RNORM(1.0,0.02,2)
C
C          DETERMINE IF THE CREW STAGES AT THIS LOCATION
C          --------- -- --- ---- ------ -- ---- --------
C
       IF (STAGE(ATRIB(2),I).EQ.1) THEN
           ATRIB(14) = TNOW
           ENDIF
C
       RETURN
C
```

```
C              ================
C              EVENT 4 - AT BIXX
C              ================
C
C             FIRST ASSIGN AN EXPECTED FLYING TIME
C                FOR THE STRAT AIRLIFTERS
C
4     IF (ATRIB(7).EQ.2) THEN
               ATRIB(4) = 3.5 + UNFRM(0.0,2.0,1)
               RETURN
               ENDIF
C
      IF (ATRIB(7).EQ.3) THEN
               ATRIB(4) = 4.5 + UNFRM(0.0,2.0,1)
               RETURN
               ENDIF
C
C       DETERMINE NEW DESTINATION FOR C-130
C       --------- --- ----------- --- -----
C
      ATRIB(12) = DEST(ATRIB(2),I)
C
C      A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
      IF (ATRIB(12).EQ.0) THEN
            ATRIB(12) = 10
            CALL ERROR(I)
            ENDIF
C
C        DETERMINE LENGTH OF NEXT LEG FOR C-130S
C        --------- ------ -- ---- --- --- ------
C
      ATRIB(4) = LENGTH(ATRIB(2),I)
C
C     A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
      IF (ATRIB(4).EQ.0) THEN
           ATRIB(12) = 20
           CALL ERROR(I)
           ENDIF
C
      ATRIB(4) = ATRIB(4) * RNORM(1.0,0.02,2)
C
C         DETERMINE IF THE CREW STAGES AT THIS LOCATION
C         --------- -- --- ---- ------ -- ---- --------
C
      IF (STAGE(ATRIB(2),I).EQ.1) THEN
          ATRIB(14) = TNOW
          ENDIF
C
      RETURN
C
C
```

```
C                           ================
C                           EVENT 5 - AT LPXX
C                           ================
C
C                FIRST ASSIGN AN EXPECTED FLYING TIME
C                   FOR THE STRAT AIRLIFTERS
C
5       IF (ATRIB(7).EQ.2) THEN
                ATRIB(4) = 11.0 + UNFRM(0.0,2.0,1)
                RETURN
                ENDIF
C
        IF (ATRIB(7).EQ.3) THEN
                ATRIB(4) = 11.0 + UNFRM(0.0,2.0,1)
                RETURN
                ENDIF
C
C
C         DETERMINE NEW DESTINATION FOR C-130
C         --------- --- ----------- --- -----
C
        ATRIB(12) = DEST(ATRIB(2),I)
C
C        A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
        IF (ATRIB(12).EQ.0) THEN
              ATRIB(12) = 10
              CALL ERROR(I)
              ENDIF
C
C          DETERMINE LENGTH OF NEXT LEG FOR C-130S
C          --------- ------ -- ---- --- --- ------
C
        ATRIB(4) = LENGTH(ATRIB(2),I)
C
C       A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
        IF (ATRIB(4).EQ.0) THEN
             ATRIB(12) = 20
             CALL ERROR(I)
             ENDIF
C
        ATRIB(4) = ATRIB(4) * RNORM(1.0,0.02,2)
C
C           DETERMINE IF THE CREW STAGES AT THIS LOCATION
C           --------- -- --- ---- ------ -- ---- --------
C
        IF (STAGE(ATRIB(2),I).EQ.1) THEN
            ATRIB(14) = TNOW
            ENDIF
C
        RETURN
C
```

```
C                       ================
C                       EVENT 6 - AT LEXX
C                       ================
C
C                FIRST ASSIGN AN EXPECTED FLYING TIME
C                   FOR THE STRAT AIRLIFTERS
C
6     IF (ATRIB(7).EQ.2) THEN
             ATRIB(4) = 12.0 + UNFRM(0.0,2.0,1)
             RETURN
             ENDIF
C
      IF (ATRIB(7).EQ.3) THEN
             ATRIB(4) = 12.0 + UNFRM(0.0,2.0,1)
             RETURN
             ENDIF
C
C
C       DETERMINE NEW DESTINATION FOR C-130
C       --------- --- ----------- --- -----
C
      ATRIB(12) = DEST(ATRIB(2),I)
C
C      A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
      IF (ATRIB(12).EQ.0) THEN
           ATRIB(12) = 10
           CALL ERROR(I)
           ENDIF
C
C        DETERMINE LENGTH OF NEXT LEG FOR C-130S
C        --------- ------ -- ---- --- --- ------
C
      ATRIB(4) = LENGTH(ATRIB(2),I)
C
C     A VALUE OF 0 INDICATES A LOGICAL ERROR WITHIN THE PROGRAM
C
      IF (ATRIB(4).EQ.0) THEN
          ATRIB(12) = 20
          CALL ERROR(I)
          ENDIF
C
      ATRIB(4) = ATRIB(4) * RNORM(1.0,0.02,2)
C
C         DETERMINE IF THE CREW STAGES AT THIS LOCATION
C         --------- -- --- ---- ------ -- ---- --------
C
      IF (STAGE(ATRIB(2),I).EQ.1) THEN
         ATRIB(14) = TNOW
         ENDIF
C
      RETURN
C
```

```
C        ==========================================================
C        EVENTS 7 - 8 WILL DETERMINE IF A CREW WILL EXCEED ITS CREW
C        DUTY DAY BY FLYING THE NEXT LEG OF ITS MISSION (AT BASES WHERE
C        A STAGE IS NOT SCHEDULED). AN AUTOMATIC TWO HOUR EXTENSION OF DUTY
C        DAY IS ASSUMED OVER THE NORMAL 16 HOUR DUTY DAY. A CREW THAT WILL
C        EXCEED THE DUTY DAY BY MORE THAN TWO HOURS IS PUT INTO CREW REST
C        FOR 12 HOURS.
C
C        CREWS ENTERING CREW REST ARE MARKED BY SETTING ATRIB(11) = 1.
C        =============================================================
C
C                      ================
C                      EVENT 7 - AT KNEX
C                      ================
C
7     ATRIB(11) = 0
C
      IF ((ATRIB(7).EQ.2).OR.(ATRIB(7).EQ.3)) THEN
            RETURN
            ENDIF
C
C                 FOR AUGMENTED CREWS, THE DUTY DAY IS LONGER
C
      IF (ATRIB(2).EQ.3) THEN
            CALL LONG
C           ---- ----
            RETURN
            ENDIF
C
      IF ((TNOW - ATRIB(14) + ATRIB(4) + .5).GT.18) THEN
            ATRIB(11) = 1
            ATRIB(14) = TNOW + 13
            XX(ATRIB(2)+31) = XX(ATRIB(2)+31) + 1
            ENDIF
      RETURN
C
C                      ===========================
C                      EVENT 8 - AT ALL OTHER BASES
C                      ===========================
C
8     ATRIB(11) = 0
C
      IF ((ATRIB(7).EQ.2).OR.(ATRIB(7).EQ.3)) THEN
            RETURN
            ENDIF
C
      IF ((TNOW - ATRIB(14) + ATRIB(4) + .5).GT.18) THEN
            ATRIB(14) = TNOW + 13
            ATRIB(11) = 1
            XX(ATRIB(2)+31) = XX(ATRIB(2)+31) + 1
            ENDIF
C
      RETURN
```

```
9     RETURN
10    RETURN
C
C                    ========
C                    EVENT 11
C                    ========
C
C       EVENT 11 WRITES INTO AN OUTPUT FILE THE TIME THAT
C       THE 15th AIRCRAFT OF EVERY C-130 SQUADRON ARRIVES
C       AT ITS BEDDOWN BASE
C
C       ALSO WRITES THE TIME OF ARRIVAL FOR THE 380TH C-130
C
11    XX(46) = XX(46)+1
C     IF (XX(ATRIB(3)+6).EQ.15) THEN
C                 WRITE (10,*) NNRUN,'    ',ATRIB(3),'     ',TNOW
C                 ENDIF
C
      IF (XX(46).EQ.380) THEN
              WRITE (10,*) NNRUN,XX(46),
     1'  C-130S HAVE CLOSED AT TIME    ',TNOW
      XX(99) = TNOW
              ENDIF
C
      RETURN
C
C                 ==============
C                 EVENTS 12 - 16
C                 ==============
C
C       EVENTS 12 - 16 WILL COLLECT OUTPUT STATISTICS ON THE NUMBER
C       STRAT AIRLIFTERS TAKING OFF LATE AT THE ENROUTE BASES
C
C                ========
C                EVENT 12
C                ========
C
12    IF (ATRIB(7).EQ.2) THEN
            IF (ATRIB(11).LE.2.5) THEN
                XX(47) = XX(47) + 1
                ELSE
                XX(48) = XX(48) + 1
                ENDIF
            ENDIF
C
      IF (ATRIB(7).EQ.3) THEN
            IF (ATRIB(11).LE.3.5) THEN
                XX(49) = XX(49) + 1
                ELSE
                XX(50) = XX(50) + 1
                ENDIF
            ENDIF
      RETURN
```

```
C
C                 ========
C                 EVENT 13
C                 ========
C
13    IF (ATRIB(7).EQ.2) THEN
            IF (ATRIB(11).LE.2.5) THEN
                XX(51) = XX(51) + 1
                ELSE
                XX(52) = XX(52) + 1
                ENDIF
            ENDIF
C
      IF (ATRIB(7).EQ.3) THEN
            IF (ATRIB(11).LE.3.5) THEN
                XX(53) = XX(53) + 1
                ELSE
                XX(54) = XX(54) + 1
                ENDIF
            ENDIF
C
      RETURN
C
C                 ========
C                 EVENT 14
C                 ========
C
14    IF (ATRIB(7).EQ.2) THEN
            IF (ATRIB(11).LE.2.5) THEN
                XX(55) = XX(55) + 1
                ELSE
                XX(56) = XX(56) + 1
                ENDIF
            ENDIF
C
      IF (ATRIB(7).EQ.3) THEN
            IF (ATRIB(11).LE.3.5) THEN
                XX(57) = XX(57) + 1
                ELSE
                XX(58) = XX(58) + 1
                ENDIF
            ENDIF
C
      RETURN
C
C
C
C
C
C
C
C
C
```

```
C                       ========
C                       EVENT 15
C                       ========
C
15     IF (ATRIB(7).EQ.2) THEN
              IF (ATRIB(11).LE.2.5) THEN
                  XX(59) = XX(59) + 1
                  ELSE
                  XX(60) = XX(60) + 1
                  ENDIF
              ENDIF
C
       IF (ATRIB(7).EQ.3) THEN
              IF (ATRIB(11).LE.3.5) THEN
                  XX(61) = XX(61) + 1
                  ELSE
                  XX(62) = XX(62) + 1
                  ENDIF
              ENDIF
C
       RETURN
C
C                       ========
C                       EVENT 16
C                       ========
C
16     IF (ATRIB(7).EQ.2) THEN
              IF (ATRIB(11).LE.2.5) THEN
                  XX(63) = XX(63) + 1
                  ELSE
                  XX(64) = XX(64) + 1
                  ENDIF
              ENDIF
C
       IF (ATRIB(7).EQ.3) THEN
              IF (ATRIB(11).LE.3.5) THEN
                  XX(65) = XX(65) + 1
                  ELSE
                  XX(66) = XX(66) + 1
                  ENDIF
              ENDIF
C
       RETURN
C
       END
C
C
C
C
C
C
C
C
```

```
C          ===============
C          SUBROUTINE LONG
C          ===============
C
      SUBROUTINE LONG
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
C
C       ============================================================
C       CREWS FOR MISSIONS ON ROUTE STRUCTURE THREE ARE AUGMENTED
C       AND HAVE A 18 OUR DUTY DAY
C       ============================================================
C
      ATRIB(11) = 0
C
      IF ((ATRIB(7).EQ.2).OR.(ATRIB(7).EQ.3)) THEN
             RETURN
             ENDIF
C
      IF ((TNOW - ATRIB(14) + ATRIB(4) + .5).GT.20) THEN
             ATRIB(14) = TNOW + 13
             ATRIB(11) = 1
             XX(ATRIB(2)+31) = XX(ATRIB(2)+31) + 1
             ENDIF
C
      RETURN
C
      END
C
C              ================
C              SUBROUTINE ERROR
C              ================
C
      SUBROUTINE ERROR(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
C
      INTEGER I
C
C     ============================================================
C     SUBROUTINE ERROR INDICATES IF THE DATA ARRAYS DO NOT HAVE
C     DATA LISTED IN THE PROPER POSITIONS. (AN ATTEMPT TO READ A
C     ZERO INDICATES THAT THE FILE IS IN ERROR.)
C     ============================================================
C
      IF (ATRIB(12).EQ.10) THEN
           PRINT*,'THERE IS AN ERROR IN DATAFILE DEST.DAT'
           PRINT*,'ATRIB(2)   ',ATRIB(2),' COLUMN   ',I
           ENDIF
C
C
C
C
```

```
      IF (ATRIB(12).EQ.20) THEN
           PRINT*,'THERE IS AN ERROR IN DATAFILE LENGTH.DAT'
           PRINT*,'ATRIB(2)  ',ATRIB(2),' COLUMN  ',I
           ENDIF
C
      MSTOP = -1
C
      RETURN
C
      END
C
C          ===============
C          USERF FUNCTIONS
C          ===============
C
      FUNCTION USERF(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
C
      REAL MINI,BIG,JUMBO
C
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15),I
C
C
C                 =======
C                 USERF 1
C                 =======
C
C         calculate amount of fuel required
C
1     IF (ATRIB(7).EQ.1.0) THEN
            USERF = MINI(I)
            ENDIF
C
      IF (ATRIB(7).EQ.2.0) THEN
            USERF = BIG(I)
            ENDIF
C
      IF (ATRIB(7).EQ.3.0) THEN
            USERF = JUMBO(I)
            ENDIF
C
      RETURN
C
C          =====================
C          UNUSED USERF FUNCTIONS
C          =====================
C
2     RETURN
3     RETURN
4     RETURN
C
C
```

```
C               =======
C               USERF 5
C               =======
C
C          TIME TO LAND AND CLEAR RUNWAY
C
5     USERF = 0.03333 + UNFRM(0.02,0.0333,2)
C
      RETURN
C
C               =======
C               USERF 6
C               =======
C
C         TIME TO TAXI FROM THE RUNWAY TO THE RAMP
C
6     USERF = RNORM(0.05.0.0,2) + ERLNG(0.05,2.0,2)
C
      IF (USERF.LE.0.05) THEN
            USERF = 0.05
            ENDIF
C
      IF (USERF.GE.0.755) THEN
            USERF = 0.755
            ENDIF
C
      RETURN
C
C             =====================
C             UNUSED USERF FUNCTIONS
C             =====================
C
C                   (7 - 10)
C
7     RETURN
8     RETURN
9     RETURN
10    RETURN
C
C               ========
C               USERF 11
C               ========
C
C           maintenance time - KNEX
C
11    IF (ATRIB(7).EQ.3) THEN
          USERF = RLOGN(3.409,3.408,1)
          ELSE
          USERF = RLOGN(3.925.4.04,1)
          ENDIF
      RETURN
C
C
```

```
c                ========
c                USERF 12
c                ========
c
c          maintenance time - CYXX
c
12    IF (ATRIB(7).EQ.3) THEN
          USERF = RLOGN(3.409,3.408,1)
          ELSE
          USERF = RLOGN(3.825,4.04,1)
          ENDIF
      RETURN
c
c                ========
c                USERF 13
c                ========
c
c          maintenance time - BIXX
c
13    IF (ATRIB(7).EQ.3) THEN
          USERF = RLOGN(3.409,3.408,1)
          ELSE
          USERF = RLOGN(3.825,4.04,1)
          ENDIF
      RETURN
c
c                ========
c                USERF 14
c                ========
c
c          maintenance time - LPXX
c
14    IF (ATRIB(7).EQ.3) THEN
          USERF = RLOGN(3.409,3.408,1)
          ELSE
          USERF = RLOGN(3.825,4.04,1)
          ENDIF
      RETURN
c
c                ========
c                USERF 15
c                ========
c
c          maintenance time - LEXX
c
15    IF (ATRIB(7).EQ.3) THEN
          USERF = RLOGN(3.409,3.408,1)
          ELSE
          USERF = RLOGN(3.825,4.04,1)
          ENDIF
      RETURN
c
      END
```

```
c
C         ============
c         FUNCTION MINI
c         ============
c
      REAL FUNCTION MINI(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
c
      INTEGER I
c
c      fuel for a C-130
c      ---- --- - -----
c
      FUEL=4800.0*ATRIB(4.0)
c
      IF (ATRIB(4).GT.3.0) THEN
            FUEL = 14400.0 + 4000.0*(ATRIB(4)-3.0)
            ENDIF
c
      IF (ATRIB(4).GT.6.0) THEN
            FUEL = 26400.0 + 3900.0*(ATRIB(4)-6.0)
            ENDIF
c
      MINI = FUEL
c
      RETURN
c
      END
c
C                ===========
c                FUNCTION BIG
c                ===========
c
      REAL FUNCTION BIG(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
c
      INTEGER I
c
c         fuel for a C-141
c         ---- --- - -----
c
      FUEL=15000.0*ATRIB(4)
c
      IF (ATRIB(4).GT.3.0) THEN
            FUEL = 45000.0 + 12500.0*(ATRIB(4)-3.0)
            ENDIF
c
      IF (ATRIB(4).GT.6.0) THEN
            FUEL = 82500.0 + 12000.0*(ATRIB(4)-6.0)
            ENDIF
c
```

```
      BIG = FUEL
C
      RETURN
C
      END
C
C              =============
C               FUNCTION JUMBO
C              =============
C
      REAL FUNCTION JUMBO(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
C
      INTEGER I
C
C                fuel for a C-5
C                ---- --- - ---
C
      FUEL=29000.0*ATRIB(4)
C
      IF (ATRIB(4).GT.3.0) THEN
           FUEL = 87000.0 + 20500.0*(ATRIB(4)-3.0)
           ENDIF
C
      IF (ATRIB(4).GT.6.0) THEN
           FUEL = 148500.0 + 19500.0*(ATRIB(4)-6.0)
           ENDIF
C
      JUMBO = FUEL
C
      RETURN
C
      END
C
C
C         ==========================================================
C                              ALLOC SUBROUTINE
C
C         THIS SUBROUTINE WILL ALLOCATE PIT AND TRUCK RESOURCES
C         AT ALL BASES.
C
C         PITS WILL BE USED FIRST, WHEN AVAILABLE, BECAUSE THEY ARE
C         FASTER.
C
C         WHEN TRUCKS ARE USED, C-5S WILL USE TWO TRUCKS (IF AVALIABLE)
C         TO SPEED REFUELING. ALL OTHER AIRCRAFT WILL USE ONLY ONE
C         TRUCK.
C         ==========================================================
C
C
C
C
```

```
      SUBROUTINE ALLOC(I.IFLAG)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW.II,MFA.MSTOP.NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW.XX(100)
C
      IFLAG = 0
C
      GO TO (1,2,3,4,5),I
C
C            =================
C            ALLOC 1 - AT KNEX
C            =================
C
1     IF (NNRSC(3).LE.0) THEN
          RETURN
          ENDIF
C
      IF (NNRSC(3).GE.1) THEN
          CALL SEIZE(3,1)
          ATRIB(9)=25/60
          IF (ATRIB(13).GT.32000) THEN
              ATRIB(9) = (-17.5 + 1.25*ATRIB(13)/1000)/60
              ENDIF
          ATRIB(11) = 3
          IFLAG = 1
          ATRIB(15) = 1
          RETURN
          ENDIF
C
      RETURN
C
C            ==================
C            ALLOC(2) - AT CYXX
C            ==================
C
2     IF ((NNRSC(6).LE.0).AND.(NNRSC(7).LE.0)) THEN
          RETURN
          ENDIF
C
      IF (NNRSC(6).GE.1) THEN
          CALL SEIZE (6,1)
          ATRIB(9) = (15.3 + 0.349*ATRIB(13)/1000)/60
          ATRIB(11) = 6
          IFLAG = 1
          ATRIB(15) = 1
          RETURN
          ENDIF
C
C
C
C
C
C
```

```
      IF (NNRSC(7).GE.1) THEN
          CALL SEIZE (7.1)
          ATRIB(9) = 25/60
          IF (ATRIB(13).GT.32000.0) THEN
               ATRIB(9) = (-17.5 + 1.25*ATRIB(13)/1000)/60
               ENDIF
          ATRIB(11) = 7
          IFLAG = 1
          ATRIB(15) = 1
          RETURN
          ENDIF
C
      RETURN
C
C         ================
C         ALLOC 3 - AT BIXX
C         ================
C
3     IF (NNRSC(10).LE.0) THEN
          RETURN
          ENDIF
C
      IF (NNRSC(10).GE.1) THEN
          CALL SEIZE(10,1)
          ATRIB(9)=25/60
          IF (ATRIB(13).GT.32000) THEN
              ATRIB(9) = (-17.5 + 1.25*ATRIB(13)/1000)/60
              ENDIF
          ATRIB(11) = 10
          IFLAG = 1
          ATRIB(15) = 1
          RETURN
          ENDIF
C
      RETURN
C
C           =================
C           ALLOC(4) - AT LPXX
C           =================
C
4     IF ((NNRSC(13).LE.0).AND.(NNRSC(14).LE.0)) THEN
          RETURN
          ENDIF
C
      IF (NNRSC(13).GE.1) THEN
          CALL SEIZE (13,1)
          ATRIB(9) = (15.3 + 0.349*ATRIB(13)/1000)/60
          ATRIB(11) = 13
          IFLAG = 1
          ATRIB(15) = 1
          RETURN
          ENDIF
C
```

```
      IF (NNRSC(14).GE.1) THEN
          CALL SEIZE (14,1)
          ATRIB(9) = 25/60
          IF (ATRIB(13).GT.32000.0) THEN
               ATRIB(9) = (-17.5 + 1.25*ATRIB(13)/1000)/60
               ENDIF
          ATRIB(11) = 14
          IFLAG = 1
          ATRIB(15) = 1
          RETURN
          ENDIF
C
      RETURN
C
C            =================
C            ALLOC(5) - AT LEXX
C            =================
C
5     IF ((NNRSC(17).LE.0).AND.(NNRSC(18).LE.0)) THEN
          RETURN
          ENDIF
C
      IF (NNRSC(17).GE.1) THEN
          CALL SEIZE (17,1)
          ATRIB(9) = (15.3 + 0.349*ATRIB(13)/1000)/60
          ATRIB(11) = 17
          IFLAG = 1
          ATRIB(15) = 1
          RETURN
          ENDIF
C
      IF (NNRSC(18).GE.1) THEN
          CALL SEIZE (18,1)
          ATRIB(9) = 25/60
          IF (ATRIB(13).GT.32000.0) THEN
               ATRIB(9) = (-17.5 + 1.25*ATRIB(13)/1000)/60
               ENDIF
          ATRIB(11) = 18
          IFLAG = 1
          ATRIB(15) = 1
          RETURN
          ENDIF
C
      RETURN
C
      END
C
C
C
C
C
C
C
```

```
C        =================
c        OUTPUT SUBROUTINE
c        =================
C
      SUBROUTINE OTPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
C
      INTEGER RUN,RATE,FIRST,ROUTE,FUEL
c
      WRITE (10,*) NNRUN,'  C-141 ON TIME AT KNEX     ',XX(47)
      WRITE (10,*) NNRUN,'  C-141 LATE AT KNEX        ',XX(48)
      WRITE (10,*) NNRUN,'  C-5 ON TIME AT KNEX       ',XX(49)
      WRITE (10,*) NNRUN,'  C-5 LATE AT KNEX          ',XX(50)
      WRITE (10,*) NNRUN,'  C-141 ON TIME AT CYXX     ',XX(51)
      WRITE (10,*) NNRUN,'  C-141 LATE AT CYXX        ',XX(52)
      WRITE (10,*) NNRUN,'  C-5 ON TIME AT CYXX       ',XX(53)
      WRITE (10,*) NNRUN,'  C-5 LATE AT CYXX          ',XX(54)
      WRITE (10,*) NNRUN,'  C-141 ON TIME AT BIXX     ',XX(55)
      WRITE (10,*) NNRUN,'  C-141 LATE AT BIXX        ',XX(56)
      WRITE (10,*) NNRUN,'  C-5 ON TIME AT BIXX       ',XX(57)
      WRITE (10,*) NNRUN,'  C-5 LATE AT BIXX          ',XX(58)
      WRITE (10,*) NNRUN,'  C-141 ON TIME AT LPXX     ',XX(59)
      WRITE (10,*) NNRUN,'  C-141 LATE AT LPXX        ',XX(60)
      WRITE (10,*) NNRUN,'  C-5 ON TIME AT LPXX       ',XX(61)
      WRITE (10,*) NNRUN,'  C-5 LATE AT LPXX          ',XX(62)
      WRITE (10,*) NNRUN,'  C-141 ON TIME AT LEXX     ',XX(63)
      WRITE (10,*) NNRUN,'  C-141 LATE AT LEXX        ',XX(64)
      WRITE (10,*) NNRUN,'  C-5 ON TIME AT LEXX       ',XX(65)
      WRITE (10,*) NNRUN,'  C-5 LATE AT LEXX          ',XX(66)
C
      BOT = 0
      DO 10 I = 1,20
           BOT = BOT + XX(46+I)
10    CONTINUE
C
      TOP = 0
      DO 20 I = 1,10
           TOP = TOP + XX(45+2*I)
20    CONTINUE
C
C     WRITE (10,*) '    '
      WRITE (10,*) NNRUN,'  OVERALL DEPARTURE RELIABILITY    ',
     1TOP/BOT
      XX(98) = TOP/BOT
C
      TOP = 0
      DO 30 I = 1,5
           TOP = TOP + XX(43+4*I)
30    CONTINUE
C
c
c
```

```
      BOT = 0
      DO 40 I = 1,5
            BOT = BOT + XX(43+4*I) + XX(43+4*I+1)
40    CONTINUE
C
c     WRITE (10,*) '     '
      WRITE (10,*) NNRUN,'  OVERALL C-141 DEPARTURE RELIABILITY     ',
     1TOP/BOT
C
c
      TOP = 0
      DO 50 I = 1,5
            TOP = TOP + XX(45+4*I)
50    CONTINUE
C
      BOT = 0
      DO 60 I = 1,5
            BOT = BOT + XX(45+4*I) + XX(45+4*I+1)
60    CONTINUE
C
C     WRITE (10,*) '     '
      WRITE (10,*) NNRUN,'  OVERALL C-5 DEPARTURE RELIABILITY     ',
     1TOP/BOT
C
      RUN=2
      RATE=1
      FIRST=1
      ROUTE=2
      FUEL=1
C
      WRITE (50,100) RUN,RATE,FIRST,ROUTE,FUEL,NNRUN,XX(99),XX(98)
100   FORMAT(1X,I2,1X,I1,1X,I1,1X,I1,1X,I1,1X,I2,1X,F6.2,1X,F6.4)
      RETURN
C
      END
```

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Major James E. Hill was born on 28 May 1950 in Fort Leavenworth, Kansas. He graduated from high school in Fairfax, Virginia in 1968. In January 1973, he graduated from Cornell University with a Bachelor of Science degree in Engineering Physics. After graduation, he received a commission in the USAF through the ROTC program. Upon entering the Air Force in June 1973, he attended the Communication Systems Operations Course at Keesler AFB, Mississippi, finishing as a Distinguished Graduate. At Langley AFB, Virginia he served as a Communications Duty Officer at the Hq TAC Command Post and as a staff officer in the Tactical Plans Division, Hq Tactical Communications Area. In January 1978, he entered undergraduate pilot training at Williams AFB, Arizona, graduating in November 1978. At Charleston AFB, South Carolina, he then served as a C-141 pilot and aircraft commander with the 20th Military Airlift Squadron, and as a C-141 instructor and flight examiner, Flight Simulator Branch, 437th Military Airlift Wing. In August 1984, Maj Hill entered the School of Engineering at the Air Force Institute of Technology. He is a member of Tau Beta Pi and Omega Rho.

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While the strategic airlift flow during a major European conflict has been thoroughly analyzed, the interaction with deploying C-130 units has not been addressed. This thesis quantifies the competition for resources at such enroute facilities as Goose Bay and Lajes. The resources modeled include ramp space, refueling units, and runway use.

The methodology was to build a simulation model using SLAM (Simulation Language for Alternative Modeling). The simulation was used to analyze the interactions and bottlenecks that occur between the strategic airlift aircraft and the C-130s as C-130 deployment flow rates vary. The measures of effectiveness are C-130 deployment closure time and strategic airlift reliability rate.

The objective was to provide HQ MAC contingency planners with a tool to verify the feasibility of their deployment plans and to evaluate the effectiveness of proposed changes to those plans. Several factors were analyzed to determine their effect on the strategic airlift flow and the time required for C-130 deployment. The results of the analysis identify resource constraints and flow limitations in the European scenario. The methodology allows study of deployments to other theaters with some changes to the simulation.

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