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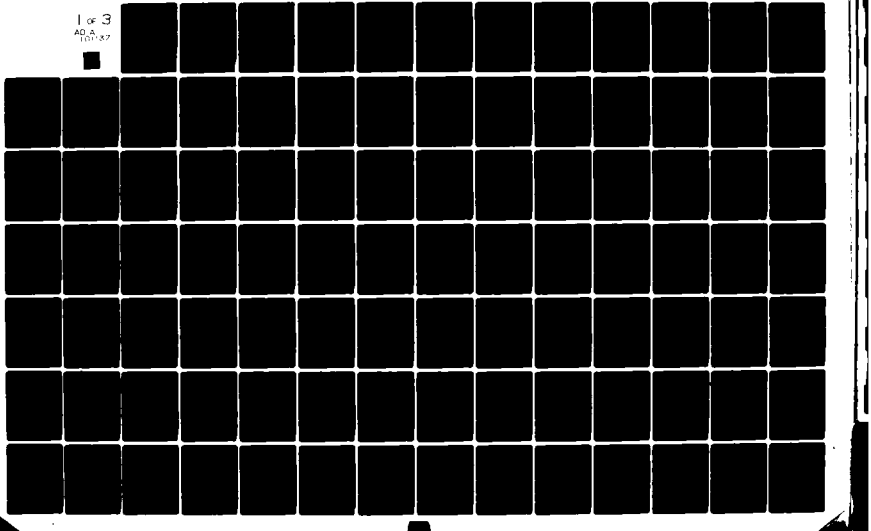

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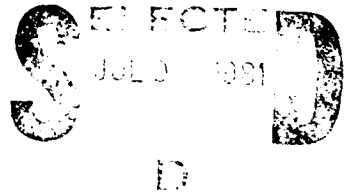
OPTIMIZATION OF STRATEGIC AIRLIFT IN-FLIGHT REFUELING

THESIS

Vernon P. Bordelon, Jr., Capt, USAF
John C. Marcotte, Jr., Major, USAF

AFIT/GST/OS/81M-3



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During the 1980s increases in the potential use of Strategic Airlift to transport equipment and personnel is anticipated. The capabilities of Strategic Airlift aircraft are extended through the inclusion of efficient in-flight refueling. The primary objective of this research was to develop a method which determines the combination of in-flight refueling rendezvous point, takeoff fuel loads and tanker base which results in the

minimum total fuel consumption for an airlifter and tanker aircraft.

The experimental design included the creation of two models. An analytic flight planning model determined the optimal rendezvous point and the takeoff fuel loads for the aircraft in a specific mission scenario. A SLAM simulation model verified the operational feasibility of the results of the analytic model by simulating the flights of aircraft.

The optimal rendezvous can only be determined by analyzing the interaction of the airlifter route distance, the cargo load, and the location of the tanker base. As the total distance of cargo load decreases or the tanker base is located farther along the airlifter's route of flight, the optimal rendezvous point is located incrementally farther from the boundary established by the maximum feasible range of the airlifter from its destination. The optimal takeoff fuel loads are dependent on the aircraft combination and will result in the smallest sum of the total fuel-carrying capacity used. By using the optimal rendezvous point for an in-flight refueling mission, significant fuel savings are realized.

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OPTIMIZATION OF STRATEGIC AIRLIFT IN-FLIGHT REFUELING

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

by

Vernon P. Bordelon, Jr.
Capt USAF

John C. Marcotte, Jr.
Major USAF

Graduate Strategic and Tactical Sciences

March 1981

Preface

Strategic airlift air-refueling planning is becoming more important as the MAC airlift fleet gains an operational in-flight refueling capability. As fuel supplies become more expensive and scarce, fuel conservation becomes increasingly more important. We sincerely hope that airlift and tanker operational planners will use the results of this research when selecting air-refueling points and takeoff fuel loads to reduce total fuel consumption.

We would like to thank Colonel C. C. Shaw, Jr., HQ USAF/SAGM, who provided the initial topic on optimizing airlift air-refueling, and Major Burgesson and Lieutenant David Sauve, AFGWC/DOY, who provided the aircraft fuel data base for the C-5A, C-141B, and the KC-135. We would especially like to thank Paul Fruge, ALD/YTE, who released the KC-10 engineering fuel consumption estimates to use as fuel consumption data for that aircraft. We would like also to thank Major Daniel Fox, our thesis advisor, for his many helpful suggestions and conscientious guidance in the preparation of this thesis. Finally, we would like to thank Colonel Donald Stevens and Professor Daniel Reynolds who sacrificed their time to read our papers and

offer their enthusiastic support. To these people and all of AFIT we wish to express our deepest thanks.

This thesis would never have been completed without the complete support, sacrifices, and love from our wives, Jan and Becky. Their steadfast encouragement and patient endurance of the long hours required to complete this thesis, contributed more than anything else towards our successful efforts. We look forward to devoting this time again to our families.

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Abstract

During the 1980s increases in the potential use of Strategic Airlift to transport equipment and personnel is anticipated. The capabilities of Strategic Airlift aircraft are extended through the inclusion of efficient in-flight refueling. The primary objective of this research was to develop a method which determines the combination of in-flight refueling rendezvous point, takeoff fuel loads and tanker base which results in the minimum total fuel consumption for an airlifter and tanker aircraft.

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maximum feasible range of the airlifter from its destination. The optimal takeoff fuel loads are dependent on the aircraft combination and will result in the smallest sum of the total fuel-carrying capacity used. By using the optimal rendezvous point for an in-flight refueling mission, significant fuel savings are realized.

OPTIMIZATION OF STRATEGIC AIRLIFT IN-FLIGHT REFUELING

I. Introduction

The Problem

Efficient in-flight refueling of strategic airlift aircraft is being recognized as vital to the Military Airlift Command (MAC) and the Department of Defense. Currently, all C-5A aircraft are air-refuelable and by the end of 1982 all MAC C-141 aircraft will be air-refuelable (Ref 21:48). As a result of this increased capability, MAC is constantly striving through innovation and research, to make air-refueling missions more productive and efficient. One way to increase the efficiency of airlift air-refueling missions is to determine the combination of planning factors; the takeoff fuel, tanker basing, and air-refueling rendezvous point, which would minimize the total fuel consumed by an airlift and tanker aircraft. No current method determines an optimal combination of these factors for in-flight refueling between strategic airlift and tanker aircraft.

Objectives

The objective of this research effort was to develop a method which determines the optimal combination of in-flight refueling rendezvous point, takeoff fuel loads

and tanker base for a refueled aircraft mission. By determining the optimal combination three questions are answered. First, should the rendezvous point be close to or far from the points of departure? Second, how much fuel should be loaded on the airlifter and tanker prior to take-off? Third, from what base should the tanker depart?

When the research was begun it was believed that the following two hypotheses would prove true.

1. The minimum total fuel consumed by the airlift and tanker aircraft for their combined flight will result from a rendezvous point located at the maximum flight range of the airlifter from its destination base. This point is always located on the boundary of the region of feasible rendezvous points closest to the airlifter takeoff base.

2. Airlifter aircraft departures with the maximum allowable fuel load will always result in the minimum total fuel consumption for both aircraft. This implies that the fuel transferred is the minimum required to complete the flight.

By demonstrating the accuracy of these hypotheses they could then be used to help define a general policy for efficient in-flight refueling.

Two models were developed in the course of this research. The first, FLTPLN, computed the optimal planning factors for an air-refueling airlift mission. The

FLTPLN results were then validated for operational suitability by a SLAM[1] (Simulation Language for Alternative Modeling) simulation model.

These two models were used to explore different scenarios and many fuel cargo combinations for the airlift aircraft. Aircraft combinations investigated are listed in Table 1. Sensitivity analysis was used to determine the effect on the response variable, total fuel consumption, to changes in the input factors of takeoff fuel onload, cargo, wind, takeoff delays, and total distance.

TABLE 1

AIRCRAFT COMBINATIONS

Airlifters	Tankers
C-5A	KC-135
C-5A	KC-10
C-141B	KC-135
C-141B	KC-10

Benefits

Three benefits are apparent from determining an optimal combination of planning factors which minimizes total fuel consumed. The first benefit is obviously fuel conservation. To emphasize the importance of conserving

[1]SLAM is a simulation language developed by Pritsker and Associates, Inc., West Lafayette, Indiana. SLAM has been designed to support engineers, managers, and researchers.

fuel, the Chairman of the Joint Chiefs of Staff stated that, the supply, access and price of oil will dominate future national security issues (Ref 13:i). By minimizing total fuel consumed, operating costs go down, and funds used in procuring the saved fuel could be used for other equally essential programs. As the cost of fuel goes up, the savings from an optimal refueling policy will also go up. For example, the price of fuel (JP-4) increased from $.42 per gallon in 1979 to $1.16 per gallon in 1980 (Ref 19). Additional increases can be expected in the future. The second benefit which results from an optimal refueling point is that individual mission flight times are reduced. While the flight time of modern jet aircraft results in a relatively short deployment time, the savings from the multiple sorties of a large-scale deployment would be significant. This means closure times can be reduced due to decreased flight times. Closure time occurs when the last aircraft of a deployment arrives at the destination. More importantly, the airframe time, which cannot be renewed, is also reduced. The third benefit from an optimal refueling point is that operational plans and contingency plans can be optimally formulated for a wide range of mission scenarios. By combining all three benefits, the advantages of determining an optimal refueling point, which ensures more efficient airlift operations are apparent.

During the 1980s, significant increases in the potential use of airlift to transport equipment and

supplies worldwide is anticipated. Due to political and natural constraints the importance of air-refueling during a rapid deployment will also increase. Therefore, the efficient use of air-refueling of airlift aircraft will result in significant economies to the Air Force.

II. Background

Military Airlift Command policies regarding air-refueling operations for airlift aircraft are relatively new and untested, compared to those of SAC and TAC. Employment plans utilizing air-refueling are founded on only a few years of experience, and have not, as yet, been tested with large-scale deployments or war-scenario exercises. Employment policy and operations concepts for air-refueling are constantly being formulated and updated as more research is conducted in this area. Chapter II provides a background in air-refueling history, employment principles and policy currently in use at HQ MAC. Included is a description of the extent of MAC air-refueling experience, active air-refueling policy research, current planning models in use at MAC and HQ USAF, and a description of mission flight planning, using a typical airlift flight profile.

History of Airlift Air-Refueling

In the last two decades, strategic airlift has become increasingly important to the Department of Defense to support the rapid deployment and resupply of Allied or United States forces overseas. To increase this resupply capability, C-5A aircraft were acquired and C-141 aircraft are being modified to utilize in-flight refueling.

In-flight refueling became available to the Military Airlift Command in December, 1969 (Ref 12), with the introduction of the C-5A aircraft into the Air Force inventory. Although the C-5 was originally built to be air-refuelable, this capability was not tested and evaluated until May, 1974, with the final evaluation report submitted in March, 1975 (Ref 5:ii,2). Presently, MAC is modifying C-141A aircraft for air-refueling operations and will change the designation to C-141B.

The need for quick and efficient airlift and the potential need for air-refueling airlift aircraft was graphically portrayed during the Arab-Israeli Conflict of 1973. In October, 1973, Egypt and her allies confronted Israel with a pre-dawn surprise attack (Ref 9:27-28). The initial impact on Israel was a large-scale loss of equipment (aircraft and tanks) as well as a large expenditure of munitions. During the first few days of the war, the United States realized that Israel would require massive and rapid resupply to avert a major catastrophe. Due to the rapid delivery requirement, the only satisfactory delivery method was airlift. Lack of support from our European Allies compounded the delivery problem, as they withheld overflight and landing rights to Israel-bound airlifters. As a result, equipment and munitions stockpiled in Europe were not available for Israeli use and all supplies and munitions destined for Israel had to come from the Continental United States (CONUS) (Ref 15:14-15).

The only European ally to offer support to the United States was Portugal, which controlled the Azores in the mid-Atlantic Ocean. Portugal approved the Azores as a MAC staging base enabling Israel to be resupplied by air without air-refueling (Ref 15:14-15). In 33 days, MAC crews airlifted 22,315 tons of equipment and supplies, flying 421 C-141 sorties and 145 C-5A sorties (Ref 8:26-32). The quick and effective resupply of Israel's military machine enabled Israel to regain the offensive on all borders and eventually dominate the war (Ref 15:14-15).

The Air Force learned a very important lesson from this resupply effort. Our strategic airlift fleet is very dependent on friendly foreign nations to provide staging bases. Without Portugal's cooperation, the airlift would not have been possible since the C-5A did not have an operational air-refueling capability at that time. To meet future challenges to the United States or her Allies, the dependence on staging bases had to be reduced through the expansion of air-refueling capabilities.

Since 1973, the Air Force has undertaken several new programs to increase the in-flight refueling capability of the strategic airlift fleet. First, the C-5A was made operationally air-refuelable and aircrews were trained (Ref 5). Second, 234 C-141A aircraft are being modified to air-refuelable C-141B aircraft (Ref 13:199). Third, a new tanker fleet of DC-10s (designated KC-10) has been purchased. With the addition of the KC-10,

multiple tankers will no longer be required to refuel the C-5 on a routine basis.[2] Fourth, a proposal to install more efficient engines in the KC-135 tanker is being studied. The addition of these new engines and their reduced fuel consumption will allow more fuel to be transferred to the airlifter or increase the rendezvous range of the KC-135 for a fixed offload of fuel. This results in increased range for the airlifters.

With all of these changes, air-refueling of airlift aircraft will make a greater contribution to the strategic and tactical posture of the United States. However, increasing airlift capability by adding new refueling assets (KC-10 and C-141B) also requires expertise and experience in creating plans and policy to employ these forces.

In the future, contingency plans which call for airlift resources will be re-evaluated using air-refueling as an option. General Huyser, CINCMAC, has stated that future airlift plans created to support war plans will address in-flight refueling as an option in order to take advantage of this increased capability and efficiency (Ref 16). In addition, studies to determine how to optimally use strategic airlift refueling must also be undertaken. These studies should research operational problems as well

[2]The C-5A fuel capacity is 315,100 pounds and the KC-10 fuel capacity is 349,153 pounds of which any portion can be transferred in-flight to the airlifters. The KC-135A fuel capacity is only 165,000 pounds.

as economic and logistic problems. Included in the operational problem area is the problem of obtaining an optimal air-refueling rendezvous point.

Current Concepts and Models

MAC planners are investigating the possible incorporation of air-refueling models in various war and operations plans.[3] This responsibility falls to the Operational Plans Office, HQ MAC/XP (Ref 16). As plans are periodically revised, air-refueling is being considered as a possible method of increasing the efficiency and effectiveness of the plans. MAC considers three areas as potentially beneficial in increasing the efficiency of airlift operations:

1. When air-refueling is the only possible method available for a particular mission. An example would be a flight from Moody AFB, Georgia, to West Cairo AB, Egypt, in a C-141B. A C-141B cannot fly from Moody AFB to Cairo AB without either stopping enroute for fuel or air-refueling. If, for political reasons, a staging base is not available, then the C-141B would be unable to accomplish the deployment. Therefore, air-refueling is the only way a C-141B can be used on this mission.

2. When a technical constraint is imposed upon an airlift operation and air-refueling is required. For

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[3]Specific contingency plans which address air-refueling are classified and will not be covered here.

example, if a C-5A were to airlift a full load of the Army's battle tanks from Peterson Field, Colorado (Colorado Springs), the C-5A would be unable to take off with a full fuel load due to inadequate runway length (11,000 FT) at the airfield's pressure altitude (6,172 FT) (Ref 10:B96). Air-refueling would add the necessary fuel, after takeoff, to continue the flight to destination.

3. Air-refueling can be used to improve closure time of a mission or a planned deployment. An example would be the deployment of a tactical fighter squadron from the CONUS to Korea. By employing air-refueling, the improved closure time may be decisive in political negotiations.

Air-refueling employment in a war plan or a large-scale operations plan has never been tested by MAC and therefore actual experience is limited. To determine the feasibility and efficiency of using strategic airlift air-refueling in a MAC plan, the planning staff must actually prepare the plan twice; once with the air-refueling included and once without, so that an intelligent choice between the two can be made. Actual mission profiles must be planned so that logistic and aircrew requirements can be determined and analyzed.

In planning the air-refueling sorties for a particular mission, coordination between the MAC staff and the SAC staff is essential. This coordination results in a tanker commitment from SAC for the particular plan.

Agreement on a rendezvous point between the two MAJCOMs is accomplished by a series of negotiations between the two planning staffs (Ref 3). During the negotiating, each staff tries to obtain a rendezvous point most advantageous for their MAJCOM. However, during this process, analytical procedures or models which can determine an optimal route of flight for each aircraft are not used (Ref 23). Therefore, during the planning process, neither staff knows if the agreed-upon rendezvous point is picked so as to minimize total fuel consumed or total mission flying time for both aircraft.

As HQ MAC/XP is planning routes of flight for war plans, other routine refueling missions are also being planned. Daily air-refueling training missions that MAC and SAC fly are planned in the same iterative manner by HQ MAC/DOOMF staff officers. Coordination and negotiations with SAC for an air-refueling rendezvous point is done in the same manner, again without the benefit of any optimizing procedures (Ref 3). Although these methods are adequate and are operationally feasible, the planning could be done quickly and more economically using analytical models.

In an effort to obtain knowledge in the area of air-refueling, HQ MAC has created air-refueling simulation models. Air-refueling deployments and operations are being analyzed in order to gain insight into the world of strategic airlift air-refueling. At HQ MAC, in the recent past, one primary model has been used to study airlift

air-refueling. The model is presently in use and is known as the M-14 model, commonly referred to as "Collosus" (Ref 14). The name M-14 identifies it as the fourteenth macro-model created at HQ MAC. This model was originally created without air-refueling, but this feature has been recently added. This Monte Carlo simulation model simulates the entire Military Airlift Command operations and incorporates all strategic airlift aircraft presently owned by MAC. M-14 includes factors such as crews, air bases, material depots, and logistic material used in daily MAC operations (Ref 14). The purpose of M-14 is to study the entire airlift capacity of MAC under almost any circumstances. Other uses for the M-14 include study and analysis of time-phased deployments, such as JCS exercises (REFORGER, JACKFROST) and to study the interaction effects of factors on airlift operations (crews, supplies, etc.). M-14 can also be used to determine or test optimal global airlift strategies in the event of a global conflict requiring massive use of airlift. Evaluation and validation of war and operations plans can also be accomplished with this model. M-14 is an extremely large model and cannot be run at HQ MAC due to a lack of computer capability (Ref 14). As a consequence, a larger computer at Kirtland AFB, NM, must be used whenever the M-14 is used.

Major initial inputs to the model include departure base, destination, route of flight, and fuel and cargo loads. Another important variable is tanker-airlifter

air-refueling rendezvous point for air-refueling missions. The M-14 model allows the manual input of a rendezvous point, or it will calculate a rendezvous point for a particular mission. In either case, the rendezvous point is determined without the benefit of analytical optimization.

At a higher command level, HQ USAF Studies and Analysis (SAGM) has created a refueling model. The purpose of this model is to study tanker force sizing (Ref 22). Given a particular deployment package, the number of tankers required can be determined, or given a particular number of tankers, the most efficient employment methods can be determined and evaluated. This model is detailed in its fuel calculations, and results have shown that the fuel figures from the model are within 1 to 2 percent of figures obtained from the aircraft performance manual and fuel planning publications (Ref 22). The model is deterministic and does not use simulation methods. Variables such as wind factors, which can change dynamically, are fixed for a particular run of the model. Rendezvous points are either manually inserted or can be calculated inside the model; however, no optimization routine is used to try to reduce fuel consumption by picking the best of all feasible rendezvous points.

Flight Planning

This section describes and explains flight planning and fuel planning to include a discussion of the terminology

and concepts used later in describing this research. Flight planning is an extremely important part of aviation, without which, intercontinental flights would be hazardous and chaotic. Since this study is concerned with detailed flight planning calculations, a brief description of flight planning methods will be presented. Appendix A will present a sample fuel planning calculation for the C-141B. These calculations will be linked to the SLAM Simulation Model in Appendix K. For the purpose of this research, flight planning is defined as the art and science of determining a route of flight and fuel required to fly between a departure and destination location. This planning is done on the ground prior to flight. AFR 60-16, General Flight Rules, states that prior to each mission the pilot in command will ensure that the flight path and fuel planning will be performed in sufficient detail for a safe flight (Ref 2:p.2-1). The initial phase of flight planning determines the route of flight. This is usually listed on a computer flight plan obtained from AF Global Weather Central (AFGWC), Offutt AFB, NE. The computer flight plan provides flight altitude, route of flight, distances, and flying times between reporting points as well as other information. The flight altitude must conform to the hemispherical altitude structure in air traffic controlled airspace.

The next and most important part of flight planning is fuel planning. Since fuel planning and fuel consumption

are of primary importance to this research, fuel planning will be decomposed into seven sections for an air-refueling mission (see Figure 1).

1. Start, taxi and takeoff.
2. Climb to an initial cruise altitude.
3. Cruise to an air-refueling rendezvous point.
4. The refueling maneuver.
5. Cruise to destination.
6. Approach and landing.
7. Holding or cruise to an alternate airport (if applicable), and appropriate fuel reserves.

Each of these seven areas will be explained so that the terms will be familiar when the air-refueling models are described. The following explanation will be for a typical MAC air-refueling mission, and is not intended to be used as a guide for planning an actual flight.

The first part of fuel planning is start, taxi, and takeoff (STTO). This encompasses the fuel required for engine start, taxi from the parking spot, and acceleration fuel during the takeoff roll. If ground delays or Air Traffic Control (ATC) delays are known or anticipated, the fuel consumed for these is also computed and added to STTO fuel. The STTO fuel is usually a constant fuel quantity for a particular aircraft. For example, 1900 pounds of fuel is used for the C-141B (Ref 1:p.2-2). The ground delay fuel is based on time and is usually computed from a

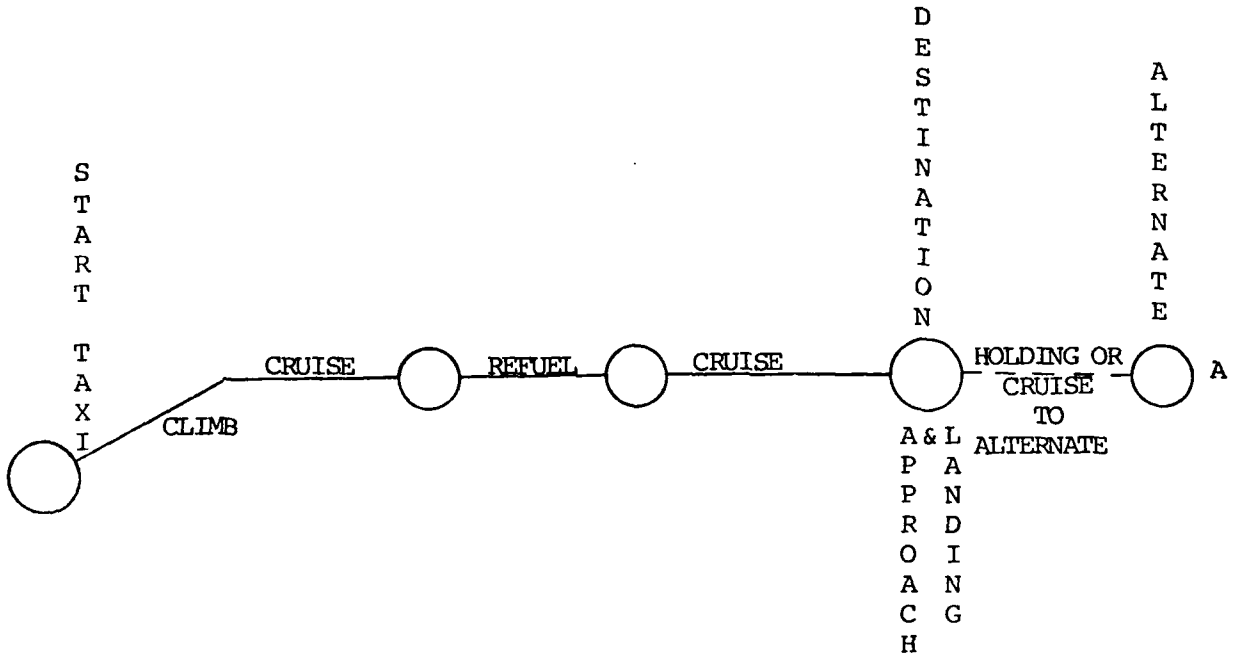

Fig. 1. Flight Planning Segments

constant fuel consumed per unit time. For the C-141B, the ground idle fuel consumption rate is 60 pounds per minute. Known ground delays are always accounted for in fuel planning.

The second part of fuel planning is the climb fuel consumption. The ground distance traveled during the climb can be obtained from the performance manual for the aircraft, or from the computer flight plan. Using distance and the time required to climb to cruise altitude, the fuel consumed in the climb can be determined from the aircraft performance manual.

The third part of fuel planning is the fuel required to cruise to the destination or air-refueling rendezvous point. To calculate this fuel, time at cruise, cruise altitude, and aircraft gross weight are required. Again tables in the performance manual for the aircraft are used.

Once the rendezvous point is reached, the fuel required for section four, the rendezvous and refueling maneuver, is computed. At this point, it is important to insure that each aircraft, the tanker and the airlifter, has sufficient fuel reserves to continue their mission. For the airlifter, sufficient fuel must be aboard prior to the refueling so that if unable to refuel, it can reach a suitable abort location and land with the proper fuel reserves. These reserves will be detailed later in this section. If additional fuel beyond that required to

accomplish the abort is available, then an air-refueling will be attempted.

The air-refueling track is usually a fixed distance, over which the refueling must be accomplished (Ref 17). The track location and length are determined prior to flight and the amount of fuel transferred from the tanker will be enough to allow the airlifter to reach its destination. The tanker, prior to the refueling, must have enough fuel to supply the airlifter and return to its recovery base with the proper fuel reserves. If either the tanker or the airlifter cannot meet these fuel requirements, the air-refueling is aborted. However, the abort rate for airlift aircraft is only between 10 and 15 percent (Ref 3). Fuel consumption during this stage of flight differs from cruise fuel rates, and must also be taken into account. Differences in fuel consumption rates are due to formation flying with the refueling boom extended. Detailed fuel computatic are discussed in Appendix A.

Once the refueling is completed, the airlifter and tanker cruise to their destinations. Cruise fuel is determined in a manner similar to the cruise to rendezvous point.

Once the aircraft approaches the destination, the enroute descent, approach, and landing maneuvers occur and fuel computations are completed for section six. Approach and landing fuel is usually given as a constant figure for all aircraft. For example, the approach and landing fuel for a C-141B is 2500 pounds of fuel (Ref 1:p.2-2).

The fuel reserves for an international MAC flight are used to insure that enough fuel is aboard the aircraft to complete the mission as planned and to account for unforeseen changes. These changes can occur at various times throughout the mission. Examples are ATC delays, changes in the direction and velocity of the wind, weather, and changes in the temperature deviation of altitude. Combining these unforeseen delays, a large quantity of fuel could be expended. To ensure that the mission is not jeopardized, AFR 60-16/MAC Supplement One provides guidelines for the aircrew establishing procedures to calculate fuel reserves. These unforeseen delays are accounted for in three ways:

1. Enroute fuel reserves.
2. Alternate fuel reserves.
3. Holding fuel reserves.

Enroute fuel reserves are added to the normal flight plan fuel load and consist of fuel which is 10 percent of the fuel used to fly over a category one route/route segment, not to exceed one hour fuel at normal cruise (Ref 1:p.2-2). A category one route is any route where a navigation aid cannot be flown directly over once every hour. This generally applies only to those portions of the flight which are over water.

The second fuel reserve is the fuel required to divert to an alternate airfield due to weather, airfield closure, or other circumstances. For flights outside the

CONUS, an alternate is always required (Ref 1:p.8-1). Fuel reserves to fly to the alternate airfield are computed as follows:

> Fuel (is required) for flight time from overhead destination or initial penetration fix to alternate, or to the most distant alternate when two are required, at the speed and altitude in the appropriate fuel planning publication. Add a ten percent reserve when time to alternate exceeds one hour for turbojet. . . . Alternate reserve plus enroute reserve will not exceed one hour at normal cruise [Ref 1:p.2-2].

The final fuel reserve to be calculated during flight planning is the holding fuel. Once an aircraft has arrived at a destination, there are many reasons why it may be instructed to hold by ATC. In any event, if holding is necessary, a holding reserve fuel can be calculated as follows: "Holding fuel will be 45 minutes fuel for turbojet . . . computed from the appropriate fuel planning publication using endurance or holding charts [Ref 1:p.2-2]."

Fuel planning is completed when all of the fuel figures are added to provide a flight plan fuel load. This is the fuel required to fly the intended mission. Each MAJCOM provides planners and aircrews with fuel management procedures to ensure a safe flight. When the fuel planning is concluded the important parts of flight planning are accomplished.

III. Design of Experiment

Scope and Assumptions

The scope of this research was limited to scenarios which require refueling of the airlifter to complete the mission and where in-flight refueling is dictated because enroute refueling bases are not available. Missions which involve more than a single tanker and airlifter aircraft are not addressed. Two scenarios have been selected for investigation. The first is an airlifter flight from McGuire AFB, NJ, to Tehran, Iran. The second scenario is a flight from Travis AFB, CA, to Yokota AB, Japan.

The following assumptions are made in this research:

1. The tanker aircraft will take off and recover from the same base which will be limited to CONUS or U.S. possession bases. The recovery restriction stems from the high demand for tankers by SAC, TAC, and MAC during a general contingency operation. Use of a single tanker base insures the availability of maintenance and staging crews for fast turnaround of the tanker to support another refueling mission. This base may be other than the tanker's home station if the tanker is prepositioned close to the refueling point.

2. The aircraft operations must be in accordance with AFR 60-16, General Flight Rules, and other major command regulations pertaining to air-refueling.

3. The maximum allowable cargo, limited by the maximum gross weight or volume of the cargo compartment, will be loaded on the airlifter. This operating practice will minimize the total number of sorties required to deliver a particular deployment package.

Conceptualization

Two models were developed for this research. The first, "FLTPLN," is deterministic and it models the aircraft flight planning as described in Chapter II. It computes the fuel requirements for a specific set of mission input parameters. The model compares the fuel requirements at 65 rendezvous points in the feasible region and selects the geographic point which minimizes the total fuel consumed by the airlifter and tanker aircraft. The second model is a SLAM simulation model whose inputs are provided by FLTPLN. The model simulates the actual flight (see Figures 1 and 2) of the two aircraft substituting a stochastic variable for the wind parameter and adding the probabilistic occurrence of takeoff delays. The mean for the wind is the constant value used by the flight planning model. The variance of the wind and the probability of delay are determined from real world events. The simulation tests the operational feasibility of the input

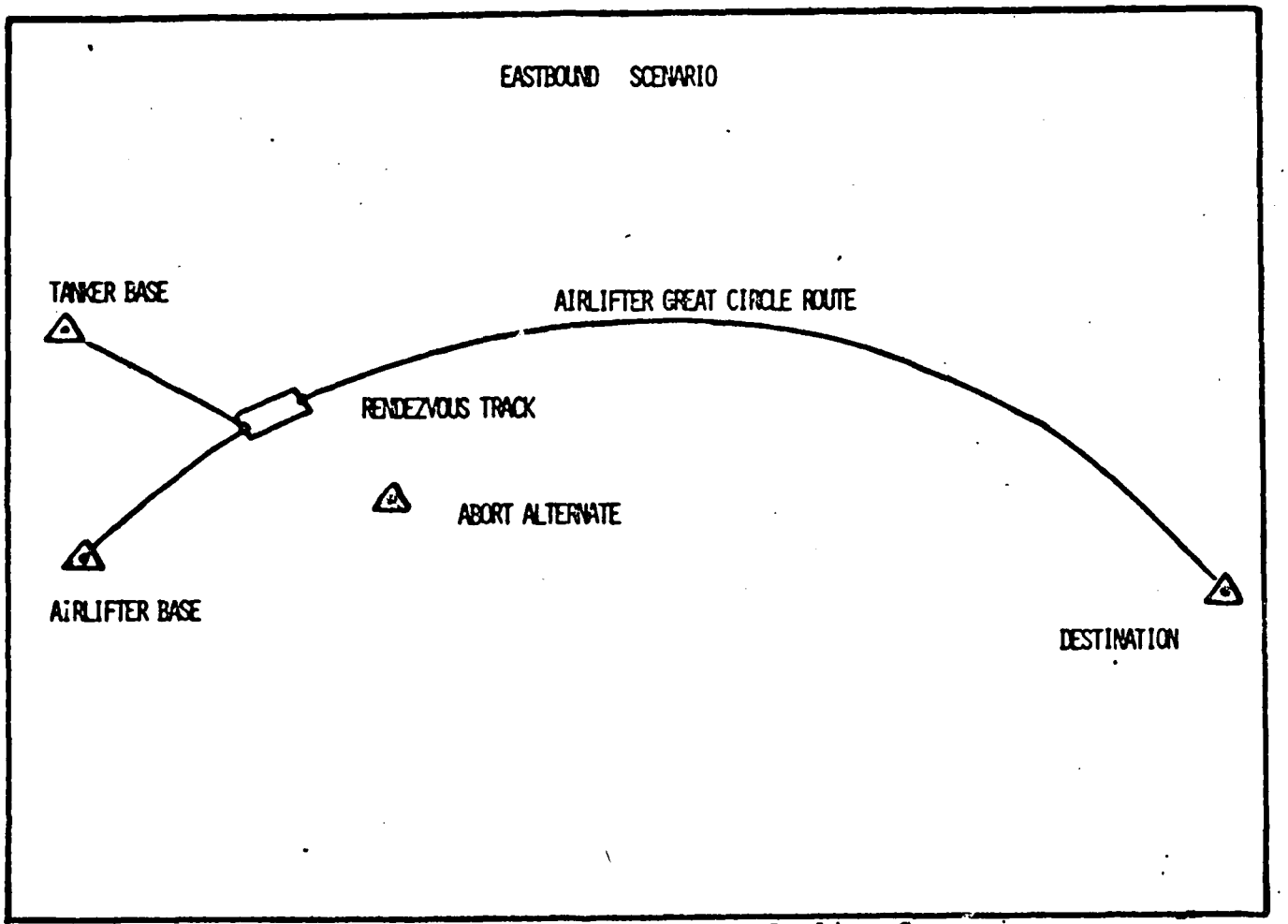

Fig. 2. In-flight Typical Refueling Scenario

parameters verifying the results of the FLTPLN model. The SLAM model was also used to determine the extreme values of variance of the stochastic variables beyond which the flight planning results were always operationally infeasible. A detailed description of the two models is in Appendix K.

The response variable under consideration in this research is the total fuel consumed by an airlifter and tanker aircraft during a mission which requires an in-flight refueling of the airlifter. As described in Chapter II, the major factors which affect the total fuel are the fuel consumption rates for each aircraft and the time that fuel is consumed at the respective rates. The fuel consumption rates are different for each aircraft and vary for a specific aircraft with changes in aircraft gross weight and meteorological conditions, such as temperature and air density. These meteorological conditions change proportionally with the flight altitude of the aircraft as well as randomly with changing weather patterns. The gross weight of the aircraft is derived from the basic airframe weight plus the cargo and fuel at takeoff. The gross weight changes constantly during flight as the fuel weight is reduced. The flight time is a function of the total distance and groundspeed. The total distance is the flight path of each aircraft between its departure and destination. Groundspeed is the sum of the aircraft true airspeed and the component of the wind velocity in the

direction of flight. The true airspeed varies with the mach number and altitude of the aircraft.

The meteorological conditions are the most difficult to predict. The computer flight plans generated by AFGWC require a wind and temperature update every 300 NM along the planned flight path to accurately compute time and fuel results. A worldwide weather data base updated in real time supports this interaction. Because this research is directed at a general policy rather than a specific solution, the scenario weather patterns are held constant. The temperature and air density are fixed at the standard day values for the cruise altitude and the wind is a constant, set to 263 degrees at 55 KNOTS. This wind is an approximate mean value for east-west flights at mid-latitudes. The cruise altitude is selected at the highest Air Traffic Control Hemispheric altitude which the aircraft can attain for its gross weight. Thus, all meteorological conditions are controlled in the models.

Each aircraft has a fixed basic airframe weight and operationally assigned cruise mach number. Therefore, only cargo and fuel weight are varied on the airlifter and only fuel weight on the tanker. The fuel consumption rates for each aircraft using these parameters are obtained from the common fuel data base, referred to as FLYME (see Appendix H).

For an actual flight, the flight path may be modified because of airspace constraints, national boundaries,

or weather considerations. Since the total distance is the only route factor pertinent to this research, the flight path is defined as the great circle route between the departure and destination points. As a result, a scenario of departure and destination bases for each aircraft completely defines the total distance. The major factors which are varied in this research are therefore:

1. the airlifter scenario,
2. the tanker scenario,
3. the aircraft combination,
4. the airlifter's cargo load, and
5. the airlift initial fuel load.

In order to investigate the interactive effect of each factor, a full factorial design is employed combining all levels of each factor with the levels of all other factors. This design varies the levels of only one factor at a time while keeping the others constant. This routine is repeated until all levels of all factors are examined. Table 2 lists the design factors and their levels.

Two airlifter scenarios were investigated, one east bound with a tail wind and one west bound with a head wind. The attempt was to offset the effects of holding the wind constant in the model. For each airlifter scenario, four tanker departure bases were considered to test the impact of tanker basing on the optimal rendezvous point. The tanker bases were selected with one near the airlifter's departure base, one to the north, one to the south, and the

TABLE 2

EXPERIMENTAL DESIGN FACTORS AND LEVELS

Factor	Level
Airlifter Scenario	a) McGuire AFB, NJ to Tehran, Iran b) Travis AFB, CA to Yokota AB, Japan
Tanker Scenario	a) Castle AFB, CA b) Charleston AFB, SC c) Eielson AFB, AL d) Fairchild AFB, WA e) Loring AFB, ME f) McGuire AFB, NJ
Aircraft Combination	a) C-5/KC-10 b) C-5/KC-135 c) C-141B/KC-10 d) C-141B/KC-135
Airlift Cargo Load	a) 1) 100,000 lbs. 2) 85,000 lbs. 3) 70,000 lbs. b) C-141B 1) 70,000 lbs. 2) 55,000 lbs. 3) 40,000 lbs.

Airlifter Maximum Fuel Load

Fuel (1000 lbs.)			
C-5	Cargo (1000 lbs.)	C-141B	Cargo (1000 lbs.)
261.3	100.0	114.0	70.0
276.3	85.0	129.0	55.0
291.3	70.0	144.0	40.0

NOTE: These initial maximum fuel loads were decremented by 20,000 lbs. ten times or until infeasible fuel loads were obtained.

fourth was Barksdale AFB, LA. Barksdale is the proposed base of assignment for the KC-10 (Ref 23). This allows comparison of the KC-10 operating from Barksdale against operating from a base closer to the airlifter departure base. The bases considered in each scenario are listed in Table 2.

For each scenario and aircraft combination, many rendezvous points are feasible. Rather than compare all of the feasible points, a small rectangular region is considered. The rectangle was fixed along the feasible boundary furthest from the airlifter destination. The size of the rectangle is 20 degrees of latitude by 24 degrees of longitude. The region was determined to always contain the optimal rendezvous point. All other points have higher total fuel values and the values increase monotonically in all directions away from the optimal point. As a result, only the matrix of points in the rectangle were required to define the optimal point. For rendezvous points near the airlifter's departure base, the leveloff point after initial climbout was considered as the first feasible rendezvous point. These cases are close to not requiring an air-refueling and are treated as extreme levels. A single abort base is designated for each scenario. In the case of an aborted refueling, the airlifter must have sufficient fuel to recover to the departure base or the abort alternate, whichever is closer. Loring AFB, ME, is

the abort alternate for the east scenario and Elmendorf AFB, AK, is the abort alternate for the west scenario.

The structure of the SLAM model exactly follows the sequence of flight planning steps outlined in Chapter II. The wind velocity is allowed to vary and delays which result in additional fuel consumption are included. The delay data is based on the actual home station delay rates from Travis AFB, CA, and Dover AFB, DE, for the C-5A, Norton AFB, CA, and Travis AFB, CA for the C-141, and March AFB, CA, and Plattsburg AFB, NY, for the KC-135. The KC-10 is not operational, so the results of the C-5A data were used for the KC-10 also. The raw sample data for these delay rates are in Appendix B.

Multiple runs of each scenario are made in the SLAM model to test the feasibility of the FLTPLN results. The sample size, or number of replications per flight was determined while the sample runs were conducted. The sample size was directly determined from results generated by the SLAM model output. Initially, runs of ten replications with a variance reduction technique were used. The variance reduction technique was antithetic variates (Ref 18:484-485). Using antithetic variates and twenty replications reduced the variance obtained from twenty replications using regular Monte Carlo simulation techniques in every case tested.

IV. Verification and Validation

The steps taken to validate the analytical flight planning model, FLTPLN, are described in this chapter. The validation included verification of three aspects of the model; input parameters, internal design, and technical accuracy of the computations. The validity of the output of the model was also measured against the objectives and assumptions used in the modeling efforts. The validity criteria was set at 5 percent deviation from the performance charts for the FLYME fuel data and 10 percent deviation of the total fuel consumption results of the model from manual computations. Final validation of FLTPLN for operational suitability was accomplished by the SLAM simulation model.

The input parameters used by FLTPLN are constants or derived results computed in other model subroutines. The constants are either levels of the factors varied in the experiment or parameters extracted directly from the respective aircraft performance manual. The use of operational constants such as cruise mach number significantly adds to the external validity of the model because these are the values in actual use by the MAJCOMs. The derived results include fuel data from the FLYME set of subroutines, great circle distance and course computations from subroutine RHOTHTA (see Appendix H), and ground speed

computations from within FLTPLN (see Appendix C). The FLYME fuel data was technically verified by comparing selected values to the aircraft performance charts. The results are presented in Table 3. The average deviation of the FLYME data from the performance charts as a percentage of the chart values is 4 percent. This deviation was consistent for all parameters in both the FLTPLN and SLAM models.

Appendix A contains a sample fuel consumption calculation of a typical C-141 mission using the aircraft performance manuals. Table 4 compares these manual fuel consumption values to the manual computations. These are sufficiently close to verify that the aircraft fuel consumption calculations are representative of the respective aircraft.

The internal design of FLTPLN was verified by proceeding manually through each step of the program to ensure that values were used as the designers intended and not changed or internally lost. The output parameters were also cross-checked to verify one result from another. For example, the onload fuels must equal the sum of the route fuels plus reserves. From these tests, the program's design was technically certified as accurately computing and printing the experimental results.

The output of the models was displayed in a 5 x 13 matrix consisting of total fuel consumption values for a specific rendezvous point. For every scenario and

TABLE 3

VALIDATION OF FLYME DATA BASE

Input Parameters		Climb Time (Min)	Climb Dist (NM)	Climb Fuel (1000 lb)	Cruise Fuel Rate (1000/Min)	Holding Fuel Rate (1000/Min)
C-5	FLYME	22	133	12.3	.32	.20
500,000#	CHT	21	129	11.7	.32	.23
FL350	% Dev	+.05	+.03	+.05	0	-.12
C-5	FLYME	25	150	16.1	.42	.23
650,000#	CHT	25	150	15.3	.42	.26
FL290	% Dev	0	0	+.05	0	-.12
C-141B	FLYME	15.4	93.6	6.6	.20	.16
240,000#	CHT	15.1	91.0	6.3	.21	.16
FL350	% Dev	+.02	+.03	+.05	-.05	0
C-141B	FLYME	15.8	92	7.6	.25	.19
300,000#	CHT	14.8	90.5	6.9	.26	.19
FL290	% Dev	+.07	+.02	+.10	-.04	0
KC-10	FLYME	18.3	127.5	10.3	.35	.24
420,000#	CHT	17.6	121	9.8	.35	.24
FL370	% Dev	+.04	+.05	+.05	0	0
KC-10	FLYME	22.2	154.5	13.7	.41	.31
575,000#	CHT	21.2	151	13.2	.39	.31
FL310	% Dev	+.05	+.02	+.04	+.05	0
KC-135	FLYME	19.3	128.6	6.6	.18	.16
180,000#	CHT	20.0	127.0	6.6	.18	.16
FL350	% Dev	-.04	+.01	0	0	0
KC-135	FLYME	27.2	171.5	9.9	.25	.20
250,000#	CHT	28.0	171.0	9.9	.25	.20
FL290	% Dev	-.03	.00	0	0	0

NOTE: CHT values are obtained from aircraft performance manuals.

TABLE 4

VALIDATION OF FLTPLN AND SLAM MODELS

Aircraft	1000s (lbs) Airlift Cargo	Complementary ACFT	Aircraft Dest.	Tanker Base	Mission Fuel Consumption 1000s lbs. JP4					
					FLTPLN Manual	FLTPLN Actual	% Dev	SLAM Manual	SLAM Actual	% Dev
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
C-5	100	KC-135	Tehran	Loring	304.0	285.1	-6.2	303.6	287.3	-5.4
C-5	70	KC-10	Yokota	Castle	305.4	297.5	-2.6	306.8	297.1	-3.1
C-141	55	KC-135	Tehran	McGuire	168.7	169.5	+ .4	175.9	178.5	1.5
C-141	40	KC-10	Yokota	Castle	176.1	169.6	-3.9	182.5	169.3	-7.2
KC-10	70	C-5	Fairchild	Fairchild	73.0	72.3	-1.0	73.2	70.1	-4.2
KC-10	55	C-141	Loring	Loring	114.0	108.4	-5.1	114.0	111.5	-2.2
KC-135	40	C-141	Eielson	Eielson	29.1	30.7	+5.5	26.8	27.9	+4.1
KC-135	70	C-5	Charleston	Charleston	44.5	47.3	+6.3	44.8	46.6	+4.0

NOTE: See column key next page.

Table 4 Column Key

Column

1 Aircraft - aircraft of interest.

2 Airlift Cargo - cargo of the airlifter in combination with column 1 aircraft.

3 Complementary aircraft - the second aircraft in the combination of interest.

4 Aircraft destination - destination of the aircraft in column 1.

5 Tanker Base - the Tanker departure base

6 FLTPLN Manual - the mission fuel consumption value obtained from a manual fuel computation using FLTPLN winds (263°/55 knots)

7 FLTPLN Actual - the mission fuel consumption value obtained from FLTPLN.

8 % Dev - the deviation of FLTPLN fuel consumption values from the manual computations.

9 SLAM Manual - the fuel consumption value obtained from a manual fuel computation using a 55-knot wind factor (SLAM model).

10 SLAM Actual - the mean fuel consumption value obtained from SLAM.

11 % Dev - the deviation of FLTPLN fuel consumption values from the manual computations.

combination of factors, FLTPLN determined an optimal rendezvous point for which the total fuel requirement was lower than any other point considered. This can be seen in the FLTPLN output in Appendix G. While this matrix represented only a portion of the feasible region of points, the optimal point was always surrounded by higher values. Every matrix of total fuel values had a gradient increasing monotonically from the optimal point out to the feasible boundary or to the edge of the matrix. Thus the minimum value of the matrices is considered the absolute minimum for the entire feasible region.

The output was further validated by checking that changes in the input parameters resulted in consistent changes in the output. For example, higher cargo weights or route distances resulted in higher total fuel consumption.

Further validation of FLTPLN results was accomplished using the SLAM model. FLTPLN output (total fuel consumption per aircraft) was compared to SLAM output and mission success rates were computed. In this way, FLTPLN output could be shown to be feasible under actual real-time flight conditions. The SLAM validation of FLTPLN was done for each aircraft. The results of this validation are described in the following paragraphs.

Each of the twenty-three C-5 flights simulated by the SLAM model was successful under the normal wind factor using probabilistic ground delays of zero or fifteen

minutes. The SLAM fuel consumption values averaged 2.1 percent higher than those calculated by the analytical model. Deviation of the SLAM fuel consumptions for the C-5 are shown in Figure 3 for particular cargo loads, tanker base, and refueling tankers. A negative value means the SLAM model computed less fuel than the analytical model and a positive value means the SLAM model computed more fuel. Even with this increased fuel consumption, the C-5 was still able to complete all flights successfully. To further validate FLTPLN a 95 percent confidence interval based on the SLAM fuel consumption mean and variance was constructed for each aircraft. Using the upper limit of the confidence interval as the actual C-5 fuel consumption, and as a mission completion success criteria, 87 percent of the flights were successful. For example, if the available fuel for the C-5 exceeded the upper limit of the fuel consumption confidence interval the mission was successful.

Every one of the twenty-three C-141B flights simulated by the SLAM model was successful. The SLAM fuel consumption values averaged 2.7 percent higher (see Figure 4) than that calculated by the analytic model. Using the upper limit of the 95 percent confidence interval as the actual fuel consumed in flight and as a mission success criteria, 83 percent of the C-141 flights were successful. Combining the success rates for both aircraft the analytic model correctly predicted the proper ramp fuel load for the airlift aircraft.

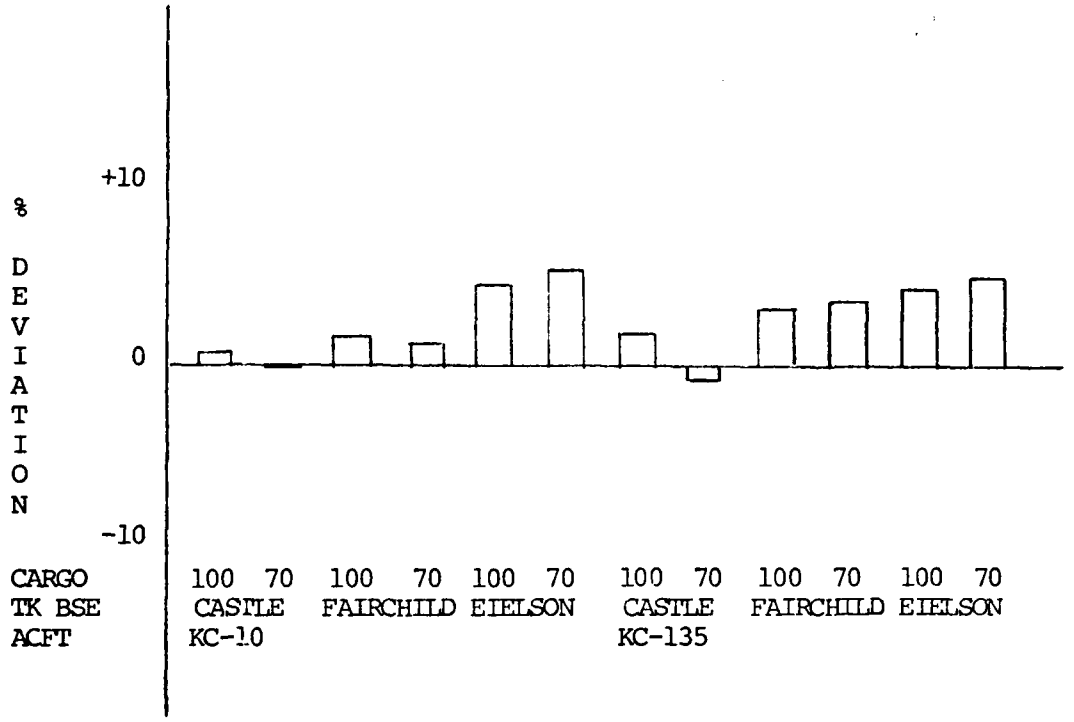

Fig. 3. C-5--Deviation of SLAM Results Compared to the Analytical Fuel Consumption Results

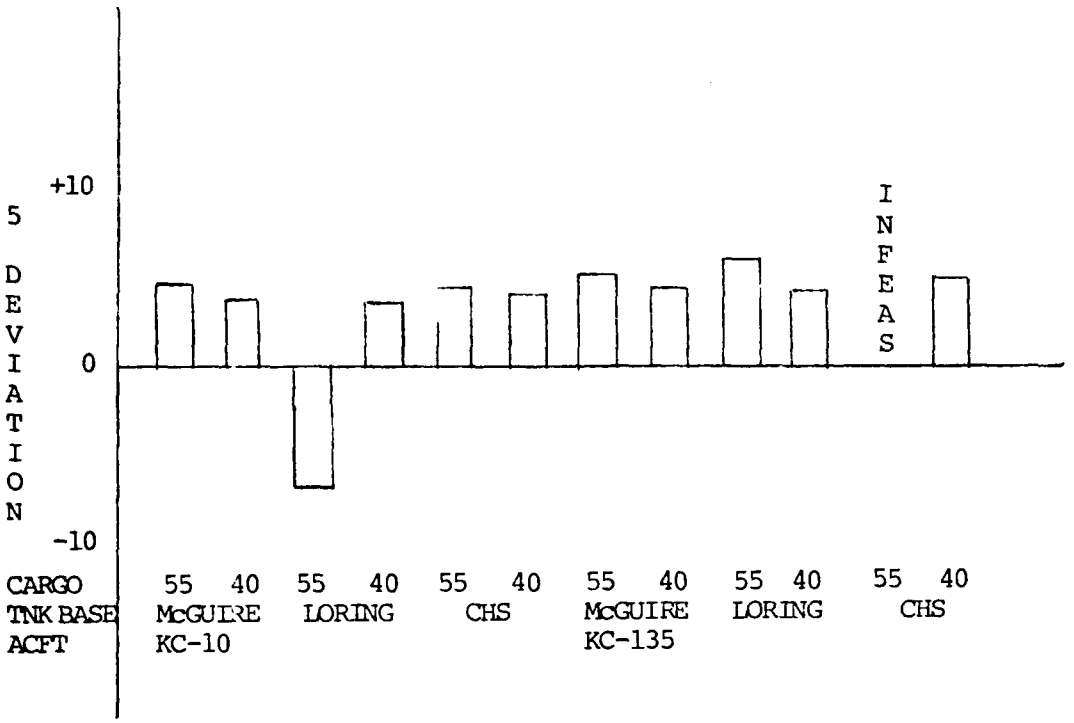

Fig. 4. C-141--Deviation of SLAM Results Compared to the Analytical Fuel Consumption Results

One hundred percent of the SLAM tanker flights were successful using the SLAM wind variant and ground delays. Also each of the flights was successful using the upper limit of the 95 percent confidence interval as the success criteria. The SLAM KC-10 fuel consumption values averaged less than a 1 percent decrease (see Figure 5) from the analytical model result and the KC-135 averaged less than a 2 percent decrease (see Figure 6) from the analytical model result. From these deviations we concluded that the analytical model provides results that are operationally feasible under actual flight conditions for all four aircraft.

Overall, the tankers burned about 1 percent less fuel in the SLAM model than in the analytical model. Conversely, the airlifters burned about 2.5 percent more fuel in the SLAM model than in the analytical model. This difference in airlift fuel can be explained from the nature of the two aircraft missions. The tanker flies to a rendezvous point and returns to his departure base which is relatively close compared to the airlifter destination; the airlifter, however, flies to the rendezvous point and then continues on to a destination which is thousands of miles longer than the tanker route of flight. Consequently, the airlifter has more time to be affected by increases in the wind factor, and these increases plus any delay in fuel consumption would cause the increased fuel requirement. There are two reasons the tanker SLAM results

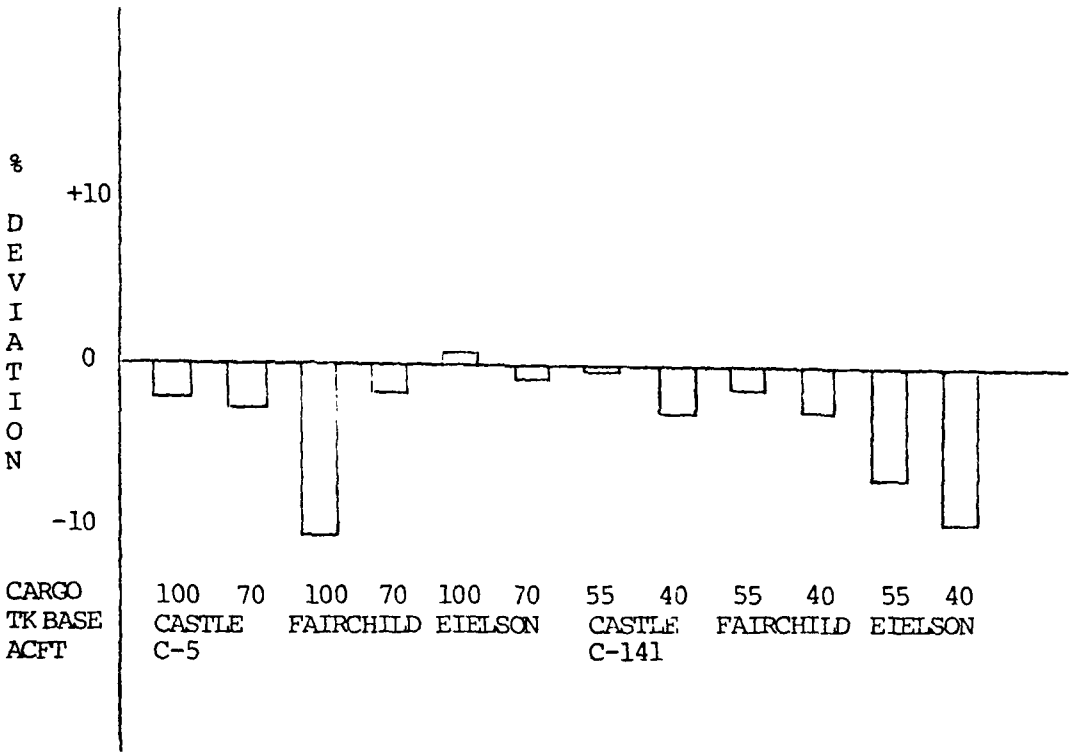

Fig. 5. KC-10--Deviation of SLAM Results Compared to the Analytical Fuel Consumption Results

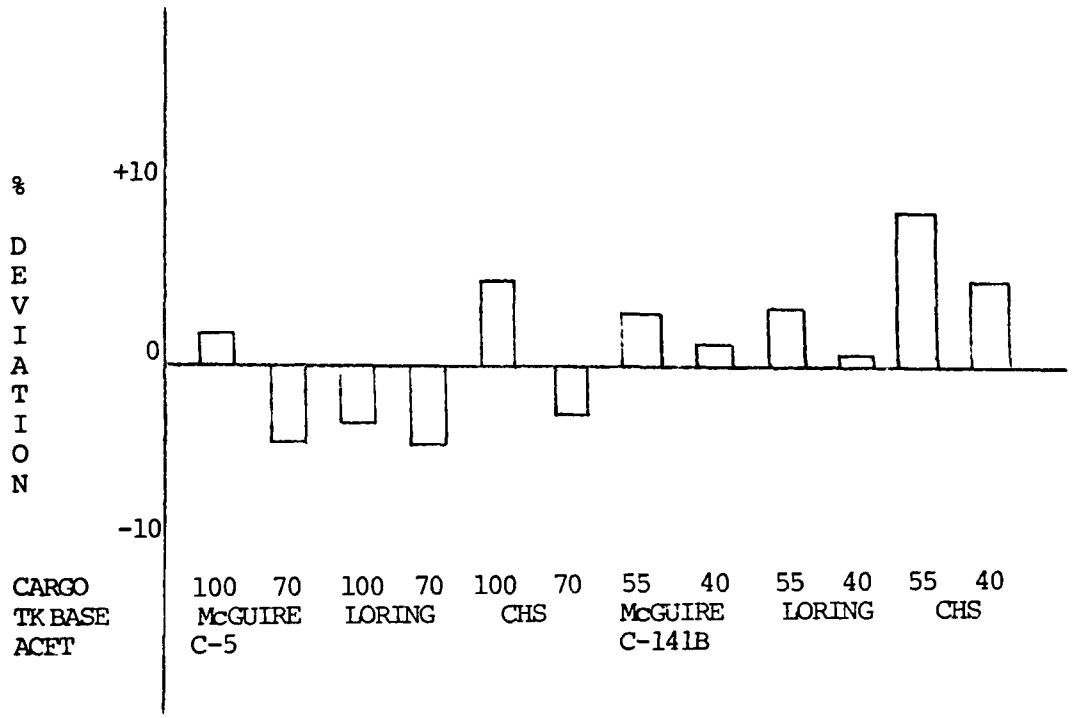

Fig. 6. KC-135--Deviation of SLAM Results Compared to the Analytical Fuel Consumption Results

are less than the analytical consumption. First is that an increase in wind factor has less effect on the tanker than on the airlifter. A head wind increase to the rendezvous point becomes a tail wind increase when returning to destination. Second, is the difference in the loiter fuel computations. In FLTPLN the tanker loiter fuel is always based on a fifteen-minute loiter duration; however, in SLAM the loiter time is based on actual aircraft arrivals which usually requires less than fifteen minutes loiter time. For the tankers, fifteen minutes loiter fuel is more than the difference between SLAM and FLTPLN fuel values. However, without any adjustments for loiter fuel the fuel consumption values remain within our 10 percent validation criteria. Finally, from these validation results we observe that the SLAM model has validated the results of the analytical model. The SLAM model validation is discussed in Appendix I.

V. Results and Analysis

The major purpose in the analysis of the research results was to identify the principal factors affecting the determination of the optimal rendezvous point and takeoff fuel loads. First, these principal factors were analyzed in terms of the two hypotheses stated in Chapter I.

The effect of cargo load on the optimal rendezvous point is the first factor to be considered. The first hypothesis stated that the optimal rendezvous point would occur at the maximum flight range of the airlifter from its destination base. This maximum range from the destination constitutes a boundary of the region of feasible rendezvous points closest to the airlifter takeoff base. The dashed lines on Figures 7 to 10 represent this boundary at the levels of the cargo weight indicated. The optimal rendezvous points determined by FLTPLN did not always occur at this boundary range. The separation between the rendezvous points and the feasible boundary is indicated on the figures by the arrows. For example, in Figure 7, the 100,000 pounds cargo load on the C-5A resulted in an optimal rendezvous point location 244 nautical miles from the respective feasible boundary. The results for the C-141 on Figure 8 are similar. As the cargo weight is decreased, the range of the airlifter increases. This

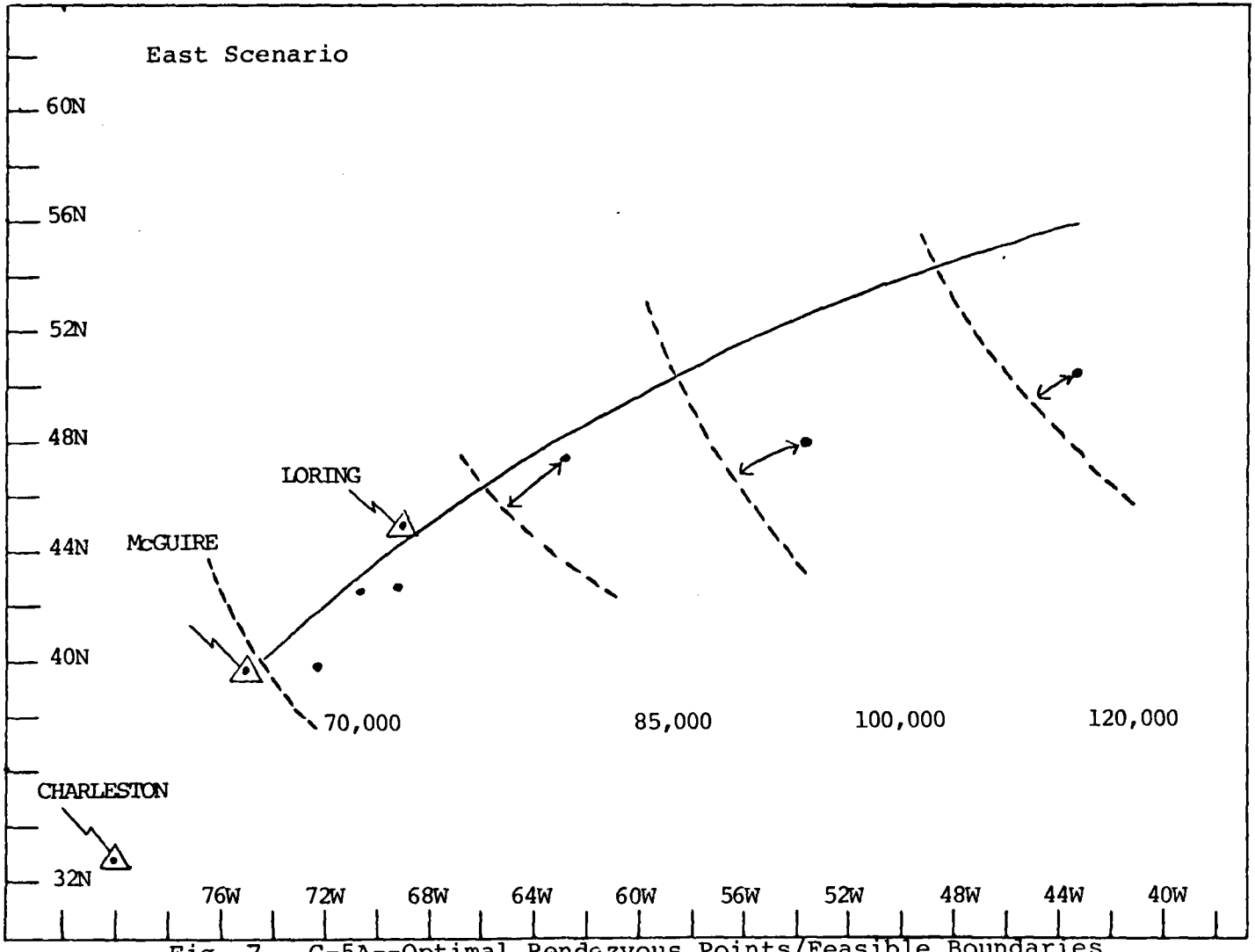

Fig. 7. C-5A--Optimal Rendezvous Points/Feasible Boundaries

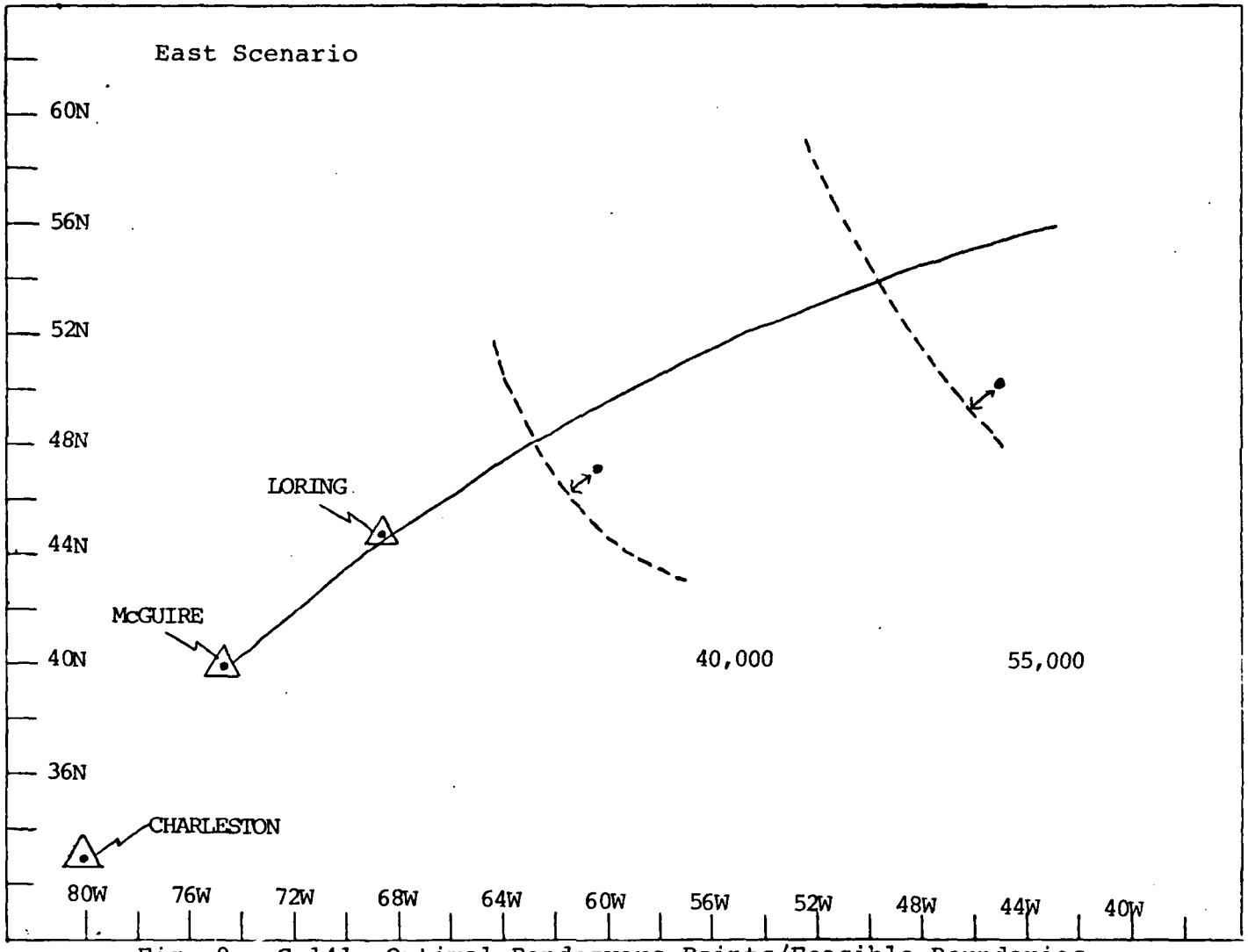

Fig. 8. C-141--Optimal Rendezvous Points/Feasible Boundaries

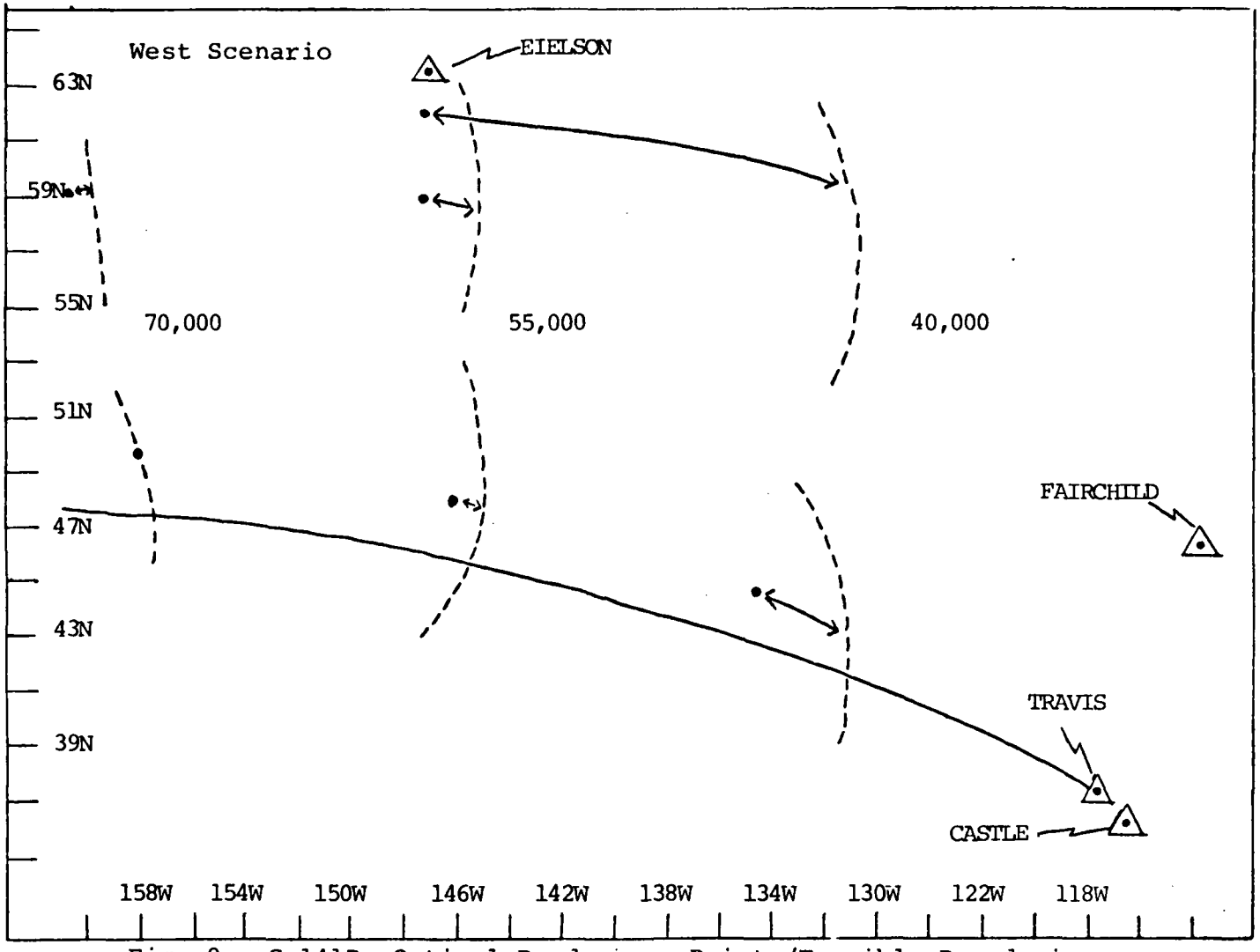

Fig. 9. C-141B--Optimal Rendezvous Points/Feasible Boundaries

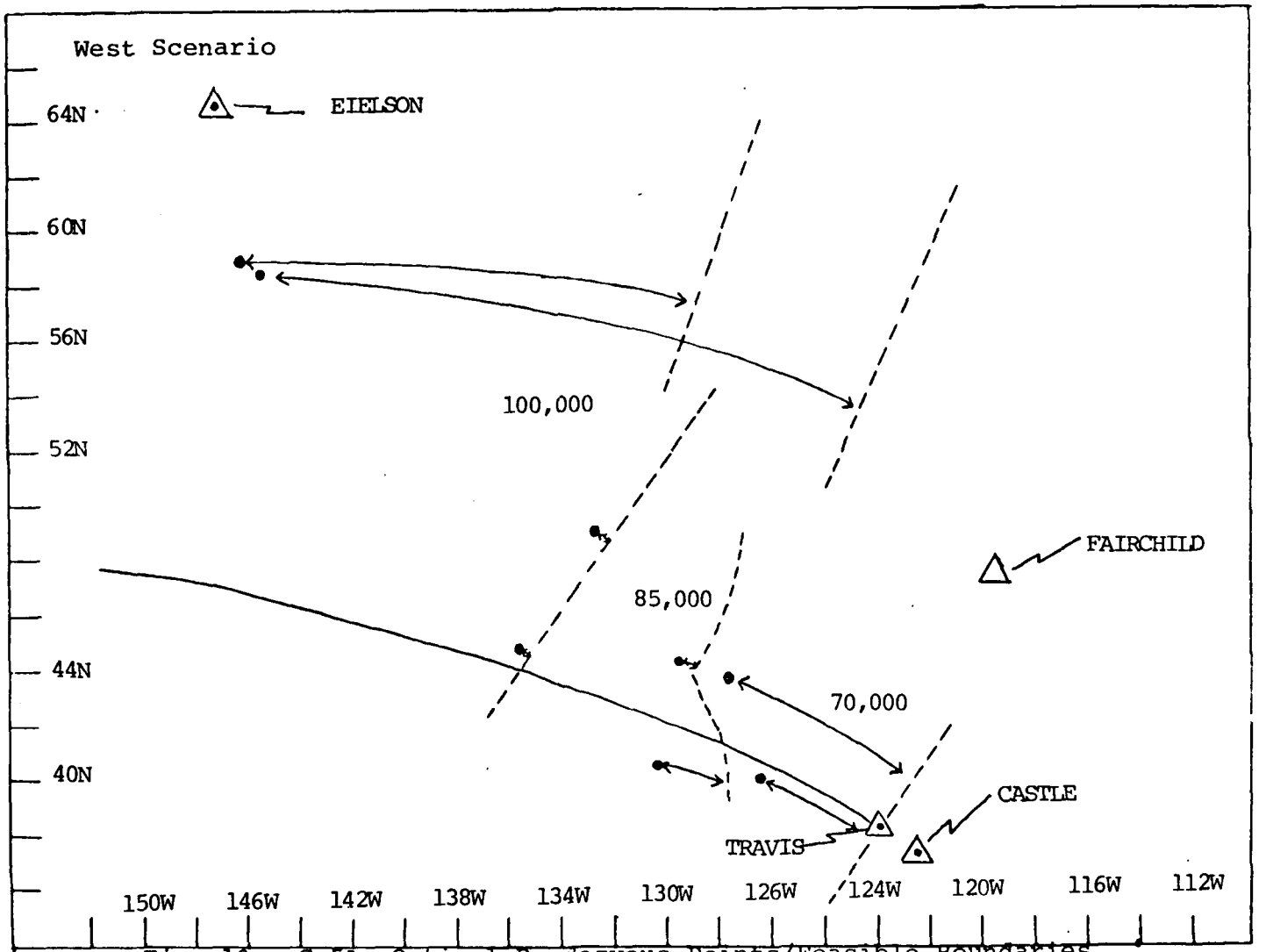

Fig. 10. C-5A--Optimal Rendezvous Points/Feasible Boundaries

shifts the feasible boundary away from the airlifter destination base. For each decrease in cargo weight, the optimal rendezvous points shift toward the airlifter takeoff base along with the corresponding feasible boundary. However, the optimal rendezvous point is located farther from the hypothesized location with each decrement. For the maximum feasible cargo weight of an airlifter, the optimal point occurs on the feasible boundary, as is indicated on Figure 9 for 70,000 pounds. Beyond these cargo weights, the shorter range of the airlifter does not permit a feasible solution. These results contradict the first hypothesis.

The second factor to be considered is tanker base selection. Five of the six airlifter/cargo weight combinations for the east scenario resulted in the same optimal rendezvous points regardless of which tanker base was used. However, for the west scenario, most tanker bases resulted in a unique rendezvous point for a given airlifter/cargo weight combination. The rendezvous point using Eielson was different from the rendezvous point using Fairchild or Castle. The location of Eielson far along the western route of the airlifter, precipitated this result. However, each of the bases had some influence on the rendezvous point measured by the distance of the point from the great circle route of the airlifter. Table 5 lists these distances by bases. The influence of the tanker base consistently increases as the bases are located farther along

TABLE 5

TANKER BASE INFLUENCE ON RENDEZVOUS POINT

Base	Location
Eielson	758.7 NM
Fairchild	402.2 NM
Castle	93.7 NM

the airlifter's route. The lack of variance due to tanker basing in the east scenario rendezvous points stems from the increased fuel requirements for the airlifter. Because of the large fuel requirement to reach the ultimate destination in the eastern scenario, little flexibility was present in determining the rendezvous point. Thus, the location of the tanker base affects the selection of the optimal rendezvous point more when the fuel constraints on the airlifter are relaxed by enroute tanker basing or shorter total distances for the airlifter.

The second hypothesis stated that the maximum allowable takeoff fuel load for the airlifter would result in less total fuel consumption than any other fuel load. However, for most scenarios, the optimal airlifter fuel load was the minimum required to reach the optimal rendezvous point and still maintain sufficient fuel reserves to abort to the closest recovery base. This is indicated by the lowest point on the graph in Figure 11.

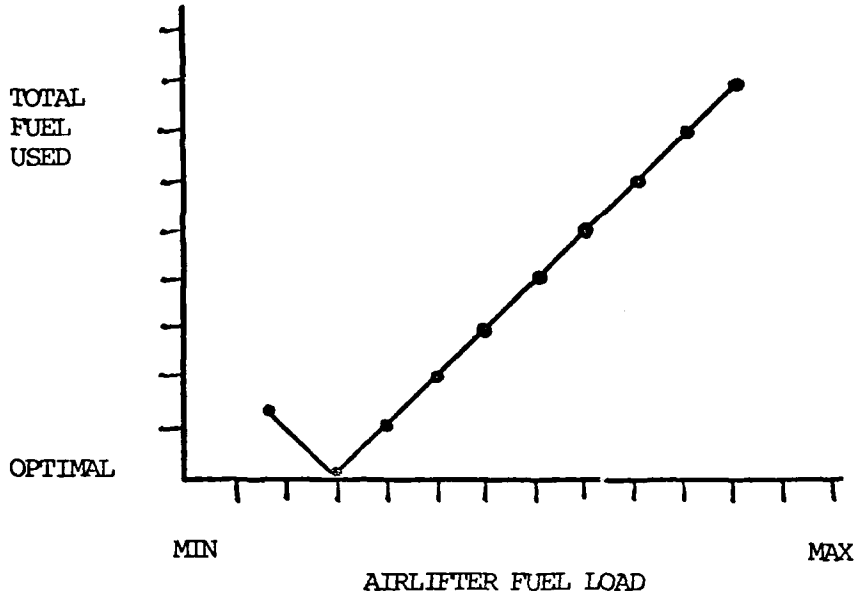

Fig. 11. Total Fuel Consumption versus Initial Airlifter Fuel Load

Investigating higher fuel onloads for the same scenario, the optimal rendezvous point was found to remain the same, but the total fuel requirement increased. This trend can be seen in the sample FLTPLN output data in Appendix B. For smaller fuel loads, the rendezvous point was located closer to the airlifter takeoff base. This, however, resulted in a larger total fuel requirement for the mission.

This trend is also shown by the graphs in Figures 12 to 15. The fuel loads of the airlifter and tanker combinations are expressed as percentages of their respective fuel capacities. Each curve corresponds to a different combination of cargo weight and tanker base. As the airlifter fuel load is reduced, the tanker fuel load is increased by an amount proportional to the tanker fuel decrease. The total fuel represented between any single point on a curve (Figures 12 to 15) varies only a few thousand pounds. Therefore, the transfer fuel is the only factor which changes significantly. The slope of each line represents the relative efficiency of the aircraft for transporting fuel to the rendezvous point. Similarities in the C-5/KC-10 graphs (Figure 12) and the C-141B/KC-135 (Figure 13) graphs can be explained by comparing fuel consumption rates. For example, the C-5 and KC-10 have similar fuel consumption rates, as do the C-141B and KC-135. The slopes of the lines for these combinations are approximately -1.2. The approximate slopes for the C-5/KC-135 (Figure 14) and C-141/KC-10 (Figure 15) which have

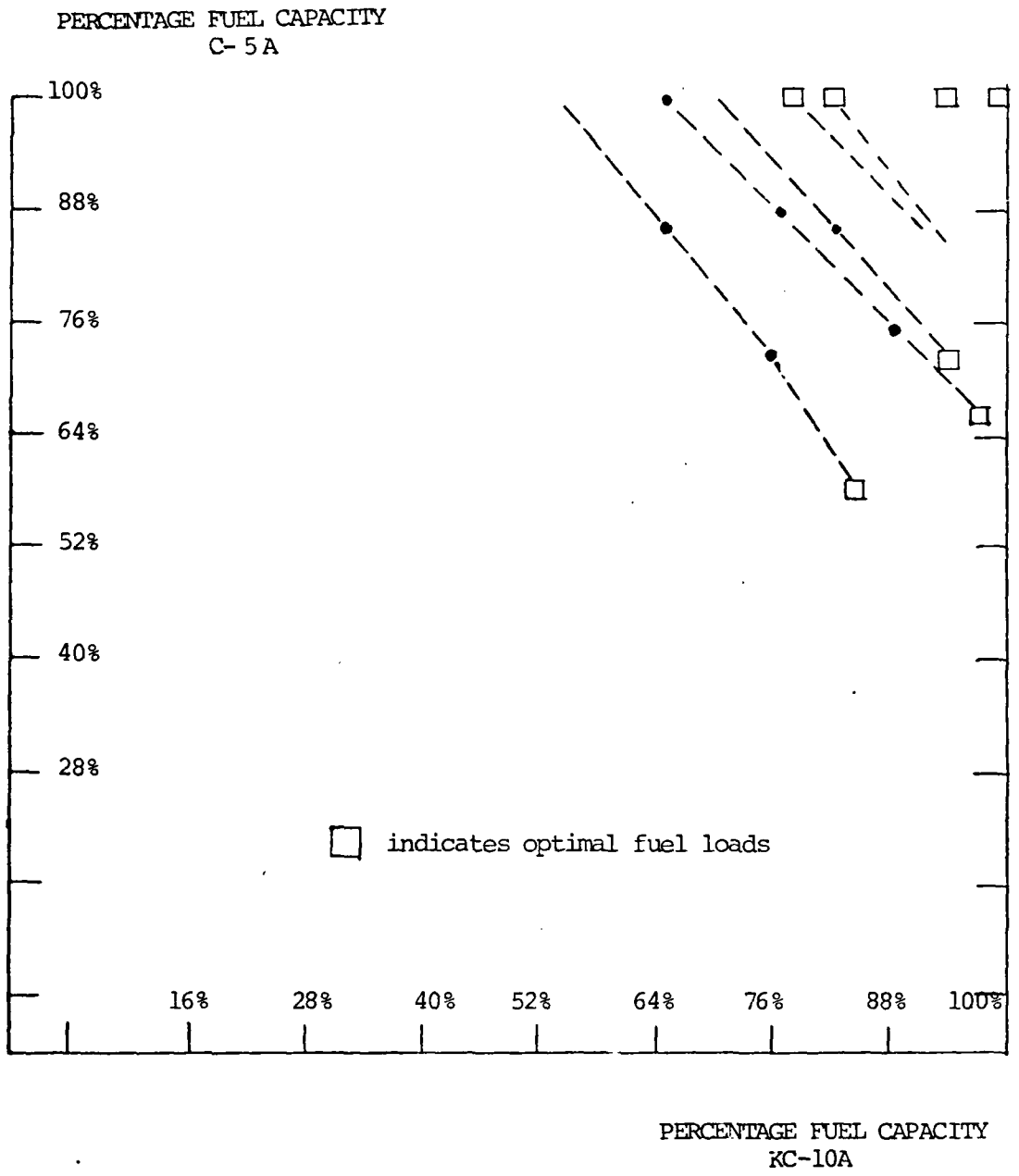

Fig. 12. C-5A and KC-10A--Fuel Loads as Percentage of Fuel Capacity

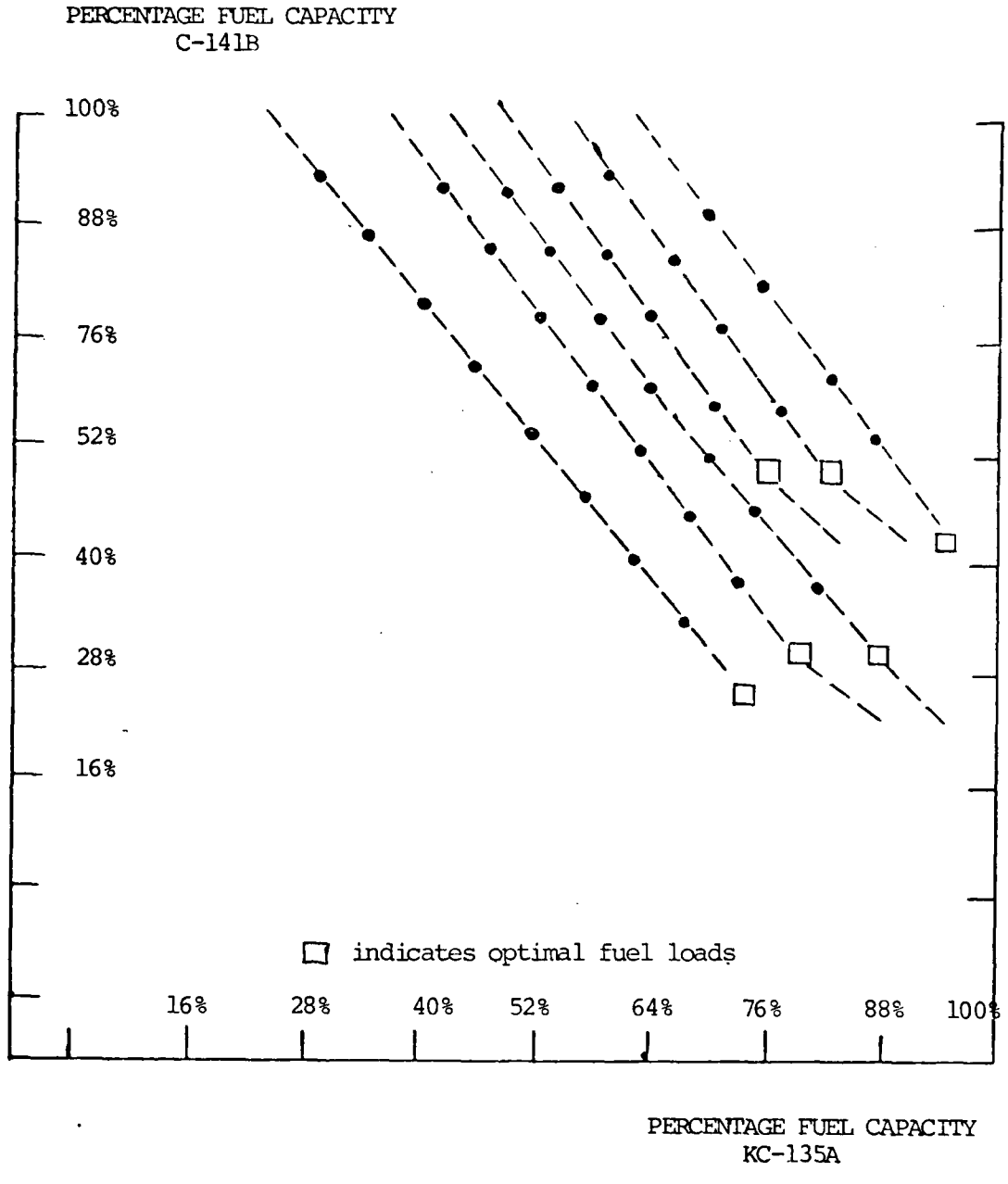

Fig. 13. C-141B and KC-135A--Fuel Loads as Percentage of Fuel Capacity

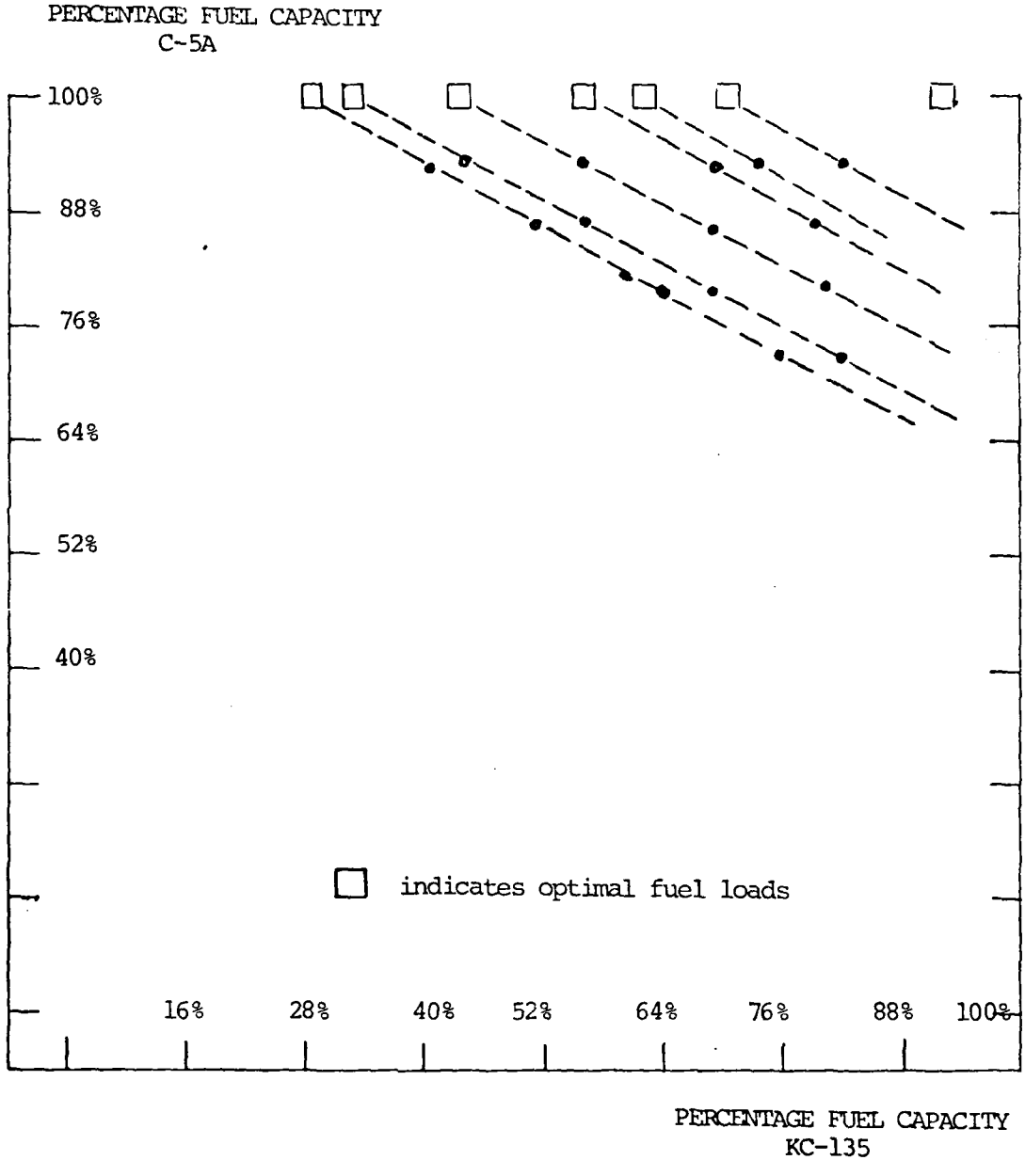

Fig. 14. C-5A and KC-135A--Fuel Loads as Percentage of Fuel Capacity

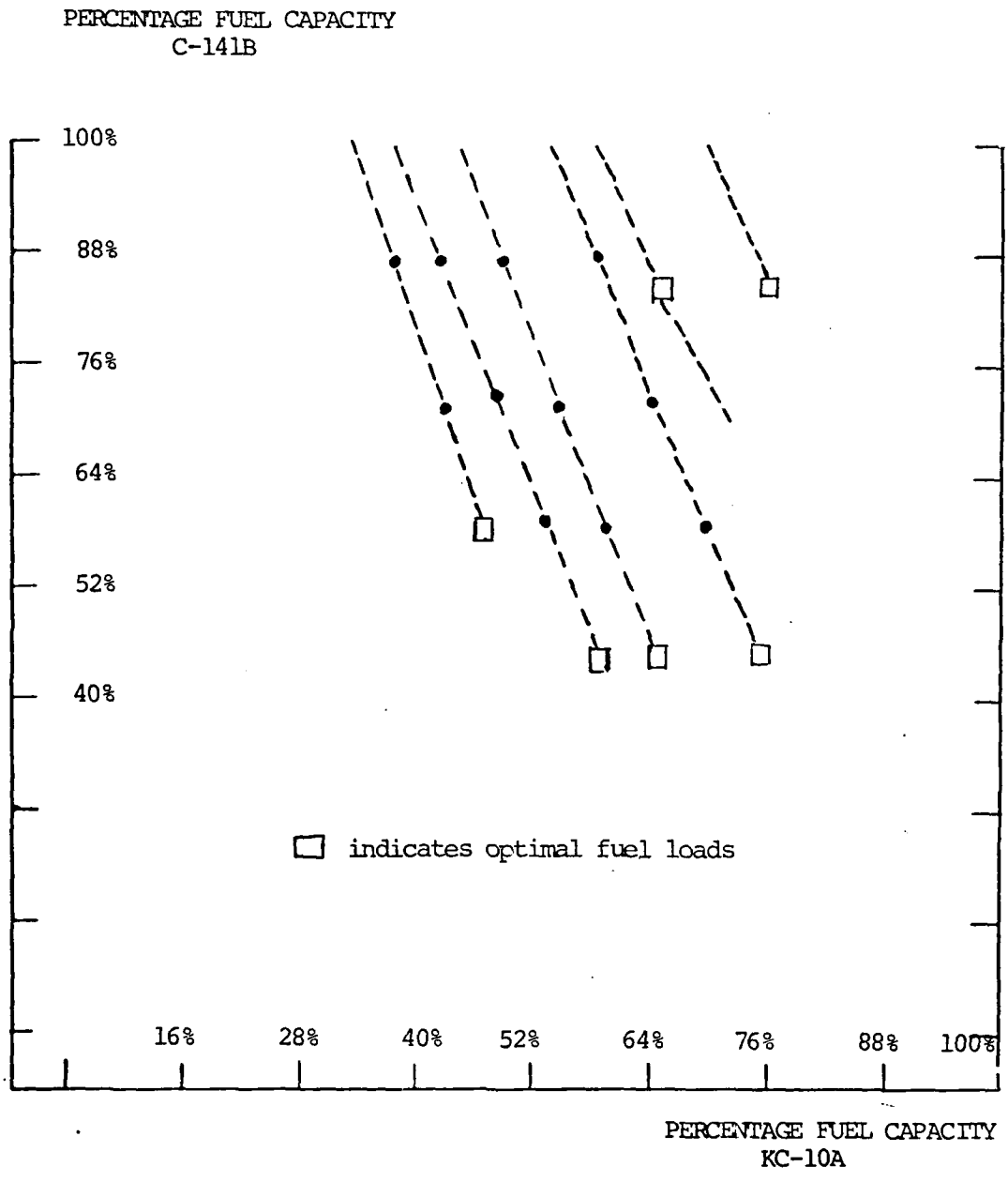

Fig. 15. C-141B and KC-10A--Fuel Loads as Percentage of Fuel Capacity

vastly different fuel consumptions, are -0.6 and -2.6 respectively. Therefore, for the latter two combinations, the C-5 and KC-10 utilize a smaller percentage of their fuel capacity than the KC-135 or C-141B for the same total amount of fuel.

The optimal fuel loads marked by a box on each curve, corresponds to the two percentages whose sum is the smallest of any two fuel load percentages on a curve. For example, the McGuire 70,000 pound line in Figure 12 has the optimal load at the point corresponding to a sum of 112 percent for both aircraft while other points on the graph increase up to 123 percent at the extreme end of the curve.

The optimal airlifter fuel load did not always occur at the minimum level. This is indicated by the boxes on Figures 13 and 15. For these curves, the maximum airlifter fuel load was optimal. However, because of the differences in slopes for these combinations, the sum of the percentages is still the minimum for all values along the curve. This minimum sum criterion contradicts hypothesis two. The relative efficiencies of the two aircraft to carry the fuel to the rendezvous point, represented by the slope of the curves in Figures 12 to 15, are the determining considerations for optimal takeoff fuel loads.

The main result of this research is the identification of significant fuel savings which can be derived from the use of the optimal rendezvous point and takeoff fuel

loads. The exact savings depend on the scenario and aircraft combination. Table 6 lists the average fuel savings by aircraft combination for the optimal rendezvous point and fuel loads compared to the point and fuel loads defined by the two hypotheses.

TABLE 6

AVERAGE FUEL SAVINGS--OPTIMAL RENDEZVOUS POINT VERSUS HYPOTHESIZED RENDEZVOUS POINT

Scenario	Aircraft Combination	Average Fuel Savings (lbs.)
East	C-5/KC-10	25,200
	C-141B/KC-10	8,300
	C-5/KC-135	19,700
	C-141B/KC-135	6,300
West	C-5/KC-10	39,400
	C-141B/KC-10	21,700
	C-5/KC-135	34,700
	C-141B/KC-135	10,300

Since the original two hypotheses were contradicted by the research results, the hoped for general optimal refueling policy was not derived. The results were examined to see if any general hypotheses were suggested.

The results are summarized below by describing the effect of the principal factors on the determination of the optimal rendezvous point and onload fuels. At the maximum feasible cargo weights, the optimal rendezvous point occurs on the feasible boundary closest to the

airlift takeoff base. For lesser cargo weights, the separation between the point and the coresponding feasible boundary increases. Enroute tanker bases draw the location of the optimal rendezvous point closer to the tanker base than do inland bases. The inland bases will most often result in the same optimal rendezvous point despite vast differences in the tanker's flight distances. The takeoff fuel loads for both aircraft are optimized by minimizing the combined percentage of fuel capacity used by the two aircraft. This sum is greatly dependent on the specific aircraft combination used.

Sensitivity Analysis

The sensitivity analysis systematically varied the levels of selected input factors and was used to verify the consistency of the results of the models for the entire feasible range of the input variables. The analytic results were collected for extreme values of airlifter and tanker total flight distances, and cargo weights for each aircraft combination. Sensitivity analysis of the SLAM model was completed for the extreme values of ground delays, wind factor, and increased in-flight cruise times.

The sensitivity of the results to the total distance flown by the airlifter was tested by generating scenarios with different destinations. For the east scenario CONUS bases, an airlifter destination at Cairo, Egypt, represented the minimum distance examined. This

reduced the Tehran flight distance by 570 NM. The maximum extreme distance examined used Kabal, Afghanistan, as a destination, which increased the airlifter flight distances by 510 NM. The Cairo data results were consistent with the Tehran data except previously unfeasible cargo loads became feasible. For example, 120,000 pounds cargo levels for the C-5A and the 70,000 pounds cargo level for the C-141B both became feasible. For the Kabal data, the 55,000 pounds cargo load for the C-141B became infeasible. As a result, few airlifter fuel loads were feasible. The rendezvous points were located closer to the airlifter destination and the transfer fuel at this increased tanker range was reduced by an average of 23,000 pounds. These results are continuations of the trends established by the main data and are consistent with the previous results.

A southwest scenario from Travis AFB, CA, to Clark AB, Philippines, provided an example of enroute basing using Hickam AFB, HI, as the tanker base. The rendezvous point moved an average of 1203 NM from the great circle route for all runs of this scenario. The use of Barksdale AFB, LA, by the KC-10 resulted in the same rendezvous point as Castle, though the extra 2500 NM route segment for the tanker increased the total fuel used. Thus, these extreme examples of enroute and deep inland tanker basing were consistent with previous results in the determination of the optimal rendezvous point.

The effects of cargo loads on the results of the analytic model were consistent with the Tehran results for all feasible values. For large cargo loads which precluded transferring sufficient fuel to complete the mission, no feasible solution was possible. This occurred at 140,000 pounds for the C-5A and 70,000 pounds for the C-141B. For small cargo loads, the allowable fuel load was sufficient to conduct the mission without refueling. Between these extremes, changes in the cargo load consistently produced the previous results illustrated in Figures 7 to 10. Therefore, the entire feasible ranges of the input parameters produced consistent results for all scenarios. Extreme values of the factors indicate feasible boundaries but do not change the trends or results.

Although the primary purpose of the SLAM model was to validate the analytical model for operational suitability, it was also used to conduct part of the sensitivity analysis. The SLAM sensitivity analysis was conducted in three major areas: (1) increases in ground delay times, (2) increases in wind factors, and (3) increases in cruise times.

The first variable investigated was the ground delays. In the SLAM model, the delay was either zero, or fifteen minutes. To determine the sensitivity of ground delay time on the results, the delay was increased to twenty-five minutes. Increased ground fuel consumption resulted; for example, 800 pounds for the C-141B, 1200

pounds for the C-5, but this had no effect on the mission completion rates for any of the aircraft or scenarios. A larger increase in the ground delay time was not explored because from the experience of the authors, an aircraft commander would not run the engines for longer than twenty-five minutes on the ground while waiting for maintenance repairs or other types of services.

The second variable investigated was the wind factor. The SLAM model was created with a normally distributed wind variant with a mean of 55 KNOTS and a standard deviation of 10 KNOTS. The wind was first changed to a mean of 55 KNOTS and standard deviation of 20 KNOTS. This caused 43 percent of the missions to fail due to inadequate fuel. When the wind standard deviation was increased to 30 KNOTS none of the missions flown against a headwind were successful. It is not surprising that the missions failed when the wind standard deviation was increased to 20 KNOTS since that is a significant increase. Those missions which failed, all flew the west scenario to Yokota, had a headwind for most of the route. The effect of an increase of 20 KNOTS on a C-141 which travels 3000 NM after the rendezvous (this is representative of the rendezvous point to destination distance for the west scenario) increased the fuel consumption by 4400 pounds. A wind increase of 30 KNOTS increased the fuel consumption by 6400 pounds which caused all C-141B missions to fail. In actual flight operations large wind factor deviations are not

expected. Combining weather satellite data and pilot mission weather reports which are forwarded to Air Force Global Weather Central, the current wind forecasts are very accurate.

The third variable investigated was the increase in unplanned cruise time for each aircraft. To examine these delays, the cruise time was increased by fifteen minutes for each aircraft. With the extra cruise time added, 83 percent of the C-5 missions were completed but for the C-141 only 74 percent of the missions were completed. For the KC-10, 100 percent of their missions were successful but for the KC-135 only 83 percent of their missions succeeded. The low mission completion rates seem to indicate that a fuel reserve is needed to make the mission completion rate acceptable. HQ MAC does have a fuel reserve for aircraft flying on overwater routes. If these fuel reserves are added to each aircraft's fuel load, the mission completion rates increase to 100 percent.

Since the original fuel load hypothesis has been rejected and the optimal airlifter ramp fuel loads are most often less than the maximum fuel allowable, adequate fuel capacity remains for a fuel reserve. The reserve would compensate for cruise delays, and should not change the trends.

The sensitivity analysis performed indicates that variations in the parameters of the FLTPLN model used in the specific scenarios of this research do not change the basic results obtained.

VI. Conclusions and Recommendations

The conclusions of this research are presented as they relate to the questions and hypotheses stated in Chapter I. For a specific mission defined by the input factors, one rendezvous point always resulted in less total fuel consumption than any other point. This point results in a significant fuel savings compared to the suboptimal points. However, the optimal point was not always located at the maximum feasible range of the airlifter from its destination as proposed by hypothesis one. The location of the optimal rendezvous point can only be determined by considering the interaction of the airlifter's total distance, cargo load and the location of the tanker base. However, definite trends in the results emerged. As the airlifter total distance to destination or cargo weight was increased, or the tanker base was located farther inland of the airlifter takeoff base, the optimal rendezvous point was located incrementally closer to the maximum feasible range boundary. If airlifter distance to destination or cargo weight were reduced or the tanker base was located along the airlifter's route of flight, the optimal rendezvous point was located farther from the feasible boundary and closer to the tanker base.

The second hypothesis is also rejected in favor of a proposal to determine the takeoff fuel loads as they relate to the percentage of the aircraft total fuel capacities. Adjusting the transfer fuel until the sum of the two percentages of fuel capacities is the minimal sum for all feasible fuel loads will result in the minimum total fuel consumed by both aircraft. This minimum sum is dependent on the aircraft combination. It typically occurred at the minimum airlifter fuel loads when the KC-10A was used and maximum airlifter fuel loads when the KC-135A was used.

The following recommendations are submitted as a result of this research:

1. The planning of Strategic Airlift air-refueling missions should incorporate the results of this research when determining the rendezvous point and takeoff fuel loads. Attempts at optimization of these factors will result in significant fuel savings to the Air Force.

2. To aid in the optimization of specific airlift missions, the concepts of the analytic flight planning model used in this research should be expanded to include three additional dimensions:

A. A real time weather data base,

B. Actual route segment flight planning to replace the great circle route planning of the FLTPLN model; and finally,

C. The inclusion of the possibility of multiple air-refuelings of a single airlifter or of multiple airlifters by a single tanker.

The computer flight planning programs maintained by AFGWC/DOY provides the best opportunity to consolidate all of these dimensions into an operational air-refueling flight planning model.

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Appendix A

Manual Fuel Consumption Computation of a Typical Airlift Mission Profile Using the C-141B Performance Manual

This appendix contains a typical fuel planning calculation for a C-141B mission. Output from these calculations will be compared to the model outputs. (All performance figures are from the C-141B performance manual, Change 16, 24 Aug 1979.)

The mission will be from McGuire AFB, NJ, to Tehran, Iran. The tanker will be a KC-135 departing and returning from and to McGuire. The following steps are used to calculate fuel requirements:

1. INITIAL CONDITIONS (C-141B): (obtained from FLTPLN)

   RAMP GROSS WEIGHT - 325,000 lbs.

   McGuire to rendezvous entry point DISTANCE - 1350 NM.

   Rendezvous track = 250 NM.

   Rendezvous exit point to destination DISTANCE - 1810 NM.

   TRANSFER FUEL - 53,000 lbs. (JP-4).

   WIND FACTOR - 55 KNOTS.

2. FUEL CONSUMPTION CALCULATIONS:

The following section calculates mission fuel consumption for the initial conditions in (1). Fuel consumption calculations consist of seven areas:

A. START, TAXI, AND TAKEOFF FUEL - 1900 lbs.

B. INITIAL CLIMB FUEL:

   (1) INITIAL PARAMETERS: TAKEOFF GROSS WEIGHT (GW) =

RAMP GW - TAKEOFF FUEL =

325,000 - 1900 = 323,100 lbs.

CLIMB ALTITUDE = 33,000 ft.

(2) FROM T.O. C-141B 1-1 Chapter 4:

CLIMB FUEL = 9050 lbs.

CLIMB DISTANCE = 144 lbs.

C. CRUISE FUEL:

(1) DISTANCE from level off to rendezvous point =

1350 - 144 = 1206 NM.

(2) Fuel flow at cruise altitude for a constant MACH (0.74) is a function of Gross Weight and Temperature Deviation from a Standard Day and is given in air nautical miles (ANM) per 1000 lbs. fuel.

(3) CRUISE GW = TAKEOFF GW - CLIMB FUEL = 323,100 - 9,050 = 314,050 lbs.

(4) TRUE AIRSPEED (TAS) AT 33,000 ft. (.74) MACH = 431 KNOTS

GROUND SPEED (GS) = TAS + WIND FACTOR = 431 + 55 = 486 KNOTS

ANM = DISTANCE * TAS/GS = 1026 NM * 486 KNOTS/ 431 KNOTS = 1081 ANM

(5) FUEL CONSUMPTION RATE = 27 ANM/1000 lbs. fuel

FUEL CONSUMPTION = 1081 ANM/27 ANM/1000 lbs. fuel = 40,000 lbs.

D. REFUELING TRACK FUEL CONSUMPTION

(1) TRACK DISTANCE = 250 NM

(2) ENTRY GW = CRUISE GW - CRUISE FUEL = 314,050 - 40,000 = 274,050 lbs.

(3) AIRSPEED = .75 MACH @ 25,000 ft. altitude.

(4) FUEL CONSUMPTION RATE = 260 lbs./minute

(5) REFUELING TIME = DISTANCE/AIRSPEED

TAS @ 25,000 ft. = 453 KNOTS

GROUNDSPEED = TAS + WIND FACTOR =
453 + 55 = 508 KNOTS

TIME = DISTANCE/GROUNDSPEED

TIME = 250 NM * 60/508 KNOTS = 29.5 min.

FUEL CONSUMPTION = 29.5 min. * 260 lbs./min =
7680 lbs.

E. POST-RENDEZVOUS CLIMB TO ALTITUDE

(1) INITIAL CLIMB GW = ENTRY GW - TRACK FUEL *
TRANSFER FUEL
274,050 + 53,000 - 7680 = 319,370 lbs.

(2) CLIMB ALTITUDE = 29,000 ft.

(3) From the C-141B performance manual:

CLIMB DISTANCE = 27 NM

CLIMB FUEL = 1400 lbs.

F. CRUISE TO DESTINATION FUEL

(1) CRUISE GW = CLIMB GW - CLIMB FUEL
= 319,370 - 1400 = 317,970 lbs.

(2) CRUISE DISTANCE = RENDEZVOUS EXIT TO
DESTINATION

DISTANCE - CLIMB DISTANCE = 3810 - 27 =
3783 NM.

(3) AT 29,000 ft. TAS = 438 KNOTS

GS = 438 + 55 = 493 KNOTS

(4) ANM = 3783 * 438 / 493 = 3361 ANM

(5) FUEL CONSUMPTION RATE = 29 NM/1000 lbs.
fuel

(6) FUEL CONSUMPTION = ANM/RATE = 3361 ANM/
29 ANM/1000 lbs. = 115,900 lbs.

G. APPROACH AND LANDING FUEL IS 2500 lbs.

The total planned fuel consumption from McGuire AFB to Tehran, Iran is:

$$\sum_{i=A}^{G} (\text{FUEL CONSUMPTION})_i = 175{,}900 \text{ lbs.}$$

Appendix B

Aircraft Ground Delay Data

The aircraft ground delays in the SLAM Simulation Model were based on the data shown below. The data was obtained from various CONUS Air Force bases for the following aircraft:

AIRCRAFT: KC-135
PERIOD: 30 DAYS
INSTALLATION: MARCH AFB, CA
TOTAL TAKEOFFS: 93
DELAYED TAKEOFFS: 12

DELAY #	LENGTH OF DELAY (MIN)	DELAY #	LENGTH OF DELAY (MIN)
1	21	7	19
2	19	8	77
3	227	9	210
4	6	10	48
5	34	11	74
6	236	12	1

AIRCRAFT: KC-135
PERIOD: 30 DAYS
INSTALLATION: PLATTSBERG AFB, NY
TOTAL TAKEOFFS: 101
DELAYED TAKEOFFS: 47

DELAY #	LENGTH OF DELAY (MIN)	DELAY #	LENGTH OF DELAY (MIN)
1	26	25	12
2	179	26	96
3	39	27	23
4	11	28	20
5	13	29	70
6	12	30	57
7	151	31	22
8	12	32	21
9	135	33	21
10	132	34	19
11	45	35	28
12	53	36	19
13	14	37	14
14	25	38	153
15	26	39	137
16	26	40	73
17	64	41	70
18	32	42	16
19	34	43	37
20	76	44	20
21	20	45	27
22	13	46	20
23	24	47	19
24	62		

AIRCRAFT: C-141
PERIOD: 30 DAYS
INSTALLATION: NORTON AFB, CA
TOTAL TAKEOFFS: 156
DELAYED TAKEOFFS: 25

DELAY #	LENGTH OF DELAY (MIN)	DELAY #	LENGTH OF DELAY (MIN)
1	72	14	152
2	122	15	99
3	150	16	134
4	25	17	87
5	78	18	41
6	22	19	117
7	85	20	61
8	27	21	25
9	177	22	16
10	42	23	66
11	29	24	42
12	90	25	56
13	42		

AIRCRAFT: C-5
PERIOD: 60 DAYS
INSTALLATION: DOVER, DE
TOTAL TAKEOFFS: 143
DELAYED TAKEOFFS: 25

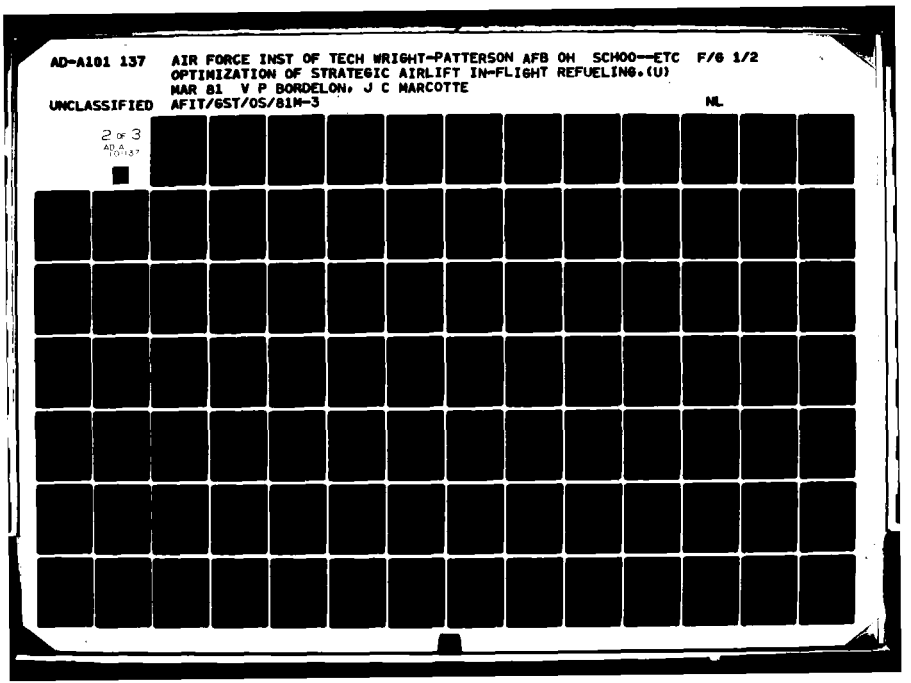
DELAY #	LENGTH OF DELAY (MIN)	DELAY #	LENGTH OF DELAY (MIN)
1	31	14	90
2	28	15	121
3	72	16	1152
4	30	17	243
5	35	18	44
6	37	19	36
7	29	20	162
8	187	21	1578
9	48	22	119
10	67	23	24
11	34	24	146
12	98	25	218
13	104		

Appendix C

FLTPLN Computer Code

```
C  THIS IS THE MASTER FLIGHT PLANNING PROGRAM
C
      PROGRAM FLTPLN (INPUT,OUTPUT)
C
      DIMENSION XX(30)
      DIMENSION LAT(7),LONG(7),PRL(7),MRN(7),CARGO(6)
      DIMENSION LEG(5),FUEL(10),FEASBL(5,13),FUELMIN(10)
      DIMENSION MACH(4),MXGWT(4),MXFUEL(4),OPWT(4),RFF(4)
      DIMENSION  RML(7), RMACH(2), STTOF(4),KK(10),LL(10)
      REAL LAT,LONG,MRN,MXGWT,MXFUEL,LEG,MACH
      INTEGER AC, TK
      DATA PI,DEG,RAD/3.141592654,57.29577951,.01745329252/
      DATA MACH /.77, .74, .82, .82/
      DATA RMACH/ .62, .74 /
      DATA RFF  /.45, .26, .27, .25/
      DATA MXGWT/712.5,323.1,590.0,270.0/
      DATA MXFUEL/315.1, 151.45, 345.4, 163.0/
      DATA OPWT/ 354.0, 141.0, 240.47, 105.0/
      DATA STTOF/2.8, 1.9, 3.0, 2.0/
      DATA CARGO/100.,85.,70.,70.,55.,40./
C
C  FUNCTION STATEMENT TO CONVERT RADIANS TO DEGREES
      DRAD(COOR) = (INT(COOR)+(COOR-INT(COOR))/.6)/DEG
C  FUNCTION STATEMENT TO CONVERT DEGREES TO RADIANS
      RDEG(ANGLE) = INT(ANGLE)+0.6*(ANGLE-INT(ANGLE))
C  GROUND SPEED CALCULATION FROM TRUE AIRSPEED AND WIND
      GS(SPD,ALT,TC) = TASP(SPD,ALT)*COS(ASIN(WV*SIN(WD-TC)
     &                 /TASP(SPD,ALT)))-WV*COS(WD-TC)
C
C  SCENARIO INPUT DATA IN DEGREES, MINUTES TENTHS
      PRINT*,"   EAST SCENARIO # 1"
      PRINT*,"  TANKER BASE # 1"
      ELEV1 = 0.0
      LAT(1) = 38.216
      LONG(1)= 121.57
      LAT(2) =  35.27
      LONG(2)=-139.126
      LAT(3) = 61.131
      LONG(3)= 149.535
      LAT(4) = 64.376
      LONG(4)= 147.03
      ELEV2 = 0.0
C  CONVERT LAT/LONG DEGREES TO RADIANS
            DO 10  I = 1, 4
            PRL(I)= DRAD(LAT(I))
            MRN(I)= DRAD(LONG(I))
10          CONTINUE
```

```
C  WIND DIRECTION IN RADIANS AT WD
      WD   =   4.6
C  WIND VELOCITY IN NM / MINUTE AT WV
      WV   =    .91666667
C
C  SELECT KC-10A TANKER FIRST THEN KC-135A TANKER
         DO  999  NN = 1, 2
         TK = 3
         IF (NN .EQ. 2) TK = 4
C
C  SELECT C-5A AIRLIFTER FIRST THEN C-141B AIRLIFTER
         DO 998  MM = 1, 6
         PRINT 700
700      FORMAT (1X,/,120("*"))
      AC   =  1
      IF (MM .GE. 4) AC = 2
      PRINT*,"  AC =",AC,"  TK =",TK,"  CARGO =",CARGO(MM)
C  CALCULATE RESERVE FUELS
      RESV = 30./ AC
      REST = 15.*(5.-TK)
      AZFW =  OPWT(AC) + CARGO(MM)
C  DETERMINE  FEASIBLE BOUNDARY RANGE
      CKFUEL = AMIN1(MXFUEL(AC),(MXGWT(AC)-AZFW))
      CALL RHOTHTA(PRL(1),MRN(1),PRL(2),MRN(2),TDIST,GC,TC)
      AGW = MXGWT(AC) - (CKFUEL-RESV)/2.
      ALT2 = CALT(AGW,AC,TC)
      CALL FLTME(AGW,MACH(AC),ALT2,4,CKFF,AC)
      LEG(2) = (CKFUEL-RESV)*GS(MACH(AC),ALT2,TC)/CKFF
C  RPT AT LEVEL OFF IF WITHIN 400 NM OF AIRLIFTER BASE
      IF (LEG(2).LT. (TDIST-400.)) GO TO 20
      PRINT*,"  RPT AT LEVEL OFF"
      AGW = MXGWT(AC)
      CALL FLTME(AGW,ELEV1,25.,2,CLMDIST,AC)
      PRINT*,"  CLMDIST =",CLMDIST
      LEG(2) = TDIST-CLMDIST-350.
20    LEG(1) = TDIST-LEG(2)
C  COMPUTE COORDINATES OF BOUNDARY RPT ON GREAT CIRCLE
      CALL LATLONG(PRL(1),MRN(1),LEG(1),GC,PRL(7),MRN(7))
C  SET SEPARATION BETWEEN RPT
      SN = 5. * RAD
      IF (PRL(7).GE.PRL(4))  SN = -SN
      EW = 2. *RAD
      IF (SIN(GC).GE.0)  EW = -EW
C  SET INITIAL AIRLIFTER FUEL LOAD AT MAXIMUM
      AFUEL = CKFUEL
```


AD-A101 137
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/G 1/2
OPTIMIZATION OF STRATEGIC AIRLIFT IN-FLIGHT REFUELING.(U)
MAR 81 V P BORDELON, J C MARCOTTE
UNCLASSIFIED AFIT/GST/OS/81M-3
NL
2 OF 3
AD A
101137

```
C  DEVELOP MATRICES FOR 10 AIRLIFTER FUEL LOAD.
         DO  100  IM = 1, 10
         PRL(5) = PRL(7)
         MRN(5) = MRN(7)
         FUELMIN(IM) = 777.777
      AGWT = AMIN1(AZFW+AFUEL,MXGWT(AC))
      AFL =CALT(AGWT,AC,TC)
C  COMPUTE CLIMB VALUES FOR CURRENT AIRLIFTER FUEL LOAD
      CALL FLYME(AGWT,ELEV1,AFL,1,CLMT,AC)
      CALL FLYME(AGWT,ELEV1,AFL,2,CLMD,AC)
      CALL FLYME(AGWT,ELEV1,AFL,3,CLMF,AC)
C
C  GENERATE 5 X 13 MATRIX OF RPT
         DO 80 L=1,13
         DO 70 K=1,5
C  COMPUTE ROUTE SEGMENT DISTANCES
150   CALL RHOTHTA(PRL(1),MRN(1),PRL(5),MRN(5),LEG(1),GC,RML(1))
      CALL LATLONG(PRL(5),MRN(5),250.,(GC-PI),PRL(6),MRN(6))
      CALL RHOTHTA(PRL(5),MRN(5),PRL(2),MRN(2),LEG(2),GC,RML(2))
      CALL RHOTHTA(PRL(6),MRN(6),PRL(3),MRN(3),LEG(3),GC,RML(3))
      CALL RHOTHTA(PRL(4),MRN(4),PRL(6),MRN(6),LEG(4),GC,RML(4))
      CALL RHOTHTA(PRL(5),MRN(5),PRL(4),MRN(4),LEG(5),GC,RML(5))
      FEASBL(K,L) = 777.777
C
C  AIRLIFTER POST RENDEZVOUS TO DESTINATION
      FAV = 120./ AC
      AGW = AMIN1(AZFW+RESV+2*FAV,MXGWT(AC))
         DO 30  JJ = 1, 3
      CLD = 0.0
      CLF = 0.0
      AFL = CALT(AGW,AC,RML(2))
      IF (AFL .EQ. 25.) GO TO 25
      CALL FLYME(AGW,25.,AFL,2,CLD,AC)
      CALL FLYME(AGW,25.,AFL,3,CLF,AC)
      CLD = CLD*GS(MACH(AC),AFL,RML(2))/TASP(MACH(AC),AFL)
25    AGW = AMIN1(AZFW+RESV+FAV,MXGWT(AC))
      CALL FLYME(AGW,MACH(AC),AFL,4,AFF,AC)
      FUEL(2)=(LEG(2)-CLD)*AFF/GS(MACH(AC),AFL,RML(2))
      AGW = AMIN1(AZFW+FUEL(2)+CLF+RESV,MXGWT(AC))
      FAV = FUEL(2) / 2.
30    CONTINUE
      AFL2 = AFL
      FUEL(2) = FUEL(2) + CLF
         IF (FUEL(2) .GT. (CKFUEL-RESV)) GO TO 60
```

```
C  AIRLIFTER DEPARTURE TO RENDEZVOUS
       LEG(1) = LEG(1) - 250.
       AFL = CALT(AGWT,AC,RML(1))
       ATIM = (LEG(1)-CLMD) /GS(MACH(AC),AFL,RML(1))
       AGW = AGWT - CLMF
       CALL FLTME(AGW,MACH(AC),AFL,4,AFF,AC)
       AGW = AGW - (ATIM * AFF/ 2.)
       CALL FLTME(AGW,MACH(AC),AFL,4,AFF,AC)
       FUEL(1) = ATIM * AFF + CLMF
       ATIM = ATIM + CLMT
 C
 C   AIRLIFTER ABORT TO ALTERNATE
       AGW = AGWT - FUEL(1)
       AFL = CALT(AGW,AC,RML(3))
       CALL FLTME(AGW,MACH(AC),AFL,4,AFF,AC)
       AGW=AGW-(LEG(3)*AFF/GS(MACH(AC),AFL,RML(3)))/2.
       CALL FLTME(AGW,MACH(AC),AFL,4,AFF,AC)
       FUEL(3)=LEG(3)*AFF/GS(MACH(AC),AFL,RML(3))
 C
 C   AIRLIFTER ABORT TO DEPARTURE BASE
       AGW = AGWT - FUEL(1)
       RML(6) = RML(1) - PI
       AFL = CALT(AGW,AC,RML(6))
       CALL FLTME(AGW,MACH(AC),AFL,4,AFF,AC)
       AGW=AGW-(LEG(1)*AFF/GS(MACH(AC),AFL,RML(6)))/2.
       CALL FLTME(AGW,MACH(AC),AFL,4,AFF,AC)
       FUEL(6)=LEG(1)*AFF/GS(MACH(AC),AFL,RML(6))
 C
 C    AIRLIFTER RENDEZVOUS TRACK FUEL
       FUEL(7)=250.*RFF(AC)/GS(RMACH(AC),25.,RML(1))
          IF ((FUEL(1)+AMIN1(FUEL(3),FUEL(6))+RESV+FUEL(7))
      &     .GT. AFUEL)  GO TO 60
 C
 C   TRFL IS THE TRANSFER FUEL AT RENDEZVOUS
       TRFL = FUEL(1)+FUEL(7)+FUEL(2)+RESV - AFUEL
          IF (AFUEL+TRFL-FUEL(1)-FUEL(7) .GT. CKFUEL) GO TO 60
 C
 C   TANKER POST RENDEZVOUS TO DESTINATION
       FAV = (5.2-TK)*8.5
       TGWT = OPWT(TK)+REST
       TGW = AMIN1(TGWT + 2.*FAV,MXGWT(TK))
          DO 40  JJ = 1, 3
       CLD = 0.0
       CLF = 0.0
       TFL = CALT(TGW,TK,RML(5))
       IF (TFL .EQ. 25.) GO TO 35
```

```
      CALL FLYME(TGW,25.,TFL,2,CLD,TK)
       CALL FLYME(TGW,25.,TFL,3,CLF,TK)
       CLD = CLD*GS(MACH(TK),TFL,RML(5))/TASP(MACH(TK),TFL)
35    TGW = AMIN1(TGWT + FAV, MXGWT(TK))
      CALL FLYME(TGW,MACH(TK),TFL,4,TFF,TK)
      FUEL(5)= (LEG(5)-CLD)*TFF/GS(MACH(TK),TFL,RML(5))
      TGW=AMIN1(TGWT+FUEL(5)+CLF, MXGWT(TK))
      FAV = FUEL(5) /2.
40    CONTINUE
      FUEL(5) = FUEL(5) +CLF
C
C   TANKER RENDEZVOUS TRACK FUEL
      FUEL(8)=250.*RFF(TK)/GS(RMACH(AC),25.,RML(1))
      TGW = AMIN1(TGW+FUEL(8), MXGWT(TK))
      CALL FLYME(TGW,MACH(TK),25.,5,WAITF,TK)
      FUEL(8) = FUEL(8) + 15.* WAITF
C
C   TANKER DEPARTURE TO RENDEZVOUS
      FAV = (6.3-TK)*5.4
      TGWT = OPWT(TK)+REST+FUEL(5)+TRFL+FUEL(8)
      TGW = AMIN1(TGWT+2.*FAV, MXGWT(TK))
         DO 50  JJ = 1, 3
      TFL = CALT(TGW,TK,RML(4))
      CALL FLYME(TGW,ELEV2,TFL,1,CLT,TK)
      CALL FLYME(TGW,ELEV2,TFL,2,CLD,TK)
      CALL FLYME(TGW,ELEV2,TFL,3,CLF,TK)
      TGW = AMIN1(TGWT+FAV, MXGWT(TK))
      CALL FLYME(TGW,MACH(TK),TFL,4,TFF,TK)
      TTIM = (LEG(4)-CLD)/GS(MACH(TK),TFL,RML(4))
      FUEL(4) = TTIM * TFF
      TGW= AMIN1(TGWT + FUEL(4) + CLF, MXGWT(TK))
      FAV = FUEL(4) / 2.
50    CONTINUE
      FUEL(4) = FUEL(4) + CLF
      TGWT = TGWT + FUEL(4)
         IF (TGWT .GT. MXGWT(TK)) GO TO 60
C
C  COMPUTE TANKER TAKE OFF FUEL LOAD AT TFUEL
      TFUEL = FUEL(4)+TRFL+FUEL(8)+FUEL(5)+REST
         IF (TFUEL .GT. MXFUEL(TK)) GO TO 60
C
C  STORE TOTAL FUEL CONSUMPTION IN FEASBL MATRIX
      FEASBL(K,L)= FUEL(1)+FUEL(2)+FUEL(7)
     &             +FUEL(4)+FUEL(5)+FUEL(8)
```

```
C  SELECT MINIMUM VALUE AND SAVE PARAMETERS
         FUELMIN(IM) = AMIN1(FUELMIN(IM), FEASBL(K,L))
         IF (FUELMIN(IM) .NE. FEASBL(K,L)) GO TO 60
         KK(IM) = K
         LL(IM) = L
         DO 55 I = 1, 5
         XX(I) = LEG(I)
         XX(I+5) = RML(I)
         XX(I+10) = FUEL(I)
         XX(I+15) = FUEL(I+5)
 55      CONTINUE
         XX(21) = AFUEL + STTOF(AC)
         XX(22) = TFUEL + STTOF(TK)
         XX(23) = TRFL
         XX(24) = AFL2
         XX(25) = 0.
         XX(26) = TTIM + 15. - ATIM
         IF (XX(26)) 56, 58, 58
 56      XX(25) = -XX(26)
         XX(26) = 0.
 58      XX(27) = PRL(6)
         XX(28) = MRN(6)
 C
 C  INCREMENT LATITUDE COLUMN
 60      PRL(5) = PRL(5) + SN
 70    CONTINUE
 C  INCREMENT LONGITUDE AFTER FIFTH LATITUDE
       PRL(5) = PRL(7)
       MRN(5) = MRN(5) + EW
 80    CONTINUE
       IF (FUELMIN(IM) .EQ. 777.777) GO TO 100
 C
 C  PRINT MATRIX VALUES AND OUTPUT FOR MINIMUM RPT
         DO 900 K = 1, 5
         PRINT 800, (FEASBL(K,L),L=1,13)
 800     FORMAT (1X,13(2X,F7.3))
 900     CONTINUE
       LAT(6) = RDEG(XX(27)*DEG)
       LONG(6) = RDEG(XX(28)*DEG)
       PRINT*,"  ",IM,FUELMIN(IM),KK(IM),LL(IM),
      &       "     RPT ENTRY =",LAT(6),LONG(6)
       PRINT*,"  LEGS =",(XX(I),I=1,5)
       PRINT*,"  TRUE COURSES =",(XX(I),I=6,10)
       PRINT*,"  FUELS =",(XX(I),I=11,18)
       ACWT = OPWT(AC)+CARGO(MM)+XX(21)
```

```
      PRINT*,"  AFUEL =",XX(21),"  ACWT =",ACWT,
     &       "  AFL2 =",XX(24),"  ATOT =",XX(26)
       TCWT = OPWT(TK) + XX(22)
       PRINT*,"  TFUEL =",XX(22),"  TCWT =",TCWT,
     &       "  TRFL =",XX(23),"  TTOT =",XX(25)
C  DECREMENT AIRLIFTER TAKEOFF FUEL LOAD
100   AFUEL = AFUEL - 20.
C  SELECT OPTIMAL RPT FROM MINIMUM VALUES
      FUELIM = FUELMIN(1)
         DO 300 M = 1, 10
         FUELIM = AMIN1(FUELIM,FUELMIN(M))
         IF (FUELIM .NE. FUELMIN(M)) GO TO 300
         IM = M
300   CONTINUE
      IF (FUELIM .NE. 777.777) GO TO 400
      PRINT*,"  NO FEASABLE SOLUTION"
      GO TO 998
400   PRINT 700
      PRINT*,"  FUELMIN(",IM,",",KK(IM),",",LL(IM),") =",FUELMIN(IM)
      LAT(7) = RDEG(PRL(7)*DEG)
      LONG(7)= RDEG(MRN(7)*DEG)
      PRINT*,"  POINT ONE =",LAT(7),LONG(7)
      PRINT 700
998   CONTINUE
999   CONTINUE
      STOP
      END
```

```
C
 C
      SUBROUTINE RHOTHTA(P1,P1M,P2,P2M,RHO,THETA,RML)
 C COMPUTES GREAT CIRCLE DISTANCE AND COURSE
         QD = 1.50796327
         IF (P1 .GT. QD) P1 = QD
         IF (P2 .GT. QD) P2 = QD
       D=ACOS(SIN(P1)*SIN(P2)+COS(P1)*COS(P2)*COS(P2M-P1M))
       RHO=D*3437.74677
          THETA=ACOS((SIN(P2)-SIN(P1)*COS(D))/SIN(D)/COS(P1))
       IF(SIN(P2M-P1M).GE.0) THETA= 6.283185308-THETA
       RML = ATAN((P1M-P2M)/(ALOG(TAN(0.7853981635+P2/2))
      &-ALOG(TAN(0.7853981635+P1/2))))
       IF(RML.LT.0)  RML=3.141592654+RML
       IF(SIN(P2M-P1M).GE.0) RML=3.141592654+RML
       RETURN
       END
 C
      SUBROUTINE LATLONG(P1,P1M,RHO,THETA,P2,P2M)
 C   COMPUTES LAT/LONG GIVEN DIST AND COURSE FROM POINT
       R = RHO / 3437.74677
       P2 = ASIN(SIN(P1) * COS(R) + COS(P1) *
      &          SIN(R) * COS(THETA))
       D = ACOS((COS(R)-SIN(P1)*SIN(P2))
      &          /COS(P1)/COS(P2))
       IF (SIN(THETA) .GE. 0.)  D = -D
       P2M = P1M + D
       IF (P2M.GT.0. .AND. SIN(P2M).LT.0.) P2M=P2M-6.283185308
       IF (P2M.LT.0. .AND. SIN(P2M).GT.0.) P2M=6.283185308+P2M
       RETURN
       END
```

Appendix D

SLAM Description

SLAM (Simulation Language for Alternative Modeling) is a new FORTRAN-based simulation language which allows simulation models to be created in three world views:

1. Network
2. Discrete
3. Continuous

A SLAM model consists of a set of interconnected symbols that describe the operation under study. SLAM provides network symbols (see Figures D-1 to D-10) which can be used to build models and which can be translated into input statements for computer processing. SLAM symbols and input statements used for the SLAM Flight Simulation Model described in Chapter IV are explained here. The following symbols, statement formats, and definitions are taken from Introduction to Simulation and SLAM by A. Alan B. Pritsker and Claude D. Pegden (1979), pp. 435-551.

Network Element	Figure
1. ASSIGN NODE	D-1
2. CREATE NODE	D-2
3. ENTER NODE	D-3
4. EVENT NODE	D-4
5. GOON NODE	D-5
6. MATCH NODE	D-6
7. QUEUE NODE	D-7
8. TERMINATE NODE	D-8
9. REGULAR ACTIVITY	D-9
10. SERVICE ACTIVITY	D-10

NODE TYPE: ASSIGN

FUNCTION: The ASSIGN node is used to assign values to SLAM variables (VAR) at each arrival of an entity to the node. A maximum of M emanating activities are initiated.

INPUT FORMAT: ASSIGN, VAR=value, VAR=value,...,M;

SPECIFICATIONS:

ENTRY	OPTIONS
VAR	ATRIB(INDEX),XX(INDEX),II, where INDEX is a positive integer or the SLAM variable II.
value	an expression containing constants, SLAM variables, or SLAM random variables.
M	positive integer.

SYMBOL:

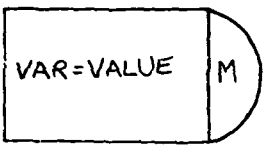


Fig. D-1. ASSIGN Node Description Summary

NODE TYPE: CREATE

FUNCTION: The CREATE node is used to generate entities within the network. The node is released initially at time TF and thereafter according to the specified time between creations, TBC, up to a maximum of MC releases. At each release a maximum of M emanating activities are initiated.

INPUT FORMAT: CREATE,TBC,TF,MA,MC,M;

SPECIFICATIONS:

ENTRY	OPTIONS
TBC	constant, SLAM variable, or SLAM random variable.
TF	constant.
MA	positive integer.
MC	positive integer.
M	positive integer.

SYMBOL:

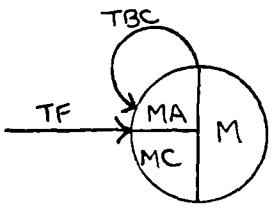


Fig. D-2. CREATE Node Description Summary

NODE TYPE: ENTER

FUNCTION: The ENTER node is provided to permit the user to enter an entity into the network from a user-written event routine. The node is released at each entity arrival and at each user call to subroutine ENTER(NUM). A maximum of M emanating activities are initiated at each release.

INPUT FORMAT: ENTER, NUM,M;

SPECIFICATIONS:

ENTRY	OPTIONS
NUM	positive integer.
M	positive integer.

SYMBOL:

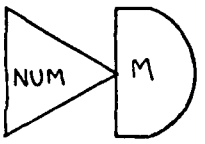


Fig. D-3. ENTER Node Description Summary

NODE TYPE: EVENT

FUNCTION: The EVENT node causes subroutine EVENT to be called with event code JEVNT at each entity arrival. This allows the user to model functions for which a standard node is not provided. A maximum of M emanating activities are initiated.

INPUT FORMAT: EVENT,JEVNT, M;

SPECIFICATIONS:

ENTRY	OPTIONS
JEVNT	positive integer.
M	positive integer.

SYMBOL:

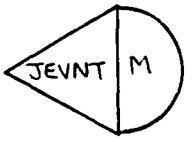


Fig. D-4. EVENT Node Description Summary

NODE TYPE: GOON

FUNCTION: The GOON node provides a continuation node where every entering entity passes directly through the node.

INPUT FORMAT: GOON,M;

SYMBOL:

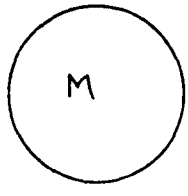


Fig. D-5. GOON Node Description Summary

NODE TYPE: MATCH

FUNCTION: The MATCH node is used to delay the movement of entities by keeping them in QUEUE nodes (QLBLs) until entities with the same value of attribute NATR are resident in every QUEUE node preceding the MATCH node. When a match occurs, each entity is routed to a route node NLBL that corresponds to QLBL.

INPUT FORMAT: MATCH,NATR,QLBL/NLBL,QLBL/NLBL,...;

SPECIFICATIONS:

ENTRY	OPTIONS
NATR	positive.
QLBL	a queue node label.
NLBL	a node label for any type of node.

SYMBOL:

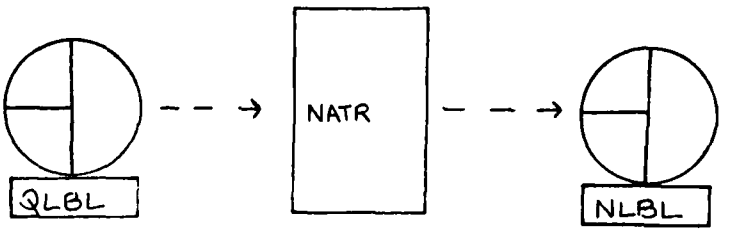


Fig. D-6. MATCH Node Description Summary

NODE TYPE: QUEUE

FUNCTION: The QUEUE node is used to delay entities in the IFL until a server becomes available. The QUEUE node initially contains IQ entities and has a capacity of QC entities.

INPUT FORMAT: QUEUE(IFL),IQ,QC,BLOCK;

SPECIFICATIONS:

ENTRY	OPTIONS
IFL	integer between 1 and MFIL.
IQ	non-negative integer.
QC	integer greater than or equal to IQ.
SLBLS	the labels of MATCH nodes separated by commas.

SYMBOL:

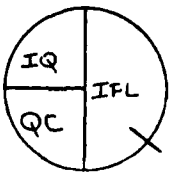


Fig. D-7. QUEUE Node Description Summary

NODE TYPE: TERMINATE

FUNCTION: The TERMINATE node is used to destroy entities and/or terminate the simulation. All incoming entities to a TERMINATE node are destroyed. The arrival of the TCth entity causes a simulation run to be terminated.

INPUT FORMAT: TERMINATE,TC;

SPECIFICATIONS:

ENTRY	OPTIONS
TC	positive integer.

SYMBOL:

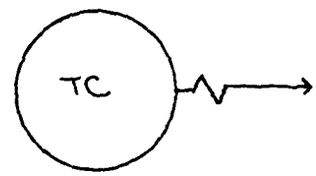


Fig. D-8. TERMINATE Node Description Summary

ACTIVITY TYPE: REGULAR

FUNCTION: A REGULAR activity is any activity enamating from a node other than a QUEUE node. The REGULAR activity is used to delay entities by a specified duration, perform conditional/probabilistic testing, and to route entities to non-sequential nodes.

INPUT FORMAT: ACTIVITY/A,duration, PROB or COND,NLBL;

SPECIFICATIONS:

ENTRY	OPTIONS
A	positive integer.
duration	constant, SLAM variable, SLAM random variable.
PROB or	probability: constant between 0 and 1.
COND	condition: value .OPERATOR. value where value is a constant, SLAM variable, or SLAM random variable and OPERATOR is LT, LE, EQ, GE, GT, OR NE.
NLBL	the label of a labeled node which is at the end of the activity.

SYMBOL:

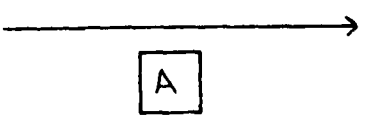


Fig. D-9. REGULAR Activity Description Summary

ACTIVITY TYPE: SERVICE

FUNCTION: The SERVICE activity is any activity emanating from a QUEUE node. The service activity is used in conjunction with the QUEUE node.

INPUT FORMAT: ACTIVITY(N)/A,duration,PROB,NLBL;

SPECIFICATIONS:

ENTRY	OPTIONS
N	positive integer.
A	positive integer between 1 and 50.
duration	constant, SLAM variable, SLAM random variable.
probability	constant between 0 and 1.
NLBL	label of a labeled node.

SYMBOL:

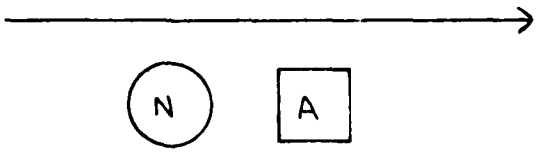


Fig. D-10. SERVICE Activity Description Summary

Appendix E

SLAM Computer Code

```
C   SLAM COMPUTER CODE
 GEN,MARCOTTE,THESIS,11/11/80,9,YES,NO,YES,NO,NO;
 LIMITS,2,5,5;
 NET;
       CREATE,,,,1,1;
       GOON,1;
       EVENT,1;
       TERM;
       ENTER,1;
 AS1   ASSIGN,II=1
       ACT,,,AS3;
       ACT,XX(11),,AS4;
       ENTER,2;
       ASSIGN,II=2;
       ACT,,,AS4;
       ACT,XX(12),,AS3;
 AS3   ASSIGN,ATRIB(1)=XX(12),ATRIB(5)=1.;
       ACT,15,ATRIB(2).EQ.1.OR.ATRIB(2).EQ.3,GO11;
       ACT,15,ATRIB(2).EQ.2.OR.ATRIB(2).EQ.4,GO33;
 GO11  GOON,1
       ACT,15,.18,ASM;
       ACT,,.82,ASN;
 GO33  GOON,1
         ACT,15,.1,ASM;
       ACT,,.9,ASN
 ASM   ASSIGN,XX(15)=15.;
       ACT,,,AS5
 ASN   ASSIGN,XX(15)=0.;
       ACT,,,AS5
 AS5   ASSIGN,ATRIB(4)=USERF(1),XX(17)=1.,1;
       ACT,3.,II.EQ.2,,AND.XX(18).EQ.1,AS7;
       ACT,,II.EQ.2,,AND.XX(18).NE.1.,D1;
       ACT,3.,,AS7
 D1    GOON,1
       ACT,XX(12)+3,,AS7;
 AS7   ASSIGN,ATRIB(4)=ATRIB(4)+USERF(3);
       ACT,USERF(5),,AS9;
 AS4   ASSIGN,ATRIB(1)=XX(11),ATRIB(5)=2.;
       ACT,15,ATRIB(2).EQ.3.OR.ATRIB(2).EQ.4,GO22;
       ACT,15,ATRIB(2).EQ.1.OR.ATRIB(2).EQ.2,GO44;
 GO22  GOON,1
       ACT,15,.18,ASQ;
       ACT,,.82, GO44;
 GO44  GOON,1
       ACT,15,.3,ASQ;
       ACT,,.7,ASR
 ASQ   ASSIGN,XX(16)=15.;
       ACT,,,ASZ
```

```
ASR   ASSIGN,XX(16)=0.;
      ACT,,,ASZ
 ASZ  ASSIGN,ATRIB(4)=USERF(2),XX(18)=1.,1;
      ACT,3,II.EQ.1..AND.XX(17).EQ.1.,AS6;
      ACT,,II.EQ.1..AND.XX(17).NE.1.,D2;
      ACT,3,,AS6;
 D2   COON,1
      ACT,XX(11)+3,,AS6;
 AS6  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(4);
      ACT,USERF(6);
 AS8  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(8),XX(20)=USERF(10);
      ACT,USERF(12);
 ASA  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(14),XX(22)=TNOW;
      ACT,,,Q2
 AS9  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(7),XX(19)=USERF(9);
      ACT,USERF(11);
 ASB  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(13),XX(21)=TNOW;
 Q1   QUEUE(1),0;
 Q2   QUEUE(2),0;
 MT1  MATCH,2,Q1/GO5,Q2/GO10;
 GO5  GOON,1;
 ASC  ASSIGN,ATRIB(4)=ATRIB(4)+1.0,1;
      ACT,,USERF(17).LT.0.,T1;
      ACT,,,ASX
 ASX  ASSIGN,ATRIB(3)=USERF(19);
      ACT,ATRIB(3),,ASE;
 T1   TERM,1;
 ASE  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(21),XX(27)=ATRIB(3)*5,
       ATRIB(3)=USERF(23);
      ACT,ATRIB(3);
 ASC  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(25);
 T3   TERM;
 GO10 GOON,1;
      ACT;
  ASD   ASSIGN,ATRIB(4)=ATRIB(4)+USERF(16),1;
      ACT,,USERF(18).LT.0.,T2;
      ACT,,,ASY;
 ASY  ASSIGN,ATRIB(3)=USERF(19);
      ACT,ATRIB(3),,ASF;
 T2   TERM;
 ASF  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(20),XX(27)=ATRIB(3)*5,
        ATRIB(3)=USERF(22);
      ACT,ATRIB(3);
 ASH  ASSIGN,ATRIB(4)=ATRIB(4)+USERF(24);
 T4   TERM;
      ENDNET;
INIT,0,900;
```

```
INIT,0,900;
 MONTR,TRACE,0,900;
 SEEDS,9375295(1)
 SIMULATE
 SEEDS,-9375295(1)
 MONTR,CLEAR,0
 MONTR,TRACE,0,900
 SIMULATE
 SEEDS,9375295(2)
 MONTR,CLEAR,0
 MONTR,TRACE,0,900
 SIMULATE
 SEEDS,-9375295(2)
 MONTR,CLEAR,0
 MONTR,TRACE,0,900
 SIMULATE
 SEEDS,9375295(3)
 MONTR,CLEAR,0
 MONTR,TRAC  ,900
 SIMULATE
 SEEDS,9375295(4)
 MONTR,CLEAR,0
 MONTR,TRACE,0,900
 SIMULATE
 SEEDS,-9375295(3)
 MONTR,CLEAR,0
 MONTR,TRACE,0,900
   SIMULATE
 SEEDS,-9375295(4)
 MONTR,CLEAR,0
 MONTR,TRACE,0,900
 SIMULATE
 SEEDS,9375295(5)
 MONTR,CLEAR,0
 MONTR,TRACE,0,900
 SIMULATE
 FIN
```

Appendix F

User Function Summaries

1. User function one (USERF1) (Figure F-1)[1], is used to calculate the fuel required during all airlifter ground operations. Normal ground operations consist of start, taxi, takeoff (STTO) and delays. STTO fuel is a constant value for a particular aircraft shown in Figure F-26. USERF1 returns fuel consumed in thousands of pounds of fuel using the equation:

USERF1 = STF + XX(15)* FF where

XX(15) = delay time (min)

STF = STTO fuel (1000 lbs)

FF = ground idle fuel consumption (1000 lbs/min)

Ground idle fuel consumption for all aircraft is shown in Figure F-26 and obtained from the aircraft's performance manuals.

2. User function two (Figure F-2) is used to calculate the fuel required during all ground operations for the tankers. Calculations are similar to USERF1 and will not be repeated. XX(16) is the tanker ground delay.

3. User function three (Figure F-3) calculates the takeoff fuel from brake release until landing gear retraction for the airlifter. Values used are:

USERF = 1000 lbs fuel for the C-5A

500 lbs fuel for the C-141B

---

[1]All of the figures referred to in this appendix appear at the end of the appendix.

4. User function four calculates the takeoff fuel for the tanker (Figure F-4). Values used are:

USERF = 1000 lbs for the KC-10

500 lbs for the KC-135

5. User function five (Figure F-5) is used to return the initial climb time for the airlifter computed by FLYME using:

XX(10) = Airlifter current gross weight

XX(32) = Cruise altitude calculated by subroutine CALT based on XX(1) and IBIRD.

XX(31) = Airlifter departure base elevation.

6. User function six (Figure F-6) calculates tanker time (sec) in the initial climbout. Calculations are similar to user function five except for the following input variables to FLYME:

XX (9) replaces XX(10) as the current tanker gross weight.

XX(42) replaces XX(32) as the tanker cruise altitude.

XX(41) replaces XX(31) as the tanker departure base elevation.

7. User function seven (Figure F-7) computes the airlifter initial climb fuel using FLYME and the same input variables as USERF5. The value returned is in thousands of pounds of fuel. Also XX(35) is set equal to the climb fuel.

8. User function eight (Figure F-8) computes the initial tanker climb fuel using FLYME with the USERF6 input parameters. Also XX(40) is set equal to the climb fuel.

9. User function nine (Figure F-9) computes the airlifter climb distance (NM) using FLYME and USERF5 input parameters. USERF9 also sets XX(19) equal to the climb distance.

10. User function ten (Figure F-10) computes the tanker initial climb distance (NM) using FLYME with input parameters of USERF6. USERF10 also sets XX(20) equal to climb distance.

11. User function 11 (Figure F-11) calculates the airlifter cruise time (min) from leveloff to rendezvous entry point. Variables used are:

a. XX(1) = distance from airlift departure to rendezvous entry point.

b. AS = airlifter true airspeed at altitude XX(32) (NM/MIN)

USERF11 = XX(33) = CRUISE TIME =

$$\frac{XX(1) - XX(19)}{AS + RNORM(1,.16)} = NM$$

RNORM = Cruise altitude winds

(μ = 1 NM/MIN; σ = .16 NM/MIN)

The parameter for these cruise winds was obtained from Global Weather Central AFGWC/DOY, Offutt AFB, NE. The winds are modeled as constant between 25,000 ft to 41,000 ft. The wind variance of .16 NM/MIN was taken

as an average of wind velocity changes over the routes selected.

12. User function 12 (Figure F-12) determines the tanker cruise time from leveloff to the rendezvous entry point in the same manner as USERF11. XX(43) is set equal to the cruise time and the user function returns time in minutes. An undefined variable used in USERF12 is XX(4) which is the distance between the tanker departure point and the rendezvous entry point.

13. User function 13 (Figure F-13) computes the airlifter cruise fuel from leveloff to rendezvous entry point. The steps used to compute the fuel are:

a. Compute the initial cruise gross weight:
XX(10) = Ramp gross weight (XX(75)) - ATRIB(4)
ATRIB(4) = total fuel consumed up to level off.

b. Compute the fuel consumption rate (V) at cruise altitude XX(32). The rate is returned from FLYME in thousands of pounds/minute.

c. Cruise fuel = V * XX(33) fuel/min * min = 1000 lbs fuel.

Finally, USERF13 decrements the aircraft gross weight by the cruise fuel.

14. User function 14 computes (Figure F-14) the tanker cruise fuel from level off to the rendezvous entry point in an analogous manner to user function 13. The user function returns cruise fuel in thousands of pounds.

15. User function 15 (Figure F-15) computes the airlifter loiter fuel. The computation is computed as follows:

a. Determine loiter time (ATIME). This is determined, after both aircraft have reached the match node, MAT1, by computing TNOW - XX(21), where XX(21) is the arrival time of the airlifter and TNOW is the arrival at MAT1 of the last aircraft. If the expression is negative or zero, the user function is returned as zero and there is no loiter time. If the expression is positive, then airlifter loiter occurred and the loiter fuel is computed.

b. Compute the loiter fuel. The loiter fuel consumption rate is determined from FLYME and returned as V. The loiter fuel is then computed as "ATIME * V" and returned in thousands of pounds.

16. User function 16 (Figure F-16) computes the tanker loiter fuel in a manner analogous to user function 15. XX(22) is the tanker arrival time at Q2.

17. User function 17 (Figure F-17) calculates the rendezvous abort fuel for the airlifter (1000 lbs fuel). If this user function is less than zero the airlifter does not have the required fuel to return to the abort base and a refueling is not possible. Therefore, the mission becomes infeasible and the model is terminated. The user function is computed by:

XX(8) = ATRIB(4) - XX(23) where

XX(8) = Airlifter ramp fuel

XX(23) = Flight plan fuel to fly from rendezvous entry point to the abort base, calculated by FLTPLN.

18. User function 18 (Figure F-18) serves the same purpose for the tanker as USERF17 serves for the airlifter and returns the remaining tanker fuel after the abort fuel has been subtracted. XX(7) is the tanker ramp fuel

and XX(24) is the flight plan fuel to fly from rendezvous entry point to the abort base, calculated by FLTPLN.

19. User function 19 (Figure F-19) computes the refueling track time. The track is 250 NM at 25,000 feet altitude. The time is computed as follows:

a. Track true airspeed (TASTRK) is computed from SUBROUTINE TASP.

b. Compute track time:

$$\left(\frac{250\ NM}{TASTRK + WIND}\right) = MINUTES$$

TASTRK = True airspeed during refueling.

20. User function 20 (Figure F-20) determines the tanker track fuel consumption. The air-refueling track fuel consumption rates for each aircraft were obtained from each aircraft's performance manual. The rates are shown in Figure F-26. Track fuel consumption is computed as:

USERF20 = (TRACK TIME * FUEL CONSUMPTION RATE)

= Thousands of pounds of fuel.

21. User function 21 (Figure F-21) computes the airlift refueling track fuel consumption similar to USERF20.

22. User function 22 (Figure F-22) determines the tanker cruise, approach, and landing time from rendezvous exit to destination as follows:

a. Compute an average gross weight (GW) from rendezvous exit to landing.

AVG GROSS WT = (RENDEZVOUS EXIT GW - TRANSFER FUEL + TANKER ZERO FUEL WT + RESERVES) ÷ 2

The gross weight at the end of the flight is computed as XX(95) + XX(46) where XX(95) = zero fuel wt and XX(46) = tanker fuel reserves. Using an average gross weight will permit the tanker to initially climb higher than allowable at his track exit gross weight. In this way the model approximates a step climb profile.

b. Cruise altitude to destination is determined from SUBROUTINE CALT using step A gross weight.

c. Climb time (CT) from 25,000 ft (refueling altitude) to cruise altitude is determined from SUBROUTINE FLYME.

d. The climb distance (CD) is determined from FLYME.

e. The climb fuel is determined from FLYME and set equal to XX(60).

f. The gross weight is decremented by the climb fuel.

g. The cruise distance (CRDIST) from the level-off point to tanker destination is computed as the distance from the rendezvous exit point to destination minus the climb distance (CD).

h. The time, XX(62), is computed as:

$$XX(62) = \frac{CRDIST}{TASK - WIND\ FACTOR} + 15 \text{ minutes}$$

The 15 minutes is a constant time all aircraft use for approach and landing.

i. USERF22 = XX(62) + CT = CRUISE TIME + CLIMB TIME

23. User function 23 (Figure F-23) computes the airlift time (min) from rendezvous exit point to landing at the airlift destination. Computations are analogous to user function 22. Variables used are defined in Figure K-3, Appendix K.

24. User function 24 (Figure F-24) computes the tanker fuel consumed from the rendezvous exit point to destination. Computations are as follows:

a. Determine the approach and landing fuel for the tanker. This value changes by aircraft; values used were taken from AFR 60-16 MAC Supplement One, except for the KC-10 which was estimated by HQ SAC/D08.

b. Determine cruise fuel consumption rate (R) from FLYME using the average gross weight computed by USERF22.

c. Compute cruise, approach, and landing fuel:

USERF24 = CRUISE TIME * FUEL CONSUMPTION RATE + APPROACH AND LANDING FUEL + CLIMB FUEL

= XX(62) * R + AAL + XX(60)

25. User function 25 (Figure F-25) computes the airlifter fuel from rendezvous exit to destination. Computations are analogous to user function 24. Variables used are defined in Figure K-3 in Appendix K.

```
      FUNCTION USERF(IFN)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR,NCRDR,NPRINT,NNRUN,
     INNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14
     1,15,16,17,18,19,20,21,22,23,24,25),IFN
C  GND FUEL FLOW & TAXI FUEL-AIRLIFT
1     IF(ATRIB(2).EQ.1..OR.ATRIB(2).EQ.3.)FF=.12
      IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4.)FF=.08
      IF(ATRIB(2).EQ.1..OR.ATRIB(2).EQ.3.)STF=1.8
      IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4.)STF=1.4
      USERF=STF+XX(15)*FF
      RETURN
```

Fig. F-1. USERF (1)--Ground Fuel Flow & Taxi Fuel-Airlifter

```
C  GND FUEL FLOW & TAXI FUEL-TANKER
2     IF(ATRIB(2).EQ.1..OR.ATRIB(2).EQ.2.)FF=.1
      IF(ATRIB(2).EQ.3..OR.ATRIB(2).EQ.4) FF=.12
      IF(ATRIB(2).EQ.1..OR.ATRIB(2).EQ.2.)STF=1.5
      IF(ATRIB(2).EQ.3..OR.ATRIB(2).EQ.4.)STF=2.0
      USERF=STF+XX(16)*FF
      RETURN
```

Fig. F-2. USERF (2)--Ground Fuel Flow & Taxi Fuel-Tanker

```
C  TAKEOFF FUEL AIRLIFT
3     IF(ATRIB(2).EQ.1..OR.ATRIB(2).EQ.3.)USERF=1.0
      IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4.)USERF=.5
      RETURN
```

Fig. F-3. USERF (3)--Takeoff Fuel Airlift

```
C  TAKEOFF FUEL TANKER
4     IF(ATRIB(2).EQ.1..OR.ATRIB(2).EQ.2.)USERF=.5
      IF(ATRIB(2).EQ.3..OR.ATRIB(2).EQ.4.)USERF=1.0
      RETURN
```

Fig. F-4. USERF (4)--Takeoff Fuel Tanker

```
C  CLIMB TIME AIRLIFT
5      IOPT=1
       IBIRD=1
       IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4.)IBIRD=2
51     XX(10)=XX(75)-ATRIB(4)
       XX(32)=CALT(XX(10),IBIRD,XX(81))
       CALL FLYME(XX(10),XX(31),XX(32),IOPT,V,IBIRD)
       USERF=V
       RETURN
```

Fig. F-5. USERF (5)--Climb Time Airlift

```
C  CLIMB TIME TANKER
6      IOPT = 1
       IF(ATRIB(2).EQ.1.OR.ATRIB(2).EQ.2.)GO TO 55
       IBIRD=3
       GO TO 56
 55    IBIRD = 4
56     XX(9)=XX(76)-ATRIB(4)
       XX(42)=CALT(XX(9),IBIRD,XX(84))
        CALL FLYME (XX(9),XX(41),XX(42),IOPT,V,IBIRD)
       USERF=V
       RETURN
```

Fig. F-6. USERF (6)--Climb Time Tanker

```
C  CLIMB FUEL AIRLIFTER
7      IOPT=3
       IBIRD=1
       IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4.)IBIRD=2
 58    CALL FLYME(XX(10),XX(31),XX(32),IOPT,V,IBIRD)
       USERF=V
       XX(35)=V
       RETURN
```

Fig. F-7. USERF (7)--Climb Fuel Airlifter

```
C  CLIMB FUEL TANKER
8      IOPT=3
       IBIRD=3
       IF(ATRIB(2).EQ.1.OR.ATRIB(2).EQ.2)IBIRD=4
 60    CALL FLYME(XX(9),XX(41),XX(42),IOPT,V,IBIRD)
       USERF=V
       XX(40)=V
       RETURN
```

Fig. F-8. USERF (8)--Climb Fuel Tanker

```
C  CLIMB DISTANCE AIRLIFTER
9      IOPT=2
       IBIRD=1
       IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4)IBIRD=2
 62    CALL FLYME(XX(10),XX(31),XX(32),IOPT,V,IBIRD)
       XX(19)=V
       USERF=V
       RETURN
```

Fig. F-9. USERF (9)--Climb Distance Airlifter

```
C  CLIMB DISTANCE TANKER
10      IOPT=2
       IBIRD=3
       IF(ATRIB(2).EQ.1..OR.ATRIB(2).EQ.2.)IBIRD=4
 64    CALL FLYME(XX(9),XX(41),XX(42),IOPT,V,IBIRD)
       XX(20)=V
       USERF=V
       RETURN
```

Fig. F-10. USERF (10)--Climb Distance Tanker

```
C  CRUISE TIME AIRLIFTER
11     AMACH=.77
       IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4)AMACH=.74
       AS=TASP(AMACH,XX(32))
       USERF=((XX(1)-XX(19)))/(AS+RNORM(1.0,.16,1))
       XX(33)=USERF
       RETURN
```

Fig. F-11. USERF (11)--Cruise Time Airlifter

```
C  CRUISE TIME TANKER
12     AMACH=.82
       AS=TASP(AMACH,XX(42))
       USERF=((XX(4)-XX(20)))/(AS+RNORM(1.0,.16,1))
       XX(43)=USERF
       RETURN
```

Fig. F-12. USERF (12)--Cruise Time Tanker

```
C  AIRLIFT CRUISE FUEL
13     IOPT=4
       IF(ATRIB(2).EQ.2.OR.ATRIB(2).EQ.4) GO TO 69
       AMACH=.77
       IBIRD=1
       GO TO 70
 69    IBIRD=2
       AMACH=.74
 70    XX(10)=XX(75)-ATRIB(4)
       CALL FLYME(XX(10),AMACH,XX(32),IOPT,V,IBIRD)
       USERF=V*XX(33)
       XX(10)=XX(10)-V
       RETURN
```

Fig. F-13. USERF (13)--Airlift Cruise Fuel

```
C  TANKER CRUISE FUEL
14     IOPT=4
       IF(ATRIB(2).EQ.1.OR.ATRIB(2).EQ.2)GO TO 71
       IBIRD=3
         AMACH=.82
       GO TO 72
 71    IBIRD=4
       AMACH=.82
       XX(9)=XX(76)-ATRIB(4)
       CALL FLYME(XX(9),AMACH,XX(42),IOPT,V,IBIRD)
       XX(9)=XX(9)-V
       USERF=V*XX(43)
       RETURN
```

Fig. F-14. USERF (14)--Tanker Cruise Fuel

```
C  LOITER FUEL AIRLIFTER
15     IOPT=5
       ATIME=TNOW-XX(21)
       IF(TNOW-XX(21))50,50,54
 50    USERF=0
       RETURN
 54    IBIRD=1
       IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4.) IBIRD=2
       CALL FLYME(XX(10),ATIME,XX(32),IOPT,V,IBIRD)
       USERF=ATIME*V
       XX(10)=XX(10)-USERF
       RETURN
```

Fig. F-15. USERF (15)--Loiter Fuel Airlifter

```
C  LOITER FUEL TANKER
16     IOPT=5
       ATIME=TNOW-XX(22)
       IF(TNOW-XX(22))52,52,53
52     USERF=0.
       RETURN
53     IBIRD=3
       IF(ATRIB(2).EQ.1..OR.ATRIB(2).EQ.2.)IBIRD=4
 76    CALL FLYME(XX(9),ATIME,XX(42),IOPT,V,IBIRD)
       USERF=ATIME*V
       XX(9)=XX(9)-USERF
       RETURN
```

Fig. F-16. USERF (16)--Loiter Fuel Tanker

```
C  ABORT CALCULATION AIRLIFTER
17     USERF=XX(8)-ATRIB(4)-XX(23)
       RETURN
```

Fig. F-17. USERF (17)--Abort Calculation Airlifter

```
C  ABORT CALC TANKER
18     USERF=XX(7)-ATRIB(4)-XX(24)
       RETURN
```

Fig. F-18. USERF (18)--Abort Calculation Tanker

```
C  REFUELING TRACK TIME
19     AMACH=.62
       IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4.)AMACH=.74
       RALT=25.0
       TASTRK=TASP(AMACH,RALT)
       USERF=250./(TASTRK+RNORM(.9,.16,1))
       RETURN
```

Fig. F-19. USERF (19)--Refueling Track Time

```
C  TANKER TRACK FUEL
20     R=.27
       IF(ATRIB(2).NE.3.OR.ATRIB(2).NE.4.)R=.25
       USERF=ATRIB(3)*R
       XX(9)=XX(9)-USERF
       RETURN
```

Fig. F-20. USERF (20)--Tanker Track Fuel

```
C  AIRLIFTER TRACK FUEL
21    R=.26
      IF(ATRIB(2).NE.2..OR.ATRIB(2).NE.4)R=.45
      USERF=R*ATRIB(3)
      XX(10)=XX(10)-USERF
      RETURN
```

Fig. F-21. USERF (21)--Airlifter Track Fuel

```
C  TANKER TIME TO DESTINATION
22    IOPT=1
      IBIRD=3
      IF(ATRIB(2).EQ.1.OR.ATRIB(2).EQ.2.) IBIRD=4
85    XX(9) = (XX(9)-XX(6)+XX(95)+XX(46))/2
      XX(70)=CALT(XX(9),IBIRD,XX(82))
      CALL FLYME(XX(9),XX(93),XX(70),IOPT,CT,IBIRD)
      IOPT=2
      CALL FLYME(XX(9),XX(93),XX(70),IOPT,CD,IBIRD)
      IOPT=3
      CALL FLYME(XX(9),XX(93),XX(70),IOPT,XX(60),IBIRD)
      AMACH=.82
      IF(ATRIB(2).EQ.1.OR.ATRIB(2).EQ.2.)GO TO 86
      IBIRD=3
      GO TO 87
86    IBIRD=4
87    XX(9)=XX(9)-XX(60)
      CRDIST=XX(5)-CD
      XX(62)= CRDIST/((TASP(AMACH,XX(70))-RNORM(.83,.16,1)))+15.
      USERF=XX(62)+CT
      RETURN
```

Fig. F-22. USERF (22)--Tanker Time to Destination

```
C  AIRLIFT TIME TO DESTINATION
23     IOPT=1
       IBIRD=1
       IF(ATRIB(2).EQ.2..OR.ATRIB(2).EQ.4.)IBIRD=2
95     XX(10)=(XX(10)+XX(6)+XX(94)+XX(45))/2.
       CALL FLYME(XX(10),XX(93),XX(73),IOPT,CT,IBIRD)
       IOPT=2
       CALL FLYME(XX(10),XX(93),XX(73),IOPT,CD,IBIRD)
       IOPT=3
       CALL FLYME(XX(10),XX(93),XX(73),IOPT,XX(61),IBIRD)
       AMACH=.77
       IF(IBIRD.EQ.2)AMACH=.74
97     XX(10)=XX(10)-XX(61)
       CRDIST=XX(2)-CD
       XX(63)= CRDIST/((TASP(AMACH,XX(73))+RNORM(.83,.16,1)))+15.
       S=TASP(AMACH,XX(73))
       USERF=XX(63)+ CT
       RETURN
```

Fig. F-23. USERF (23)--Airlift Time to Destination

```
C  FUEL CRUISE & LANDING TANKER
24     IOPT=4
       AMACH=.82
       IF(ATRIB(2).EQ.1.OR.ATRIB(2).EQ.2.)GO TO 150
       IBIRD=3
       AAL=5.
       GO TO 151
150    IBIRD=4
       AAL=2.4
151     CALL FLYME(XX(9),AMACH,XX(70),IOPT,V,IBIRD)
       R=V
       USERF=(XX(62)-15)*R+AAL+XX(60)
       RETURN
```

Fig. F-24. USERF (24)--Fuel Cruise & Landing Tanker

```
C  FUEL & LND AIRLIFTER
25     IOPT=4
       IF(ATRIB(2).EQ.2.OR.ATRIB(2).EQ.4.)GO TO 152
       AMACH= .77
       AAL=5.2
       IBIRD=1
       GO TO 153
152    AMACH=.74
       AAL=2.5
       IBIRD=2
153     CALL FLYME(XX(10),AMACH,XX(73),IOPT,V,IBIRD)
       R=V
       USERF=(XX(63)-15)*R+AAL+XX(61)
       RETURN
```

Fig. F-25. USERF (25)--Fuel Cruise & Landing Airlifter

A. START, TAXI, TAKEOFF FUEL CONSUMPTION VALUES

Aircraft	STTO (lbs)
C-5	2800
C-141	1900
KC-10	3000
KC-135	2000

B. GROUND IDLE FUEL CONSUMPTION RATES

Aircraft	RATE (lbs/min)
C-5	120
C-141	80
KC-10	120
KC-135	100

C. AIR-REFUELING FUEL CONSUMPTION RATES (lbs/min)

Aircraft	RATE (lbs/min)
C-5	450
C-141	260
KC-10	270
KC-135	250

Fig. F-26. Aircraft Fuel Consumption Values

Appendix G

Sample Raw Output Data

FLTPLN Output

```
WEST SCENARIO # 1
TANKER BASE # 2

##########################################################################################################################
AC =2  TK =3  CARGO =40.
777.777  777.777  777.777  777.777  266.244  272.317  278.459  284.647  290.862  297.071  303.414  309.641  316.961
777.777  777.777  244.633  249.757  259.717  265.457  271.238  277.063  282.999  288.903  294.974  300.919  306.873
777.777  244.212  248.333  257.992  261.810  266.759  271.826  276.991  282.234  287.543  292.984  298.386  303.833
258.775  261.686  264.892  269.355  272.843  275.926  279.979  284.181  288.512  292.956  297.493  302.215  306.915
260.005  281.799  283.831  286.226  288.810  291.611  294.609  297.786  301.123  304.698  309.255  313.032  316.917

  1 244.2120718617 3 2     RPT ENTRY =50.03611433136 133.3541731376
LEGS =854.4503724951 3531.223875E9 862.7701327989 646.2629195486 889.3586270781
TRUE COURSES =5.701983716231 4.886568378997 5.597787790817 4.939544185684 2.841727883661
FUELS =36.78067189535 125.5837811458 29.69581641935 31.17739315285 28.23638595241 24.98651170824 9.32862189412 13.13021
AFUEL =144.  AGWT =325.  AFLZ =31.  ATOT =0.
TFUEL =150.1120718617  TGWT =538.5820718617  TRFL =44.51807413531  TTOT =38.5710718659

##########################################################################################################################
777.777  777.777  777.777  777.777  264.416  270.242  276.343  282.393  288.329  295.492  301.756  307.929  321.633
777.777  777.777  246.686  252.234  257.726  263.327  269.011  274.756  280.544  287.219  293.118  299.119  305.034
777.777  245.929  250.290  254.847  259.578  264.432  269.410  274.485  279.639  285.691  291.821  296.373  301.392
256.469  259.332  262.485  265.892  269.520  273.341  277.338  281.466  285.527  290.953  295.477  300.178  304.861
277.988  279.701  281.761  284.122  286.702  289.497  292.487  295.659  298.989  302.556  306.164  316.878  321.021

2 245.9291483096 3 2     RPT ENTRY =50.03611433136 133.3541731376
LEGS =854.4503724951 3531.223875E9 862.7701327989 646.2629195486 889.3586270781
TRUE COURSES =5.701983716231 4.886568378997 5.597787790817 4.939544185684 2.841727883661
FUELS =34.76529346219 125.5837811458 26.57935152743 34.68996481386 28.23638595241 23.79504182132 9.32862189412 13.13021
AFUEL =124.  AGWT =305.  AFLZ =31.  ATOT =0.
TFUEL =171.8291483096  TGWT =428.2991483096  TRFL =62.52269570213  TTOT =40.86691696516

##########################################################################################################################
777.777  777.777  777.777  777.777  260.385  269.241  275.176  281.166  287.244  299.737  299.374  777.777  777.777
777.777  777.777  245.388  250.553  255.941  262.856  267.695  273.397  279.144  284.925  237.229  303.568  302.337
777.777  244.144  248.406  252.928  258.123  262.962  267.915  272.965  278.075  283.292  294.844  300.548  299.283
254.841  257.782  260.852  264.252  267.872  271.634  275.662  279.788  287.697  294.414  299.232  304.227  302.895
275.533  277.297  283.812  286.366  289.167  292.190  295.416  298.826  302.402  306.228  310.282  307.893  310.689

3 244.1440970143 3 2     RPT ENTRY =50.03611433136 133.3541731376
LEGS =854.4503724951 3531.223875E9 862.7701327989 646.2629195486 889.3586270781
TRUE COURSES =5.701983716231 4.886568378997 5.597787790817 4.939544185684 2.841727883661
FUELS =33.00324216688 125.5837811458 25.23867699993 34.68996481386 28.23638595241 21.56775714158 9.32862189412 13.13021
AFUEL =104.  AGWT =205.  AFLZ =31.  ATOT =0.
TFUEL =198.0440970143  TGWT =438.5140970143  TRFL =60.73764449683  TTOT =39.93101572213

##########################################################################################################################
777.777  777.777  777.777  777.777  264.928  270.661  276.861  777.777  777.777  777.777  777.777  777.777  777.777
777.777  777.777  243.178  248.286  253.369  263.017  269.778  777.777  777.777  777.777  777.777  777.777  777.777
777.777  241.472  245.619  249.945  254.424  263.359  268.461  273.655  777.777  777.777  777.777  777.777  777.777
251.047  257.120  260.428  263.934  267.757  271.718  275.845  280.115  284.510  289.015  287.384  777.777  777.777
274.602  276.685  278.856  281.267  279.477  286.839  284.765  287.669  290.725  294.010  297.328  300.759  777.777

4 241.4723010247 3 2     RPT ENTRY =50.03611433136 133.3541731376
LEGS =854.4503724951 3531.223875E9 862.7701327989 646.2629195486 889.3586270781
TRUE COURSES =5.701983716231 4.886568378997 5.597787790817 4.939544185684 2.841727883661
FUELS =29.93026972515 125.5837811458 25.68714533958 35.20998446597 28.23638595241 20.41330511373 9.32862189412 13.13021
AFUEL =84.  AGWT =265.  AFLZ =31.  ATOT =0.
TFUEL =207.3723010247  TGWT =455.8423010247  TRFL =97.66769196511  TTOT =41.61251662789

##########################################################################################################################
FUELMIN(4,3,2) =241.4723010247
POINT ONE =43.46037399951 134.4065083327

##########################################################################################################################
```

SLAM TRACE BEGINNING AT TNOW= 0.

TNOW	JEVNT	NODE ARRIVAL LABEL	TYPE	ATTRIBUTE # 1	CURRENT ATTRIBUTE BUFFER 2	3	4	5	REGULAR ACTIVITY SUMMARY INDEX	DURATION	END NODE
0.			CREATE	0.	0.	0.	0.	0.			
0.			GOON	0.	0.	0.	0.	0.			
0.			EVENT	0.	0.	0.	0.	0.			
IL-YORK4/PC 0.			TERM	0.	.4000E+01	0.	0.	0.			
0.		AS1	ASSIGN	0.	.4000E+01	0.	0.	0.			
0.		AS3	ASSIGN	0.	.4000E+01	0.	0.	0.	0 0	0.0000 227.0000	AS3 AS4
.150.0E+ 2		GO33	GOON	0.	.4000E+01	0.	0.	.1000E+01	0 0	NOT RELEASED 15.0000	GO11 GO33
.1500E+ 2		ASN	ASSIGN	0.	.4000E+01	0.	0.	.1000E+01	0 0	NOT RELEASED .00000	ASN ASN
.1500E+ 2		AS5	ASSIGN	0.	.4000E+01	0.	0.	.1000E+01	0	0.0000	AS5
.18.. E+ 2		AS7	ASSIGN	0.	.4000E+01	0.	.1400E+01	.1000E+01	0 0 [illegible]	NOT RELEASED NOT RELEASED 3.[illegible]	AS7 D1 AS7
.3750E+ 2		AS3	ASSIGN	0.	.4000E+01	0.	.1900E+01	.1000E+01	0	19.5.32	AS9
.2270E+ 3		AS4	ASSIGN	0.	.4000E+01	0.	0.	0.	0	215.0143	AS8
.2420E+ 3		GO22	GOON	.2270E+03	.4000E+01	0.	0.	.2000E+01	0 0	15.0000 NOT RELEASED	GO22 GO44
.2420E+ 3		GO44	GOON	.2270E+03	.4000E+01	0.	0.	.2000E+01	0 0	NOT RELEASED .00000	AS0 GO44

.2420E+ 3	AS?	ASSIGN	.227UE+03	.4J0E+J1	L.	0.	.2JUCE+C1	0 NOT RELEASED ASQ U ASR
.2430E+ 3	AS*	ASSIGN	.227JE+J3	.4400E+J1	U.	*.	.2JCJE+C1	0 ASZ
.2451E+ 3	AS5	ASSIGN	.C270E+03	.4J0JE+J1	J.	.2900E+J1	.2J1UE+C1	0 3.0000 AS6
.2332E+C3	AS8	ASSIGN	0.	.4400E+01	0.	.1128E+02	.100JE+C1	0 18.3000 AS8
.2332E+.3	Q1	DJEJE	C.	.4400E+J1	0.	.5715E+J2	.1JCJE+C1	
.2331E+ 3	AS3	ASSIGN	.227UE+03	.4J00E+J1	U.	.2J00E+J1	.20JUE+C1	
.3113E+ 3	AS4	ASSIGN	.227JE+03	.4000E+01	0.	.1330E+02	.2J00E+01	0 37.5712 ASA
.3115E+ 3	Q2	DJEJC	.227JE+03	.4J0JE+J1	0.	.2567E+J2	.2J00E+C1	0 0.J000 Q2
.3110E+ 3	GG?	GGDN	0.	.4400E+01	0.	.5715E+J2	.1J00E+C1	
.3179E+ 3	AS6	ASSIGN	0.	.4400E+01	0.	.5715E+12	.1J00E+C1	
.3014E+ 3	AS*	ASSIGN	0.	.4400E+01	0.	.5815E+12	.1300E+C1	0 NOT RELEASED T1 U ASX
.3J0E+ 3	GG1	GGDN	.0270E+03	.4J00E+J1	U.	.2563E+12	.2JUUE+C1	0 26.0726 ASE
.3J0E+ 3	AS?	ASSIGN	.227JE+03	.4U00E+01	U.	.2563E+12	.2U0UE+C1	U 0.0000 ASD
.3000E+ 3	AS*	ASSIGN	.027JE+03	.4J00E+J1	0.	.2563E+12	.200UE+C1	0 NOT RELEASED T4 U ASY
.3230E+.3	AS?	ASSIGN	0.	.4400E+J1	.2547E+12	.5815E+12	.1400E+C1	U 30.5493 ASF
.3314E+ 3	AS*	ASSIGN	.227UE+03	.4U00E+01	.3055E+02	.2563E+12	.2J0UE+C1	U 346.592 ASG
.4110E+ 3	AS4	ASSIGN	.0270E+03	.4000E+01	.7539E+ 2	.3326E+12	.2000E+C1	U 79.0003 ASH
.41..E+ 3	T4	TER4	.227JE+03	.4J00E+J1	.7E.9E+.2	.5730E+12	.2000E+C1	
.6715E+.3	AS5	ASSIGN	U.	.4000E+01	.3465E+13	.5815E+12	.1000E+C1	
R=.2911E1.77.041 .6751E+ 3	T3	TER4	L.	.4J01E+J1	.3+65E+13	.1675E+13	.1J00E+C1	

Appendix H

FLYME Subroutine

FLYME is the control program for a set of subroutines which provides the fuel data for both the flight planning and simulation models. The fuel data bases for the C-5A, C-141B, and KC-135 aircraft were provided by the Air Force Global Weather Central and is the same data used to generate operational computer flight plan fuel requirements. Fuel data for the KC-10 was available from the KC-10 System Project Office, AFSC, WPAFB, OH in the form of experimental performance charts. Data points from these charts were compiled into FLYME to permit the same subroutine calls to address all four aircraft.

FLYME transfers control to one of the four aircraft subroutines labeled C-5A, C-141B, KC-10, and KC-135. The aircraft subroutine's coefficients, in dimensioned variables, compute the fuel data from six-degree polynomials evaluated in subroutines POLLY and POLY. Five options are available for each aircraft. Option one computes time in the climb to cruise altitude in minutes. Option two computes the ground distance, in nautical miles, traveled in the climb. Option three computes the fuel consumed in the climb in 1000s of lbs. Option four computes the cruise fuel rate in 1000s lbs per minute. Option five computes the rendezvous loiter fuel in 1000s lbs per minute. Each option contains input and output parameter checks and

error statements printed by subroutine ERROPS. The data is restricted to cruise altitudes between 25,000 and 41,000 feet and a standard day temperature with a temperature deviation of zero.

The C-141B data is the same data used for the E-3A aircraft with a 3 percent degrade in all fuel computations. The current C-141B fuel curves have not been prepared by AFGWS at the time this data was obtained. However, the data provided with the 3 percent degraded data matches the performance charts in the C-141B technical orders.

FLYME calls two other subroutines, CALT and TASP. CALT returns the highest altitude at which an aircraft can cruise for a given gross weight, and Air Traffic Control (ATC) hemispherical altitude structure. The calculations are derived for a given gross weight linear regression of the performance ceiling charts for each aircraft.

TASP returns the true airspeed of the aircraft at the given cruise altitude and mach number derived from the equation:

TAS = MACH NUMBER * SPEED OF SOUND AT ALTITUDE

The listing of the computer code for these subroutines follows:

```
      SUBROUTINE FLYME (V1,V2,V3,IOPT,V,IBIRD)
       IF (IBIRD .GE. 1  .AND.  IBIRD .LE. 4)  GO TO 50
         CALL ERROR ("IBIRD ERRO","R IN FLYME")
          RETURN
   50   GO TO (100,200,300,400),IBIRD
  100   CALL C5A (V1,V2,V3,IOPT,V)
        RETURN
  200   CALL C141B (V1,V2,V3,IOPT,V)
        RETURN
  300   CALL KC10A (V1,V2,V3,IOPT,V)
        RETURN
  400   CALL KC135A (V1,V2,V3,IOPT,V)
        RETURN
        END
C
C
C
C   RETURNS TRUE AIRSPEED IN NM/ MIN
        FUNCTION TASP(AMACH,ALT)
        DIMENSION SSND(7)
        DATA SSND/9.56333, 9.61167, 9.69667,
       &     9.78333, 9.86833, 9.95333, 10.03667/
        DO 10  J = 1, 7
        J = I
        IF (ALT.GE.(39.-2*I))  GO TO 20
   10   CONTINUE
   20   TASP=AMACH*SSND(J)
        RETURN
        END
C
        FUNCTION CALT(GWT,IBIRD,TC)
        DIMENSION ALPHA(4),BETA(4)
        DATA ALPHA/61.12378,61.79053,56.58588,60.13695/
        DATA  BETA/-.0455556,-.0950702,-.0435342,-.1073168/
        HIALT = ALPHA(IBIRD) + BETA(IBIRD) * GWT
        DO 10  I = 1, 4
        ALT = 41. - 4*I
        IF (TC .GE. 3.14159) ALT = 43- 4*I
        IF (HIALT.GE.ALT)  GO TO 20
   10   CONTINUE
   20   CALT = ALT
        RETURN
        END
```

```
      SUBROUTINE ERROR (MSG,NSUB)
       PRINT*,MSG,NSUB
       STOP
       END
C
C
C
       FUNCTION POLY(C,M,X)
       DIMENSION C(M)
       SUM = 0.0
       DO 10 IM=2,M
       J=M-IM+2
10     SUM = X * (C(J) + SUM)
       POLY = C(1) + SUM
       RETURN
       END
C
C
  C
       FUNCTION POLLY(C,K,L,X,Y)
       DIMENSION C(K,L)
       SUM = 0.0
       DO 20 IM=2,L
       JJ = L-IM+2
20     SUM = Y * (POLY(C(1,JJ),K,X) + SUM)
       POLLY = POLY(C(1,1),K,X) + SUM
       RETURN
       END
C
C
C
       SUBROUTINE C5A (V1,V2,V3,IOPT,V)
       DIMENSION A15CT1(5,5),A15CT2(5,5),A15CF1(5,5)
       DIMENSION A15CR1(5,5),A15CR2(5,5),A15CF2(5,5)
       DIMENSION A15E1I(36),A15E1J(36)
       DIMENSION A15E1E(36),A15E1F(36),A15E1G(36),A15E1H(36)
       DIMENSION A15E1A(36),A15E1B(36),A15E1C(36),A15E1D(36)
       DIMENSION A15E1(36,10),P15E1(10), A15H(9,3)
       EQUIVALENCE (A15E1A,A15E1(1,1)), (A15E1B,A15E1(1,2))
       EQUIVALENCE (A15E1C,A15E1(1,3)), (A15E1D,A15E1(1,4))
       EQUIVALENCE (A15E1E,A15E1(1,5)), (A15E1F,A15E1(1,6))
       EQUIVALENCE (A15E1G,A15E1(1,7)), (A15E1H,A15E1(1,8))
       EQUIVALENCE (A15E1I,A15E1(1,9)), (A15E1J,A15E1(1,10))
C
```

```
C              DIST FOUR ENGINE COEFFICIENTS
C
      DATA A15CT1/ .57427667E+02,  .34032210E+00, -.96786741E-03,
     &             .11785422E-05, -.52[illegible]E-09, -.15142192E+02,
     &             .87184921E-01, -.18747[illegible]E-03,  .18196550E-06,
     &            -.67785817E-10,  .16693[illegible]E+01, -.45886963E-02,
     &             .65205448E-05, -.26624[illegible]E-08,  .18817465E-12,
     &             .24328336E-[illegible], -.14959[illegible]E-03,  .64197566E-06,
     &            -.94270221E-[illegible],  .42165[illegible]E-12, -.42545431E-03,
     &             .45448911E-05, -.14307783E-07,  .17446845E-10,
     &            -.63041522E-14/
      DATA A15CT2/ .54754219E+02, -.23078033E+01,  .28967473E-01,
     &            -.13647746E-03,  .22826511E-06, -.57847884E+02,
     &             .17056432E+01, -.18578769E-01,  .88505101E-04,
     &            -.15507611E-06,  .10515166E+02, -.31197773E+00,
     &             .34091933E-02, -.16248261E-04,  .28528073E-07,
     &            -.54684296E+00,  .16210824E-01, -.17712504E-03,
     &             .84476539E-06, -.14849271E-08,  .78714622E-02,
     &            -.23314340E-03,  .25464057E-05, -.12152650E-07,
     &             .21423090E-10/
      DATA A15CF1/ .96216572E+02,  .46821259E-01, -.16876350E-03,
     &             .24597604E-05, -.12776860E-09,  .25693796E+02,
     &            -.20863673E+00,  .60823261E-03, -.74967174E-06,
     &             .33341333E-09, -.37019160E+01,  .29754803E-01,
     &            -.84654569E-04,  .16280328E-06, -.44437083E-10,
     &             .15301547E+00, -.12106921E-02,  .33924581E-05,
     &            -.48105508E-08,  .16675677E-11, -.17377349E-02,
     &             .13313674E-04, -.35575162E-07,  .38965935E-10,
     &            -.14014112E-13/
      DATA A15CF2/-.40738972E+02,  .51338421E+00, -.76424177E-03,
     &            -.47785562E-05,  .17378157E-07, -.21514860E+02,
     &             .64395325E+00, -.70698844E-02,  .33659370E-04,
     &            -.58310999E-07,  .35193831E+01, -.10336716E+00,
     &             .11091308E-02, -.51409909E-05,  .86739767E-08,
     &            -.15464019E+00,  .44733040E-02, -.47239814E-04,
     &             .21518054E-06, -.35559627E-09,  .17643395E-02,
     &            -.49841420E-04,  .51203461E-06, -.22595754E-08,
     &             .36056788E-11/
      DATA A15CR1/ .44697424E+02,  .44392409E+01, -.12569410E+00,
     &             .15163651E-02, -.66759124E-05,  .35202002E+02,
     &            -.26318901E+01,  .80245119E-01, -.96009867E-03,
     &             .41252071E-05, -.47324632E+01,  .37229611E+00,
     &            -.10247921E-01,  .11873635E-03, -.48624332E-06,
     &             .20004488E+00, -.15339955E-01,  .41028842E-03,
     &            -.45638295E-05,  .17466855E-07, -.23668958E-02,
     &             .17409888E-03, -.43687668E-05,  .43637131E-07,
     &            -.13221863E-09/
```

```
      DATA A15CR2/-.16485248E+02, -.50688613E+01,  .91317535E-01,
     &           -.47095761E-03,  .80535576E-06,  .48088850E+02,
     &           -.18183532E+01,  .24180545E-01, -.13075209E-03,
     &            .27494952E-06,  .41731172E+01, -.65913136E-01,
     &            .11004094E-07,  .37693611E-05, -.13293508E-07,
     &           -.42739199E+00,  .96429417E-02, -.68030746E-04,
     &            .12779689E-06,  .13743494E-09,  .67064995E-02,
     &           -.14846954E-03,  .99727726E-06, -.14487723E-08,
     &           -.35185374E-11/
C
C          CONSTANT ALTITUDE CRUISE COEFFICIENTS
C
C    A=23M  B=25M  C=27M  D=29M  E=31M
C    F=33M  G=35M  H=37M  I=39M  J=41M
C
C
      DATA A15E1A/
     & .36542733E+02,-.45837638E+03, .35939765E+04,-.18186684E+05,
     & .12110256E+05,-.51979966E+04, .24923058E+03,-.24911629E+01,
     & .82959266E+01,-.10881882E+02, .49621873E+01, .00000000E+00,
     &-.91220072E-04,-.88490494E-03, .21114037E-02,-.12173669E-02,
     & .00000000E+00, .00000000E+00, .51904278E-06,-.86674241E-06,
     & .41012003E-06, .00000000E+00, .00000000E+00, .00000000E+00,
     &-.14850194E-09, .11516674E-09, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .13463593E-13, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A15E1B/
     & .36923396E+03,-.34399478E+04, .13934186E+05,-.27229535E+05,
     & .25433674E+05,-.91344236E+04, .21229635E+03,-.17476749E+01,
     & .43489347E+01,-.38746322E+01, .93332913E+00, .00000000E+00,
     &-.48998729E-03, .15584518E-02,-.28440724E-02, .19580386E-02,
     & .00000000E+00, .00000000E+00, .17967823E-06, .13420929E-06,
     &-.47227338E-06, .00000000E+00, .00000000E+00, .00000000E+00,
     &-.17424758E-09, .20846602E-09, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .13671432E-13, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A15E1C/
     & .65587749E+03,-.59701378E+04, .22727169E+05,-.41833570E+05,
     & .37112890E+05,-.12793483E+05, .27039710E+03,-.20908794E+01,
     & .37259380E+01,-.18520188E+01,-.76937575E-01, .00000000E+00,
     &-.47849695E-03, .33346749E-02,-.54214154E-02, .25531933E-02,
     & .00000000E+00, .00000000E+00,-.48063804E-06,-.52678847E-07,
     & .35202594E-06, .00000000E+00, .00000000E+00, .00000000E+00,
     & .53650935E-09,-.18593184E-09, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00,-.17615817E-12, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
```

```
      DATA A15E1D/
     & .92684244E+03,-.86401176E+04, .31567536E+05,-.55822964E+05,
     & .48803676E+05,-.16138089E+05, .85019164E+00,-.27896598E+01,
     & .36659084E+01,-.15603997E+01,-.25354725E+00, .00000000E+00,
     &-.24617458E-02, .54736937E-02,-.57854236E-02, .26719656E-02,
     & .00000000E+00, .00000000E+00, .24964565E-05,-.26043423E-05,
     & .43694527E-06, .00000000E+00, .00000000E+00, .00000000E+00,
     &-.14378157E-08, .96079748E-09, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .26103084E-12, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A15E1E/
     & .16539089E+04,-.14967868E+05, .53058558E+05,-.91498270E+05,
     & .76760864E+05,-.25157148E+05, .14764374E+01,-.61687006E+01,
     & .10769359E+02,-.62977836E+01, .31091440E+00, .00000000E+00,
     &-.28883011E-02, .70281398E-02,-.11876892E-01, .68525515E-02,
     & .00000000E+00, .00000000E+00, .26828716E-05, .11516276E-05,
     &-.15449815E-05, .00000000E+00, .00000000E+00, .00000000E+00,
     &-.29812734E-08, .59255984E-09, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .94644581E-12, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A15E1F/
     & .20139264E+04,-.18702246E+05, .67729056E+05,-.11818523E+06,
     & .99665268E+05,-.32703118E+05, .28423929E+01,-.15697268E+02,
     & .28932324E+02,-.21733831E+02, .50587702E+01, .00000000E+00,
     &-.28562462E-02, .98565148E-02,-.17417374E-01, .95731861E-02,
     & .00000000E+00, .00000000E+00, .18265941E-05, .19568276E-05,
     &-.15151388E-05, .00000000E+00, .00000000E+00, .00000000E+00,
     &-.27468373E-08, .36785770E-09, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .99517707E-12, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A15E1G/
     & .28490053E+04,-.26965649E+05, .96884871E+05,-.16703878E+06,
     & .13863563E+06,-.44587107E+05, .57149618E+01,-.27435599E+02,
     & .51758489E+02,-.36757652E+02, .71298942E+01, .00000000E+00,
     &-.68590099E-02, .17735313E-01,-.35468957E-01, .28999188E-01,
     & .00000000E+00, .00000000E+00, .73097283E-05, .85733339E-05,
     &-.59460357E-05, .00000000E+00, .00000000E+00, .00000000E+00,
     &-.11842027E-07, .38336188E-09, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .53978787E-11, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A15E1H/
     & .39282854E+04,-.34613444E+05, .12031914E+06,-.20631798E+06,
     & .17445189E+06,-.59253633E+05, .52447126E+01,-.37227186E+02,
     & .77265491E+02,-.62140611E+02, .47564683E+02, .00000000E+00,
     &-.18107558E-02,-.82951086E-01, .58299573E-01,-.55756284E-01,
     & .00000000E+00, .00000000E+00, .14456525E-04,-.32033687E-04,
     & .59782966E-24, .00000000E+00, .00000000E+00, .00000000E+00,
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     &-.38569803E-08,-.33034820E-07, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .13092549E-10, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A15E1I/
     & .47390746E+04,-.43851544E+05, .15327303E+06,-.26482742E+06,
     & .22152288E+06,-.72523140E+05, .97822384E+01,-.69884915E+02,
     & .13869259E+03,-.12736934E+03, .45499131E+02, .00000000E+00,
     & .65030759E-03,-.87193318E-02,-.14193117E-01,-.18037217E-02,
     & .00000000E+00, .00000000E+00, .70362638E-05, .27444919E-04,
     & .17727124E-04, .00000000E+00, .00000000E+00, .00000000E+00,
     &-.23357964E-07,-.32630960E-07, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .24050306E-10, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A15E1J/
     &-.13825056E+03, .12171563E+04,-.19473890E+04, .92843440E+03,
     & .00000000E+00, .00000000E+00,-.97332943E+00, .16383971E+01,
     &-.95436383E+00, .00000000E+00, .00000000E+00, .00000000E+00,
     & .59334393E-03, .14846428E-03, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00,-.66797221E-06, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00,
     & .00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
C
      DATA P15E1/  23.0, 25.0, 27.0, 29.0, 31.0,
     &             33.0, 35.0, 37.0, 39.0, 41.0/
C
      DATA A15H/
     & .18000, .18167, .18667, .20167, .20333, .20833,
     & .22333, .22333, .23000, .24500, .24667, .25500,
     & .26667, .27000, .28167, .28833, .29333, .99999,
     & .31000, .32000, .99999, .33333, .36000, .99999,
     & .36000, .99999, .99999/
C
C
      IF (IOPT .GE. 1  .OR.  IOPT .LE. 5) GO TO 450
         CALL ERROR ("IOPT ERROR"," IN C5A")
         RETURN
C
C
450   GO TO ( 500,600,700,800,900), IOPT
C
```

```
C
C      C5A CLIMB TIME, RANGE, FUEL COMPUTATIONS
C
C      V1=GWT   V2=INIT ALT   V3=TERM ALT
C
C      AT 500   OUTPUT V = TIME TO CLIMB (MINUTES)
C
500   GWS=AMAX1(V1,354.)
      PAS=V2
      TD=20.
      PAT=V3
      PAS=AMAX1(PAS,0.)
      GWT=GWS-((.00125*GWS-.2375)*PAT)
         IF ((GWT.LT.335.).OR.(GWT.GT.770.) .OR.
     &       (GWS.LT.350.).OR.(GWS.GT.770.) .OR.
     &       (PAT.LE.PAS))  GO TO 11111
      TIMES = 0.
      IF (PAS.EQ.0.)  GO TO 550
         TIMES=POLLY(A15CT2,5,5,POLLY(A15CT1,5,5,GWS,PAS),TD)
         TIMES=AMAX1(TIMES,2.5)
550   IF (GWT.LT. 690.)  GO TO 575
         GWT=GWT-130.
575   TESTGW=GWT
      TEMP=POLLY(A15CT1,5,5,GWT,PAT)
      TIMET=POLLY(A15CT2,5,5,TEMP,TD)
      TIMET=AMAX1(TIMET,4.5)
      V=TIMET-TIMES
         IF ((V.LT.0.).OR.(V.GT.55)) GO TO 22222
      RETURN
C
C
C      AT 600   OUTPUT V = CLIMB RANGE (NMS)
C
600   GWS=AMAX1(V1/10, 35.4)
      PAS=V2
      TD=20.
      PAT=V3
      PAS=AMAX1(PAS,0.)
      GWT=GWS-((.0125*GWS-.2375)*(.1*PAT))
         IF ((GWT.LT.33.5).OR.(GWT.GT.77.).OR.
     &       (GWS.LT.35.) .OR.(GWS.GT.77.).OR.
     &       (PAT.LE.PAS))  GO TO 11111
      RANGES=0.
      IF (PAS.EQ. 0.0)  GO TO 650
         RANGES=POLLY(A15CR2,5,5,POLLY(A15CR1,5,5,GWT,PAS),TD)
         RANGES=AMAX1(RANGES,25.)
650   TEMP=POLLY(A15CR1,5,5,GWT,PAT)
      RANGET=POLLY(A15CR2,5,5,TEMP,TD)
```

```
      V=RANGET-RANGES
         IF ((V.LT.0.).OR.(V.GT.550)) GO TO 22222
       RETURN
C
C
C       AT 700    OUTPUT V = CLIMB FUEL (1000S OF LBS)
C
700    GWS=AMAX1(V1,354.)
       PAS=V2
       TD=20.
       PAT=V3
       PAS=AMAX1(PAS,0.)
       GWT=GWS-((.00125*GWS-.2375)*PAT)
          IF ((GWT.LT.335.).OR.(GWT.GT.770.).OR.
      &       (GWS.LT.350.).OR.(GWS.GT.770.).OR.
      &       (PAT.LE.PAS))  GO TO 11111
       FUELS=0.
       IF (PAS.EQ. 0.0)  GO TO 750
          FUELS=POLLY(A15CF2,5,5,(POLLY(A15CF1,5,5,GWS,PAS)),TD)
          FUELS=AMAX1(FUELS,2.5)
750    IF (GWT.LT. 691.)  GO TO 775
          GWT=GWT-51.
775    TESTGW=GWT
       TEMP=POLLY(A15CF1,5,5,GWT,PAT)
       FUELT=POLLY(A15CF2,5,5,(POLLY(A15CF1,5,5,GWS,PAT)),TD)
       FUELT=AMAX1(FUELT,3.5)
       V=FUELT-FUELS
          IF ((V.LT.0.).OR.(V.GT.55.)) GO TO 22222
       RETURN
C
  C
C       C5A CONSTANT ALTITUDE CRUISE
C
C       V1=GWT  V2=MACH  V3=ALT    OUTPUT V = 1000 LBS / MIN
C
800    GW = AMAX1(V1,354.)
       AMACH = V2
       PA = V3
          IF (PA.LT.0.0  .OR.  PA.GT.45.  .OR.
      &    AMACH.LT.0.2  .OR.  AMACH.GT.0.9  .OR.
      &       GW.LT.350. .OR.  GW.GT.775.)
      &   GO TO 11111
       DO 850  J = 2, 10
       I = J-1
       IF (PA.LT. P15E1(J)) GO TO 875
850    CONTINUE
875    T1=POLLY(A15E1(1,I),6,6,AMACH,GW)
```

```
      T2=POLLY(A15E1(1,I+1),6,6,AMACH,GW)
       V=T1 + (PA-P15E1(I)) * (T2-T1)/(P15E1(I+1)-P15E1(I))
          IF (V.LT.9. .OR. V.GT.50.) GO TO 22222
       V = TASP(AMACH,PA) / V
       RETURN
C
C
C         C5A RENDEZVOUS HOLDING FUEL
C
C           V1=GWT  V3=ALT
C           OUTPUT V = 1000 LBS/MIN
C
900    GWT = AMAX1(V1,354.)
       PA = V3
          IF (GWT.LT.350.  .OR.  GWT.GT.775.   .OR.
     &     PA.LT.0.0   .OR.   PA.GT.45.) GO TO 11111
       DO 920  I = 1, 9
       J = I
       IF (GWT .LE. (320.+I*40.)) GO TO 940
920    CONTINUE
940    DO 960  I = 1, 3
       K = I
       IF (PA .LE. (25.+I*4.)) GO TO 980
960    CONTINUE
980    V = A15H(J,K)
          IF (V .LT. 0. .OR.  V .GE. .99999) GO TO 22222
       RETURN
11111  PRINT*,"  IOPT =",IOPT,"  GWT =",V1
       CALL ERROR ("  INPUT","  C5A")
       RETURN
22222  CALL ERROR ("OUTPUT ERR","OR IN C5A")
       RETURN
       END
C
C
C     *       *       *       *       *       *       *       *
C
C
C
       SUBROUTINE C141B (V1,V2,V3,IOPT,V)
C
C
       DIMENSION C1A(16),C2A(16),C3A(16)
       DIMENSION CA(16,3),E1(16,8),F1(8),HFF(8)
       DIMENSION E1A(16),E1B(16),E1C(16),E1D(16)
       DIMENSION E1E(16),E1F(16),E1G(16),E1H(16)
       DIMENSION D1B(2),D2B(2),D3B(2),DB(2,3)
```

```
C
      EQUIVALENCE (C1A,CA(1,1)) , (C2A,CA(1,2))
      EQUIVALENCE (C3A,CA(1,3)) , (DB(1,1),D1B)
      EQUIVALENCE (DB(1,2),D2B) , (DB(1,3),D3B)
      EQUIVALENCE (E1A,E1(1,1)) , (E1B,E1(1,2))
      EQUIVALENCE (E1C,E1(1,3)) , (E1D,E1(1,4))
      EQUIVALENCE (E1E,E1(1,5)) , (E1F,E1(1,6))
      EQUIVALENCE (E1G,E1(1,7)) , (E1H,E1(1,8))
C
C  CLIMB  COEFFICIENTS
C
      DATA C1A/
     & .41809526E+02,-.53315043E+00, .21076803E-02,-.27565421E-05,
     &-.86764842E+01, .11135442E+00,-.43600370E-03, .57718697E-06,
     & .44696824E+00,-.56370250E-02, .22183130E-04,-.29504408E-07,
     &-.66485889E-02, .84090284E-04,-.33228785E-06, .46018632E-09/
C
      DATA C2A/
     & .10035453E+03,-.94521497E+00, .19945408E-02,-.36946845E-06,
     &-.19226782E+02, .17217714E+00,-.26683940E-03,-.10645122E-06,
     & .79824708E+00,-.55605173E-02,-.10689811E-05, .26085471E-07,
     &-.90131161E-02, .45378160E-04, .18272715E-06,-.51003139E-09/
C
      DATA C3A/
     &-.63033390E+01, .87664303E-01,-.40523200E-03, .58257411E-06,
     & .10373707E+01,-.14134949E-01, .69608771E-04,-.97339575E-07,
     &-.48141505E-01, .70068203E-03,-.33180695E-05, .46038939E-08,
     & .55985559E-03,-.81442520E-05, .37446303E-07,-.44546775E-10/
C
C
C   OUTPUT PARAMETER LIMITS
C
      DATA D1B,D2B,D3B/ 0., 40., 0., 240., 0., 13.4/
C
C           CONSTANT ALTITUDE CRUISE COEFFICIENTS
C
C           A=25M  B=27M  C=29M  D=31M
C           E=33M  F=35M  G=37M  H=39M
C
      DATA E1A/
     & .39044847E+03,-.15574907E+04, .24064098E+04,-.12901585E+04,
     &-.37646194E+01, .16677557E+02,-.25008147E+02, .12568017E+02,
     & .11089616E-01,-.53777762E-01, .85958771E-01,-.45049201E-01,
     &-.85304424E-05, .45865470E-04,-.79139909E-04, .43972623E-04/
```

```
C
      DATA E1B/
     & .51692612E+03,-.16723254E+04, .18833207E+04,-.68276804E+03,
     &-.65156544E+01, .23482624E+02,-.26162985E+02, .85415492E+01,
     & .26863672E-01,-.10330544E+00, .12390802E+00,-.45274434E-01,
     &-.35491305E-04, .13838067E-03,-.16990271E-03, .64497096E-04/
C
      DATA E1C/
     & .28949557E+03,-.69582085E+03, .61718559E+03,-.19434718E+03,
     &-.50477516E+01, .17664305E+02,-.19722525E+02, .69444219E+01,
     & .25822704E-01,-.10275986E+00, .13256223E+00,-.55888790E-01,
     &-.40238875E-04, .16510637E-03,-.22185642E-03, .98219017E-04/
C
      DATA E1D/
     & .21070841E+04,-.90042572E+04, .13304971E+05,-.66442359E+04,
     &-.29396097E+02, .12850585E+03,-.18790712E+03, .91879841E+02,
     & .13199537E+00,-.58536003E+00, .86239993E+00,-.42290730E+00,
     &-.19004980E-03, .84411525E-03,-.12452789E-02, .61091292E-03/
C
      DATA E1E/
     & .96574555E+03,-.31155806E+04, .35877400E+04,-.14375898E+04,
     &-.16021388E+02, .57571855E+02,-.68477408E+02, .26970186E+02,
     & .83720121E-01,-.31892526E+00, .40158349E+00,-.16752504E+00,
     &-.14019367E-03, .54454386E-03,-.70079586E-03, .29909214E-03/
C
      DATA E1F/
     & .22519003E+03, .21770855E+03,-.13115426E+04, .92519815E+03,
     &-.64746063E+01, .14899445E+02,-.58683456E+01,-.31632492E+01,
     & .42731702E-01,-.13992524E+00, .14366786E+00,-.45329795E-01,
     &-.77190006E-04, .27475383E-03,-.31878586E-03, .12081834E-03/
C
      DATA E1G/
     & .87808213E+04,-.28376209E+05, .28571235E+05,-.83724016E+04,
     &-.14980194E+03, .51387621E+03,-.56633828E+03, .19514269E+03,
     & .88464275E+00,-.28944027E+01, .33813903E+01,-.12726897E+01,
     &-.13887352E-02, .51224322E-02,-.61882965E-02, .24391291E-02/
C
      DATA E1H/
     &-.53651077E+04, .31569176E+05,-.56586409E+05, .32138929E+05,
     & .61113514E+02,-.38123027E+03, .71183330E+03,-.41571353E+03,
     &-.21370924E+00, .14613062E+01,-.28613717E+01, .17208628E+01,
     & .22027926E-03,-.17809603E-02, .37514610E-02,-.23425345E-02/
C
      DATA F1/  25., 27., 29., 31., 33., 35., 37., 39./
C
      DATA HFF/ .12167, .13333, .14333, .15667,
     &          .16833, .17833, .19333,  .20833 /
```

```
C
      IF (IOPT .GE. 1  .OR.  IOPT .LE. 5) GO TO 1000
         CALL ERROR ("IOPT ERROR"," IN C141B")
         RETURN
C
C
1000  GO TO (1100,1100,1100,1200,1300), IOPT
C
C
C     C141B CLIMB TIME, RANGE, FUEL COMPUTATIONS
C
C     V1=GWT   V3=INIT ALT   V3=TERM ALT
C
C       J=1   OUTPUT V = CLIMB TIME (MIN)
C
C       J=2   OUTPUT V = CLIMB RANGE (NM)
C
C       J=3   OUTPUT V = CLIMB FUEL (1000 LBS)
C
1100  GW = AMAX1(V1,141.)
      PAS = V2
      PAT = V3
      GWT = GW - ((PAT-PAS)*.000943*GW)
      TD = 20.
      J = IOPT
         IF (GW  .LT. 141.  .OR.  GW  .GT. 340.  .OR.
     &       PAS .LT. 0.0   .OR.  PAS .GT. 45.   .OR.
     &       PAT .LT. 0.0   .OR.  PAT .GT. 45.) GO TO 11111
      T1 = POLLY(CA(1,J), 4, 4, GW, PAS)
      T1 = AMAX1( T1, 0.0)
      T2 = POLLY(CA(1,J), 4, 4, GWT,PAT)
      V  = (T2 - T1)
      IF (J.EQ.3) V = .98 * V * .97
         IF (V .LT. DB(1,J) .OR. V .GT. DB(2,J)) GO TO 22222
      RETURN
C
C
C     CONSTANT ALTITUDE CRUISE COMPUTATIONS
C
C     V1=GWT  V2=MACH#  V3=ALT   OUTPUT V = 1000 LBS/MIN
C
1200  GRW = AMAX1(V1,141.)
      AMACH = V2
      PA  = V3
         IF (GRW .LT. 141. .OR. GRW .GT. 340.  .OR.
     &     AMACH .LT. .2 .OR. AMACH .GT. .8  .OR.
     &        PA .LT. 0.0  .OR. PA  .GT. 45.) GO TO 11111
```

```
      DO 1250  J = 1, 8
       IF (F1(J) .LE. PA) I = J
1250  CONTINUE
      V = POLLY(E1(1,I),4,4,AMACH,GRW)*1.04
         IF (V .LT. 10.  .OR. V .GT. 80.) GO TO 22222
      V = TASP(AMACH,PA) / V * .97
      RETURN
C
C
C     HOLDING FUEL AT FL250
C
C     V1=GWT  V2=XXX  V3=ALT
C
C     OUTPUT V = 1000 LBS / MIN
C
1300  GWT = AMAX1(V1,141.)
      PA = V3
         IF (GWT.LT.141.  .OR.  GWT.GT.340.   .OR.
     &    PA .LT. 0.0  .OR.  PA .GT. 45.) GO TO 11111
      DO 1320  I = 1, 8
      J = I
      IF (GWT .LE. (160.+I*20.)) GO TO 1340
1320  CONTINUE
1340  CONTINUE
      V = HFF(J)
         IF (V .LT. 0. .OR. V .GT. .22) GO TO 22222
      RETURN
11111 PRINT*,"  IOPT =",IOPT,"  GWT =",V1,"  PA =",V3
      CALL ERROR ("  INPUT","  C141B")
      RETURN
22222 CALL ERROR ("OUTPUT ERR","OR IN C141")
      RETURN
      END
C
C
C
C     ************************************************************
C
C
      SUBROUTINE KC10A (V1,V2,V3,IOPT,V)
C
      DIMENSION TKCLM(7,3),Z25(7,3)
      DIMENSION TKCRU(6,7),TKH(14)
```

```
C
C   KC10A CLIMB COEFFICIENTS
C
      DATA TKCLM/  17.3,  17.6,  18.3,  19.6,  20.8,  22.2,  19.2,
     &           118.,  124.,  127.5,  132.,  144.3,  154.5,  130.5,
     &             8.6,   9.5,  10.3,  11.1,  12.5,  13.7,  12.0/
C
      DATA Z25/  7.5,  8.6,  10.2, 11.7, 13.4, 15.6, 15.6,
     &          48.5, 56.,  64.,  73.5, 87.,  99.5,  99.5,
     &          5.1,  5.9,  6.75,  7.7,  8.9,  10.4, 10.4/
C
      DATA TKCRU/ 19.4, 20.6, 23.4, 26.0, 28.4, 30.7,
     &            20.2, 22.5, 24.9, 27.1, 29.1, 31.1,
     &            18.1, 20.1, 22.1, 23.9, 25.7, 27.3,
     &            16.5, 18.3, 19.9, 21.4, 23.9, 24.3,
     &            20.4, 21.7, 23.1, 24.3, 25.5, 26.7,
     &            19.3, 20.5, 21.6, 22.6, 23.6, 24.5,
     &            19.3, 19.3, 20.2, 21.1, 21.9, 22.6/
C
      DATA TKH/  19.6, 19.9, 20.3, 20.8, 21.6, 21.8, 22.5,
     &           23.3, 24.0, 24.5, 25.3, 25.8, 26.4, 27.1/
C
C
      IF (IOPT .GE. 1  .OR.  IOPT .LE. 5) GO TO 1495
         CALL ERROR ("IOPT ERROR"," IN KC10A")
         RETURN
C
C
1495  GO TO (1500,1500,1500,1700,1800), IOPT
C
C
C   KC10A CLIMB  COMPUTATIONS
C
C   V1=GWT  V2=INIT ALT  V3=TERM ALT
C
C   J = 1   OUTPUT V = CLIMB TIME (MIN)
C
C   J = 2   OUTPUT V = CLIMB RANGE (NM)
C
C   J = 3   OUTPUT V = CLIMB FUEL (1000 LBS)
C
1500  J = IOPT
      GWT = AMAX1(V1,248.)
      PAS = V2
      PAT = V3
         IF (GWT.LT.248.  .OR.  GWT.GT.591.  .OR.
     &    PAT.LT.PAS)  GO TO 11111
```

```
C
      DO 1550  I = 1, 7
      K = I
      IF(PAT .GE. (43.-I*2.)) GO TO 1600
 1550 CONTINUE
 1600 START = 0.
      IF (PAS .LT. 20.) GO TO 1650
      START = Z25(K,J)
 1650 V = TKCLM(K,J) - START
         IF ((V.LT.3.  .OR. V.GT.23.  ).AND.  J.EQ.1) GO TO 22222
         IF ((V.LT.30. .OR. V.GT.155. ).AND.  J.EQ.2) GO TO 22222
         IF ((V.LT.1.5 .OR. V.GT.14.  ).AND.  J.EQ.3) GO TO 22222
      RETURN
C
C   KC10A CRUISE COMPUTATIONS
C
C   V1=GWT  V2=XXX  V3=ALT
C
C   OUTPUT V = 1000 / MIN
C
 1700 GWT = AMAX1(V1,248.)
      PA = V3
      IF (GWT.LT.248.  .OR.  GWT.GT.591.  .OR.
     &    PA .LT. 26.   .OR.  PA .GT.  45.) GO TO 11111
C
      DO 1720  I = 1, 7
      J = I
      IF (PA .GE. (43.-I*2)) GO TO 1740
 1720 CONTINUE
 1740 DO 1760  I =1, 6
      K = I
      IF (GWT.GE.(360+(40*J)-(20*I))) GO TO 1780
 1760 CONTINUE
 1780 V = TASP(.82,PA)/TKCRU(K,J)
         IF (V .LT. .2   .OR.   V .GT. .5)  GO TO 22222
      RETURN
C
C    KC10A RENDEZVOUS HOLDING FUEL
C
C    V1=GWT  V2=XXX  V3=XXX
C
C    OUTPUT V = 1000 LBS / MIN
C
 1800 GWT = AMAX1(V1,248.)
      IF (GWT .LT. 248.  .OR. GWT .GT. 591) GO TO 11111
      DO 1840  I = 1, 14
      J = I
```

```
      IF (GWT .GE. (600-20*I))  GO TO 1860
 1840 CONTINUE
 1860 V = 6.22/ TKH(J)
         IF (V.LT. .22   .OR.   V.GT. .32)  GO TO 22222
      RETURN
C
11111 PRINT*,"  IOPT =",IOPT,"  GWT =",V1,"PA =",V3
      CALL ERROR ("  INPUT","  KC10A")
      RETURN
22222 PRINT*,"  IOPT =",J,"  GWT =",V1,"  PA =",V3,"  V =",V
      CALL ERROR ("  OUTPUT","  KC10A")
      RETURN
      END
C
C
C
C     *       *       *       *       *       *       *       *
C
      SUBROUTINE KC135A (V1,V2,V3,IOPT,V)
C
C
      DIMENSION A2C8A(36),A2C9A(36),A2C10A(36)
      DIMENSION A2F3(3,2), A2F2(4,4,2)
      DIMENSION F2F1(10),  A2H1(4,7,2),  A2F1(7,3,10)
      DIMENSION  A2F1A(7,3),A2F1B(7,3),A2F1C(7,3),A2F1D(7,3),
     &A2F1E(7,3),A2F1F(7,3),A2F1G(7,3),A2F1H(7,3),A2F1I(7,3),
     &A2F1J(7,3),A2F1K(7,3),A2F1L(7,3),A2F1M(7,3),A2F1N(7,3),
     &A2F1O(7,3),A2F1P(7,3),A2F1Q(7,3)
      EQUIVALENCE (A2F1A,A2F1(1,1,1)),(A2F1B,A2F1(1,1,2)),
     &           (A2F1C,A2F1(1,1,3)),(A2F1D,A2F1(1,1,4)),
     &           (A2F1E,A2F1(1,1,5)),(A2F1F,A2F1(1,1,6)),
     &           (A2F1G,A2F1(1,1,7)),(A2F1H,A2F1(1,1,8)),
     &           (A2F1I,A2F1(1,1,9)),(A2F1J,A2F1(1,1,10))
C
C      CONSTANT ALTITUDE CRUISE
C
      DATA A2F1A/ .70390E+02, .15779E+03,-.34584E+03,-.22653E+03,
     &           .53343E+03,-.15145E+03,  0.00,
     &          -.12288E+01, .26182E+01,-.33988E-00,-.16085E+01,
     &           .12868E+01,-.87724E-00,  0.00,
     &           .39967E-03, .30006E-02,-.12897E-01, .75622E-02,
     &           .91780E-02,-.73220E-02,  0.00/
      DATA A2F1B/ .25127E+03,-.52458E+03, .29179E+02, .10933E+04,
     &          -.11432E+04, .27593E+03,  0.00,
     &          -.26611E+01, .71286E+01,-.19412E+01,-.74513E+01,
     &           .39220E+01, .14017E+01,  0.00,
     &           .38753E-02,-.75104E-02,-.80590E-03,-.18701E-01,
     &           .61283E-01,-.39947E-01,  0.00/
```

```
      DATA A2F1C/ .16692E+03,-.59347E+03, .20278E+04,-.36450E+04,
     &            .29337E+04,-.88312E+03,  0.00,
     &           -.11260E+00,-.45446E+01, .17073E+02,-.26518E+02,
     &            .23118E+02,-.91965E+01,  0.00,
     &           -.29285E-02, .12494E-01, .11816E-01,-.10285E+00,
     &            .13671E-00,-.55658E-01,  0.00/
      DATA A2F1D/ .37546E+03,-.11655E+04, .15523E+04,-.95808E+03,
     &            .70124E+03,-.58030E+03,  0.00,
     &           -.31465E+01, .80893E+01, .36599E-00,-.18085E+02,
     &            .15781E+02,-.23145E+01,  0.00,
     &           -.17231E-02, .18111E-01,-.24390E-01,-.66848E-01,
     &            .14904E-00,-.83233E-01,  0.00/
      DATA A2F1E/ .26778E+03,-.10178E+04, .21887E+04,-.17785E+04,
     &           -.39576E+03, .14393E+04,-.76060E+03,
     &           -.14745E+01, .38478E+01,-.17543E+01,-.45214E+01,
     &           -.41767E+01, .20446E+02,-.12100E+02,
     &           -.60467E-02, .18524E-01, .21271E-01,-.12339E+00,
     &            .13240E-00,-.29116E-01,-.15790E-01/
      DATA A2F1F/ .38353E+02, .82684E+03,-.25352E+04, .30980E+04,
     &           -.15543E+04, .88689E+02,  0.00,
     &           -.46961E+01, .18500E+02,-.30075E+02, .16853E+02,
     &            .78351E+01,-.82616E+01,  0.00,
     &           -.12904E-01, .79415E-01,-.12653E-00,-.60159E-02,
     &            .14923E-00,-.85378E-01,  0.00/
      DATA A2F1G/-.14850E+03, .12985E+04,-.26248E+04, .34314E+04,
     &           -.31385E+04, .11625E+04,  0.00,
     &            .95392E-00,-.95819E+01, .17752E+02,-.17308E+02,
     &            .17847E+02,-.95525E+01,  0.00,
     &            .43332E-03, .29842E-01,-.64608E-01,-.19098E-01,
     &            .11980E+00,-.67919E-01,  0.00/
      DATA A2F1H/ .26278E+03,-.84408E+03, .18182E+04,-.12964E+04,
     &           -.33707E+03, .49613E+03,-.12800E+03,
     &           -.15025E+01, .17988E+01,-.14204E+01, .29452E+01,
     &           -.13479E+02, .28024E+02,-.16496E+02,
     &           -.82385E-02, .60915E-01,-.97733E-01,-.19848E-02,
     &            .84582E-01,-.22388E-01,-.17244E-01/
      DATA A2F1I/ .36995E+03,-.36260E+03,-.55631E+03, .57083E+03,
     &            .85640E+03, .69447E+02,-.11494E+04,
     &           -.72100E+01, .11838E+02, .79164E+01,-.17946E+02,
     &            .66275E-00,-.74328E+01, .14691E+02,
     &            .30834E-01,-.32639E-01,-.66065E-01, .10251E-01,
     &            .86320E-01, .12952E-00,-.16609E-00/
      DATA A2F1J/ .27878E+03,-.41841E+03, .38329E+03,-.11309E+04,
     &            .30117E+04,-.22212E+04,  0.00,
     &            .57355E-00,-.70987E+01, .11937E+02,-.10787E+02,
     &            .34726E+01,-.28971E+01,  0.00,
     &           -.87416E-03, .37478E-01,-.10366E+00, .96931E-01,
     &           -.21423E-01,-.10306E-01,  0.00/
```

```
      DATA F2F1/23.0, 25.0, 27.0, 30.0, 32.0,
     &         33.0, 35.0, 38.0, 40.0, 43.0/
      DATA A2F2/  2.5322E+01,-7.1468E+01, 1.4859E+02,-8.8123E+01,
     &           -1.6356E+00, 4.7214E+00,-1.9222E+00,-1.9480E+00,
     &            5.9305E-02,-8.0547E-03,-2.2566E-01, 2.6586E-01,
     &           -7.1011E-04, 2.2246E-04, 3.4366E-03,-3.9212E-03,
     &           -2.2914E+01, 1.0035E+01, 6.2623E+01,-5.7393E+00,
     &            1.6534E+00, 2.7132E+00,-3.1916E+00,-4.7127E+00,
     &           -3.9468E-02, 5.8768E-03,-1.0385E-01, 2.9979E-01,
     &            2.6324E-04, 5.1179E-04, 1.1279E-03,-3.4574E-03/
      DATA A2F3/  8.5849E-02, 8.7513E-01, 6.3284E-05,
     &            3.9702E-02, 9.3699E-01, 4.4710E-05/
C
C
C       BEST ENDURANCE (CONSTANT ALTITUDE)
C
      DATA A2H1/  1.6779E-01, 4.6661E-04, 3.2904E-06,-6.9689E-09,
     &           -3.2913E-02, 5.7376E-04,-2.5602E-06, 3.5941E-09,
     &            3.4754E-03,-5.4775E-05, 2.2136E-07,-2.4929E-10,
     &           -4.1633E-05, 1.4629E-06,-5.2848E-09, 3.2877E-12,
     &           -8.5510E-06, 4.9191E-08,-1.2665E-10, 1.1304E-13,
     &            3.6958E-07,-2.3980E-09, 2.3022E-12, 9.6055E-15,
     &           -4.0134E-09, 1.5045E-11, 9.9904E-14,-4.2645E-16,
     &            1.2338E-02,-1.3786E-03, 4.5368E-05, 2.4758E-09,
     &            5.1107E-02,-2.7877E-04,-9.2074E-07,-7.1474E-09,
     &           -8.9942E-04, 2.5439E-06, 2.8382E-09, 2.5989E-10,
     &           -1.5669E-05, 9.3960E-08, 8.8267E-10, 1.3121E-12,
     &           -7.1696E-08, 7.3507E-09,-2.0970E-11,-1.4532E-13,
     &            9.1835E-10,-2.1766E-12,-5.4770E-13,-1.3963E-15,
     &            6.3501E-11,-9.3625E-13,-3.5161E-15, 9.2636E-17/
C
C       280 KCAS CLIMB DATA (NRT,TEMP DEV = 0)
C         8 = TIME,  9 = RANGE,  10 = FUEL MILAGE
C
      DATA A2C8A/
     &.18842792E+02, .61363807E+01,-.55344857E+00, .19261210E-01,
     &-.29292379E-03,.15829321E-05,-.63323568E+00,-.89573058E-01,
     &.59825186E-02,-.13521327E-03, .10564593E-05, .00000000E+00,
     &.77333210E-02, .47702502E-03,-.19896540E-04, .20861935E-06,
     &.00000000E+00, .00000000E+00,-.43755351E-04,-.10713172E-05,
     &.22596734E-07, .00000000E+00, .00000000E+00, .00000000E+00,
     &.11643423E-06, .83801229E-09, .00000000E+00, .00000000E+00,
     &.00000000E+00, .00000000E+00,-.11782181E-09, .00000000E+00,
     &.00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
```

```
      DATA A2C9A/
     &.34485743E+02, .38518397E+02,-.37067432E+01, .14247979E+00,
     &-.23552669E-02,.13631375E-04,-.14653674E+01,-.55894354E+00,
     &.36877233E-01,-.90076950E-03, .76295163E-05, .00000000E+00,
     &.20797579E-01, .31199162E-02,-.11842322E-03, .13343168E-05,
     &.00000000E+00, .00000000E+00,-.13253396E-03,-.77260867E-05,
     &.13643622E-06, .00000000E+00, .00000000E+00, .00000000E+00,
     &.38867161E-06, .71928750E-05, .00000000E+00, .00000000E+00,
     &.00000000E+00, .00000000E+00,-.42601289E-09, .00000000E+00,
     &.00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
      DATA A2C10A/
     &.94779048E+00, .10616707E+01,-.94014545E-01, .31300793E-02,
     &-.44661942E-04,.22872864E-06,-.39877427E-01,-.15479922E-01,
     &.10646246E-02,-.23404925E-04, .16700743E-06, .00000000E+00,
     &.54313748E-03, .83767423E-04,-.37418748E-05, .40830338E-07,
     &.00000000E+00, .00000000E+00,-.32533517E-05,-.20992312E-06,
     &.43817701E-08, .00000000E+00, .00000000E+00, .00000000E+00,
     &.89364865E-08, .19833183E-09, .00000000E+00, .00000000E+00,
     &.00000000E+00, .00000000E+00,-.92200077E-11, .00000000E+00,
     &.00000000E+00, .00000000E+00, .00000000E+00, .00000000E+00/
C
      IF (IOPT.GE.1  .OR. IOPT.LE.5)  GO TO 1950
         CALL ERROR ("IOPT ERROR"," IN KC135A")
         RETURN
1950  GO TO (2000,2100,2200,2300,2400), IOPT
C
C
C
C            CONSTANT ALTITUDE CRUISE
C
C       V1=GWT  V2=MACH  V3=ALT
C
C         OUTPUT V = 1000LBS / MIN
C
2300  GW = AMAX1(V1,100.)
      AMACH = V2
      PA = V3
2310  IF (PA .LT. 0.0 .OR. PA .GT. 50.  .OR.
     & AMACH .LT. 0.2 .OR. AMACH .GT. 0.9 .OR.
     &     GW.LT. 100. .OR. GW.GT. 300.) GO TO 11111
      DO 2320  J = 2, 10
      I = J-1
      IF (PA .LT. F2F1(J)) GO TO 2330
2320  CONTINUE
2330  T1 = POLLY(A2F1(1,1,I),7,3,AMACH,GW)
      T2 = POLLY(A2F1(1,1,I+1),7,3,AMACH,GW)
      T = T1 + (PA-F2F1(I)) * (T2-T1)/(F2F1(I+1)-F2F1(I))
```

```
      IF (T .LT. POLLY(A2F2(1,1,1),4,4,AMACH,PA)) GO TO 2340
      T = POLY(A2F3(1,1),3,T)
      GO TO 2350
 2340 IF (T.LT.POLLY(A2F2(1,1,2),4,4,AMACH,PA)) GO TO 2350
      T = POLY(A2F3(1,2),3,T)
 2350    IF (T .LT. 14.   .OR. T .GT. 80. ) GO TO 22222
      V = TASP(AMACH,PA) / T
      RETURN
C
C
C        BEST ENDURANCE (CONSTANT ALTITUDE)
C
C          V1=GWT  V2=MACH  V3=ALT
C
C          OUTPUT V= 1000LBS / MIN
C
 2400 GW = AMAX1(V1,100.)
      PA = V3
      I = 1
      IF (PA .GT. 30.0 )  I = 2
      AMACH = POLLY(A2H1(1,1,I),4,7,GW,PA)
      GO TO 2310
C
C
C           280KCAS CLIMB TIME,RANGE,FUEL (NRT)
C
C         V1=GWT  V2=INIT ALT  V3=TERM ALT
C
C         OUTPUT  V = TIME TO CLIMB (MIN)
C
 2000 GW= AMAX1(V1,100.)
      PAS = V2
      PAT = V3
      T1 = POLLY(A2C8A,6,6,PAS,GW)
      T2 = POLLY(A2C8A,6,6,PAT,GW)
      V = T2 - T1
         IF (V .LT. 0.0  .OR. V .GT. 60. )  GO TO 22222
      GO TO 2250
C
C     OUTPUT V = RANGE IN CLIMB (NM)
C
 2160 GW = AMAX1(V1,130.)
      PAS = V2
      PAT = V3
      T1 = POLLY(A2C9A,6,6,PAS,GW)
      T2 = POLLY(A2C9A,6,6,PAT,GW)
      V = T2 - T1
```

```
        IF (V .LT. 0.0   .OR.  V .GT. 340. ) GO TO 22222
      GO TO 2250
C
C      OUTPUT V = FUEL TO CLIMB (1000LBS)
C
2200  GW = AMAX1(V1,100.)
      PAS = V2
      PAT = V3
      T1 = POLLY(A2C10A,6,6,PAS,GW)
      T2 = POLLY(A2C10A,6,6,PAT,GW)
      V = T2 - T1
         IF (V .LT. 0.0  .OR.  V .GT. 17. ) GO TO 22222
2250  IF (GW .LT. 100.  .OR. GW .GT. 300.  .OR.
     &   PAS .LT. 0.0   .OR. PAT.GT.  50. ) GO TO 11111
      RETURN
C
C
C
11111 CALL ERROR ("INPUT ERRO","R TO KC135")
      RETURN
C
22222 CALL ERROR ("OUTPUT ERR","OR, KC135A")
      RETURN
      END
```

Appendix I

SLAM Validation

This appendix describes the procedure used to validate the SLAM simulation model. Validation of the SLAM model is broken down into two steps: (1) verification, and (2) external validation. Verification insures that the model behaves as intended and designed; this includes internal mechanical verification. External validation tests the agreement between the model output data and the true output obtained from the real world. The validity of the SLAM model was only evaluated in terms of the model's purpose which is to validate the analytical model's output under the real world conditions of stochastic wind factors and ground delays.

Verification of the SLAM model ensured that the model produced mechanically correct results and that the results were calculated as intended. This verification step was done independently three times during the creation of the model due to discovery of internal errors. During the verification process errors in design and programming were found and corrected. After each design or programming change, the verification process was repeated until the SLAM model output was verified to be correct and the internal mechanical aspects of the model were also determined to be correct.

The verification process consisted of two stages:

1. Verification of the random wind variables and probabilistic ground delays.

2. Internal mechanical verification.

The first stage verified that the climb and cruise winds as specified in the SLAM model were actually providing sample winds for those distributions and that delays occurred appropriately. For example, the cruise wind used a normal distribution (μ = .917, σ = .16 NM/MIN). To determine that this SLAM wind distribution actually provided the model with a normal distribution as defined, wind values were obtained from the model and tested using a Kolmogorov-Smirnov Goodness-of-Fit Test. Figure I-1 contains the Vogelbach Computing Center Statistical Package for the Social Sciences (SPSS) Computer Program used to test the wind output distribution. The Kolmogorov-Smirnov Test tested the SLAM wind distribution against a theoretical normal distribution with the μ and σ previously defined. The null hypothesis (H_0) used in the test was that "There is no significant difference between the observed data and that given by normal distribution with mean equal to .917 and a standard deviation equal to .16. For each case the Kolmogorov-Smirnov critical value was greater than the Kolmogorov-Smirnov value calculated by the SPSS Program; therefore, H_0 was not rejected. However, since the mean and standard deviation are estimated parameters the Lilliefors Test Statistic should also be used to test H_0. The example in Figure I-1 contains ten samples. The Kolmogorov-Smirnov (K-S) critical value for ten samples and α = .05

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SPSS -- STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES

VERSION 8.0 -- JUNE 18, 1979


RUN NAME        K-S SLAM WIND VARIANCE VALIDATION
VARIABLE LIST   X
N OF CASES      10
INPUT FORMAT    FREEFIELD
NPAR TESTS      K-S(NORMAL,.9,.16)=X
READ INPUT DATA

GIVEN 1 VARIABLES, INITIAL CM ALLOWS FOR  1736 CASES
                   MAXIMUM CM ALLOWS FOR 11336 CASES

1K-S SLAM WIND VARIANCE VALIDATION

FILE NONAME (CREATION DATE = 02/26/81)

-- KOLMOGOROV - SMIRNOV GOODNESS OF FIT TEST

TEST. DIST. - NORMAL (MEAN = .9000 STD. DEV. = .1600)

    CASES       MAX(ABS DIFF)      MAX(+ DIFF)      MAX(- DIFF)
      10            .2368             .1599            -.2368


    K-S Z       2-TAILED P
     .749           .629
```

Fig. I-1. SLAM Wind Variance Validation; SPSS Program and Results; Kolmogorov-Smirnov Test

(Ref. Shannon, Systems Simulation: The Art and Science, Prentice-Hall, 1975) is 0.410. The critical value for ten samples, α = .05 from Lilliefors (1967) is 0.258. Since our largest deviation was .2368, we do not reject the H_0 and the wind distribution is validated under with the K-S and Lilliefors criteria.

The second stage of verification consisted of ensuring the internal mechanical operations of the SLAM model were functioning as designed. To accomplish this the SLAM Output Trace (see Appendix G) was completely analyzed for mechanical verification. The items verified were the time, distance, and the fuel calculations in the user functions and the network portion of the model. The mechanical verification of the ASSIGN nodes was accomplished for each node. For example, in ASB (see Appendix K for SLAM description) (Yokota Scenario--C-141/KC-135) the C-141 cruise to rendezvous point fuel consumption is computed in USERF 13 as 19,300 lbs. and this fuel is added to ATRIB(4), airlifter total fuel consumption. Looking at a SLAM Trace (see Appendix G), ATRIB(4)'s value prior to the completion of node ASB was 11,280 lbs which represented fuel consumption up to that point. Upon departing node ASB, ATRIB(4) equalled 30, 650 lbs (11,280 + 1,936) which was determined to be correct. Throughout the SLAM model each node was verified in this way to insure the results were mathematically and functionally correct.

The second stage of internal mechanical verification was the verification that the SLAM discrete event simulation was providing the SLAM network model with the proper input information. This was easily verified by assigning SLAM input parameters, such as aircraft ramp fuel and takeoff times, calculated by the analytical model, to global variables in the discrete part of the SLAM model, node EVENT 1. These input values are then made to print out on the SLAM Trace as they are used in the user functions. The agreement between the input values assigned to global variables and those used in the user functions was 100 percent. Therefore, this verified that the SLAM network model was indeed using the proper input parameters defined at the start of the simulation. By verifying the SLAM network input parameters by this method, validation of the input values themselves was not necessary; only the verification that they were transferred correctly to the user functions as required was necessary. Since these SLAM input parameters have been previously validated in the analytical model, it can be said with confidence that the input parameters for SLAM are not only verified but also validated.

By insuring that the internal mechanical function of the model is correct, a significant degree of confidence is built up in the model. If the model could then be shown to predict flight plan fuel consumptions correctly, then validation of the SLAM model is completed.

To validate the SLAM model, the input parameters computed for the analytical model, which have already been validated against real world data, were used to manually compute total fuel consumed for each aircraft. This was done for each aircraft combination and each scenario. The fuel consumption figures using SLAM compared to manual computations are shown in Table 4. As can be seen, the total aircraft fuel consumption SLAM figures are within 7 percent of the manual computations. These reassuring results increase the validity of the SLAM model.

The verification and validation resulted in increasing confidence in the SLAM model. When the analytical model verification and validation processes are included the models have been validated to the point where experimental data can be obtained and used with confidence over a varying range of input parameters.

The final validation of FLTPLN was accomplished using the SLAM model. The FLTPLN output (fuel loads, distances, takeoff times, etc.) was entered as SLAM input parameters and SLAM output (total fuel consumption per aircraft). Figures 3 - 6 show the percent deviation of the SLAM fuel consumption mean compared to the analytical model fuel consumption value. A negative value means that the SLAM model used less fuel than the analytical model and a positive value means the SLAM model consumed more fuel.

The specific SLAM results are discussed in conjunction with Tables L-1 to L-4 by aircraft. Generally,

the SLAM results for all aircraft and cargo loads compare favorably with the analytical results, which indicates that the analytical data is realistic and can be used with confidence. Overall, the tankers burned about 1 percent less fuel in the SLAM model than in the analytical model. Conversely, the airlifters burned about 2.5 percent more fuel in the SLAM model than in the analytical model. This difference in airlift fuel can be explained from the nature of the two aircraft missions. The tanker flies to a rendezvous point and returns to his departure base which is relatively close compared to the airlifter destination; the airlifter, however flies to the rendezvous points and then continues on to his destination which is thousands of miles farther than the tanker route of flight. Consequently, the airlifter has more time to be affected by increases in the wind factor, and these increases plus any delay fuel consumption would cause the increased fuel requirement. There are two reasons the tanker SLAM results are less than the analytical consumption. The first is that an increase in wind factor has less effect on the tanker than on the airlifter. The headwind increase to the rendezvous point becomes a tailwind increase when returning to destination. The second is the difference in the loiter fuel computations. In FLTPLN the tanker loiter fuel is always based on a fifteen-minute loiter duration; however, in SLAM, the loiter time is based on actual

aircraft arrivals which usually requires less than fifteen minutes loiter time. For the tankers, fifteen minutes loiter fuel is more than the difference between SLAM and FLTPLN fuel values.

The final validation of the model is subjective and consisted of asking the question, "Does the output data make sense?" Speaking as a MAC pilot and navigator, the output fuel consumptions do make sense. As distance between the departure and destination bases increases, the total fuel consumption also increases. In the case of the tanker, as the distance from the departure base to the rendezvous entry point increases, total tanker fuel consumption also increases. As the cargo decreases on the airlifter, the total fuel consumption decreases for each airlifter in each instance. Also, for a route segment with a tail wind, fuel consumption decreases compared to a comparable route segment with a head wind. All of these general observations from the data make sense to an operational pilot or navigator and none of them is counter-intuitive. The result of these general observations by professional aircrew is that the model validity is increased and will help reassure a future decision maker or user of the completeness of the research and the validity of the results. By obtaining reasonable results, user concerns about the details of the model or the methodology are minimized.

Appendix J

Confidence Intervals

This appendix explains the methodology used to calculate the 95 percent confidence intervals portrayed in Tables L-1 to L-4, Appendix L, and provides a sample calculation.

A. The results of the SLAM model replications for a particular mission scenario, aircraft combination, and cargo load were combined to obtain a sample mean. However, since they are only estimates, a confidence interval surrounding the mean is a means of indicating the accuracy of the results compared to the true population mean. Given the sample mean ($\bar{x}$), the sample size (n), and the sample standard deviation (s), a confidence interval can be created using the t statistic. From the confidence interval, with an upper and lower boundary, it can be said that the probability of the mean being between the upper and lower limits is equal to probability: $1 - \alpha$. Alpha (α) is defined as .05, hence a 95 percent confidence interval will be created. If normality is assumed (see Part B for normality validation of fuel consumption data) a confidence interval can be estimated using:

$$P\ (LL \leq \mu \leq UL) = 1 - \alpha = 1 - .05 = 0.95$$

where,

$$LL = \bar{x} - t_{crit} * s\ /\sqrt{n-1}\ ;$$

$$UL = \bar{x} - t_{crit} * s/\sqrt{n-1}\ ;$$

t_{crit} = critical values of t for n-1 degrees of freedom; and

α = .05.

and where,

LL = lower limit;

UL = upper limit;

$\bar{x}$ = sample mean;

s = sample standard deviation; and

n = sample size.

From Hines and Montgomery (1972):

t_{crit} = 2.26 for a sample size of 10 with 9 degrees of freedom.

Therefore, the confidence interval for a KC-135 departing McGuire, refueling a C-141B with 55,000 pounds of cargo with 10 samples is:

SLAM Mean ($\bar{x}$) = 90,840 lbs.

Sample Standard Deviation (s) = 1,690 lbs.

$$t_{crit} * s/\sqrt{n-1} = \frac{(2.26)(1.69)(1000)}{\sqrt{10-1}} = 1,270 \text{ lbs.}$$

$$\bar{x} + t_{crit} * s/\sqrt{n-1} = 90,840 + 1270 = 92,110 \text{ lbs.}$$

$$\bar{x} - t_{crit} * s/\sqrt{n-1} = 89,570$$

Therefore, the confidence interval is:

$$P(89570 \leq \mu \leq 92,110) = .95$$

B. Normality Verification. To compute a confidence interval using the sample t statistic as in Part A of this appendix, normality must be assumed. Using the K-S Test, using Lilliefors' Statistic, normality will be validated for the SLAM output. Figure J-1 is the SPSS Program and results for a SLAM run (C-141B / KC-135, tanker base is McGuire AFB, cargo load is 55,000 lbs). For the KC-135 the largest deviation was .2368; since this is not larger than the Lilliefors critical value of .258 ($n = 10$, $\alpha = .05$) the H_0 that, "There is no significant difference between the data and a normal distribution," cannot be rejected. Therefore, normality can be assumed for the SLAM output and the t statistic can be used to create a 95 percent confidence interval.

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VERSION 8.0 -- JUNE 18, 1979


RUN NAME        K-S SLAM KC-135 NORMALITY VALIDATION
VARIABLE LIST   X
N OF CASES      10
INPUT FORMAT    FREEFIELD
NPAR TESTS      K-S(NORMAL)=X
READ INPUT DATA

GIVEN 1 VARIABLES, INITIAL CM ALLOWS FOR  1736 CASES
                   MAXIMUM CM ALLOWS FOR 11336 CASES

1K-S SLAM KC-135 NORMALITY VALIDATION

FILE NONAME (CREATION DATE = 02/26/81)

-- KOLMOGOROV - SMIRNOV GOODNESS OF FIT TEST


TEST DIST. - NORMAL (MEAN = 90.8400 STD. DEV. = 1.6959)

    CASES      MAX(ABS DIFF)      MAX(+ DIFF)      MAX(- DIFF)

      10           .2294              .1402           -.2294


    K-S Z      2-TAILED P

     .725          .669
```

Fig. J-1. SLAM Output Normality Validation; SPSS Program and Results; Kolmogorov-Smirnov Test

Appendix K

Model Description

The experimental model consists of two models, an analytical model and a SLAM model. This appendix provides a detailed description of both models.

"FLTPLN" is a FORTRAN model which computed the minimum fuel required to operate an airlifter and tanker aircraft through the optimal rendezvous point for a specific scenario. Inputs to the program are:

1. The aircraft combination.
2. The airlift cargo weight.
3. The average wind for the scenario.
4. The geographic locations of the departure, destination, and abort bases.

The program outputs include:

1. The coordinates of the optimal rendezvous point.
2. The total fuel and all route segment fuels.
3. The takeoff fuel loads for both aircraft.

Additional parameters which are generated and used as inputs to the SLAM simulation will be described later in this appendix.

"FLTPLN" is the executive program calling several subroutines to accomplish the flight planning computations. The FLYME set of subroutines provides the fuel data base

for all calculations. The FORTRAN source code for FLTPLN is listed in Appendix C.

The "FLTPLN" program begins by computing the maximum allowable fuel loads. This forms one boundary of the region of feasible rendezvous points. A geographic point on this boundary is defined as the rendezvous exit point. A second point, 250 NM closer to the airlifter departure base, is defined as the rendezvous entry point. These two points define the rendezvous track. If the exit point is within 400 NM of the airlifter departure base the entry point is redefined at the distance flown by the airlifter in initial climbout. Rendezvous is then planned when 25,000 feet is first reached. The exit point is redefined 250 NM downtrack. These rendezvous points fall along the Great Circle course between the airlifter's departure and destination bases. Subroutine RHOTHTA returns this course and distance from the equation:

$$\theta = \cos^{-1}\left[\frac{\text{SIN(LAT2)} - \text{SIN(LAT1)} * \text{COS(D)}}{\text{SIN(D)} * \text{COS(LAT1)}}\right]$$

where,

θ = the Great Circle course;

LAT1 = the latitude of the first point;

LAT2 = the latitude of the second point; and

D = the distance between these points computed from the equation:

$$D = \cos^{-1}\left[\sin(LAT1) * \sin(LAT2) + \cos(LAT1) * \cos(LAT2) * \cos(LONG2-LONG1)\right]$$

where,

LONG1 = the longitude of the first point; and

LONG2 = the longitude of the second point.

The geographic coordinates of these points are computed in subroutine LATLONG by the equations:

$$LAT3 = \sin^{-1}\left[\sin(LAT1) * \cos(D) + \cos(LAT1) * \sin(D) * \cos(\theta)\right]$$

$$LONG3 = LONG1 + \cos^{-1}\left[\frac{(\cos(D)-\sin(LAT1) * \sin(LAT2)}{\cos(LAT1)\cos(LAT2)}\right]$$

All angles used in these equations are computed in radians with the following relationships:

1. One degree of latitude = 60 nautical miles (NM).
2. One radian = 57.2957 degrees.

The fuels for the individual route segments between the coordinates are computed using the equation:

FUEL = DISTANCE/GROUNDSPEED * FUEL RATE

where the distance is obtained from subroutine RHOTHTA, the fuel rate is obtained from the subroutine FLYME data base, and ground speed is obtained from the statement function of the wind triangle equation:

$$\text{GROUND SPEED} = TAS * \cos(\sin^{-1}(WV/TAS*\sin(WL-TC)))$$
$$- WV * \cos(WD*TC)$$

where TAS is the aircraft true airspeed for a given cruise mach number at the cruise altitude and is computed in subroutine TASP, WD is the wind direction, WV is the wind velocity, and TC is the rumbline course between the points computed in subroutine RHOTHTA. The wind is held constant throughout this study at 260° at 55 KNOTS. The fuels for eight route segments are computed in the following order:

1. Airlifter rendezvous exit to destination.
2. Airlifter departure to rendezvous entry.
3. Airlifter rendezvous entry to departure base for abort.
4. Airlifter rendezvous entry to alternate base for abort.
5. Airlifter rendezvous track.
6. Tanker rendezvous exit to recovery base.
7. Tanker rendezvous track.
8. Tanker departure to rendezvous entry.

The fuels are computed in the reverse order from which they are flown so that fuel loads determined for each route segment are the minimum feasible to accomplish the remainder of the flight. The fuel rate returned by subroutine FLYME is dependent on the cruise altitude and gross weight of the aircraft. A step climb profile is approximated by computing the fuel rate at the average gross weight and

altitude for the route segment. These average values are obtained by estimating half of the fuel to be used. The fuel computations are repeated until the fuel rate represents the average for the route segment. Experimentation with this process determined that the fuels converged to within 1000 pounds at the second iteration, 50 pounds at the third, and 2 pounds by the fourth. Three iterations were selected for the averaging process.

Climb profiles are computed for the initial departure segments up to cruise altitude and the post-rendezvous segments from 25,000 feet to the cruise altitude. The climb time, range, and fuel consumed are returned from FLYME and added to their corresponding components in the fuel computations. The initial takeoff fuel load for the airlifter is the maximum allowable for the specified cargo load. The fuel to be transferred from the tanker is the difference between the airlifter's total fuel requirements and its takeoff fuel. The tanker's takeoff fuel load is computed as its total fuel requirements plus the transfer fuel. All aircraft maintain a fuel reserve to accomplish holding, flight to an alternate, and landing after the final cruise segment. This reserve is 30,000 lbs for the C-5A and KC-10 and 15,000 lbs for the C-141 and KC-135.

After each fuel computation, the fuel load is checked for feasibility against the current maximum fuel capacity. Both aircraft must maintain sufficient fuel to

abort to the departure base or, for the airlifter, to the alternate base, if the alternate is closer than the departure base. If the required fuel load is feasible, the sum of the route segment fuels, not including the abort fuels is stored as a matrix data point. If infeasible, the value 777.777 is stored in the matrix.

Next, the coordinates of the rendezvous exit point are adjusted in five degree increments north or south, whichever is closer to the direction of the tanker base and the entire routine is recomputed. Five latitude values covering twenty degrees are used. The latitude is then reset at the initial value and the longitude is adjusted in two degree increments towards the airlifter destination. The five values of latitude are repeated for each of the thirteen values of longitude covering twenty-four degrees. The 5 x 13 matrix of total fuel values is sorted and the minimum value from the sixty-five points is selected as the output variable. The fuel loads for both aircraft for this point are increased by the respective start, taxi, and takeoff constant and these values represent ramp fuel onloads and are listed along with the planned transfer fuel.

At this point, the airlifter takeoff fuel load is decremented by 20,000 pounds generating matrices for ten values of the fuel load. Only matrices which contain at least one feasible value are printed and if no feasible values are computed, the statement "NO FEASIBLE SOLUTION"

is printed. The minimum values for each matrix are sorted and the overall minimum fuel is printed for this specific scenario, cargo load, and aircraft combination.

The initial cargo weight for each airlifter is the maximum allowable cargo defined by operational or performance limitations. Two additional cargo weights are considered. One weight is the lowest that could be expected if the airlifter were filled with bulky, lightweight cargo, and the other is the mean of the maximum weight and the minimum expected weight. For the C-5A, these weights are 100,000, 85,000, and 70,000 lbs. For the C-141B, the cargo weights are 70,000, 55,000, and 40,000 lbs. Three separate runs are iteratively made at these cargo weights for a specific airlifter and tanker combination. Since data was desired from all four aircraft combinations, for a specific scenario, the combinations are changed within the FLTPLN program. The combinations are listed in Table 1. Thus, only the specific scenario must be changed to obtain data for all four aircraft combinations at the six desired cargo weights.

The SLAM model was used to verify the analytical solution with the addition of two stochastic variables, winds and takeoff delays. The SLAM model also determines the flight times for each aircraft. The model follows the mission profile shown in Figure K-1 and conforms to the flight planning segments discussed in Chapter II. Figure K-2 is the SLAM network description of the model.

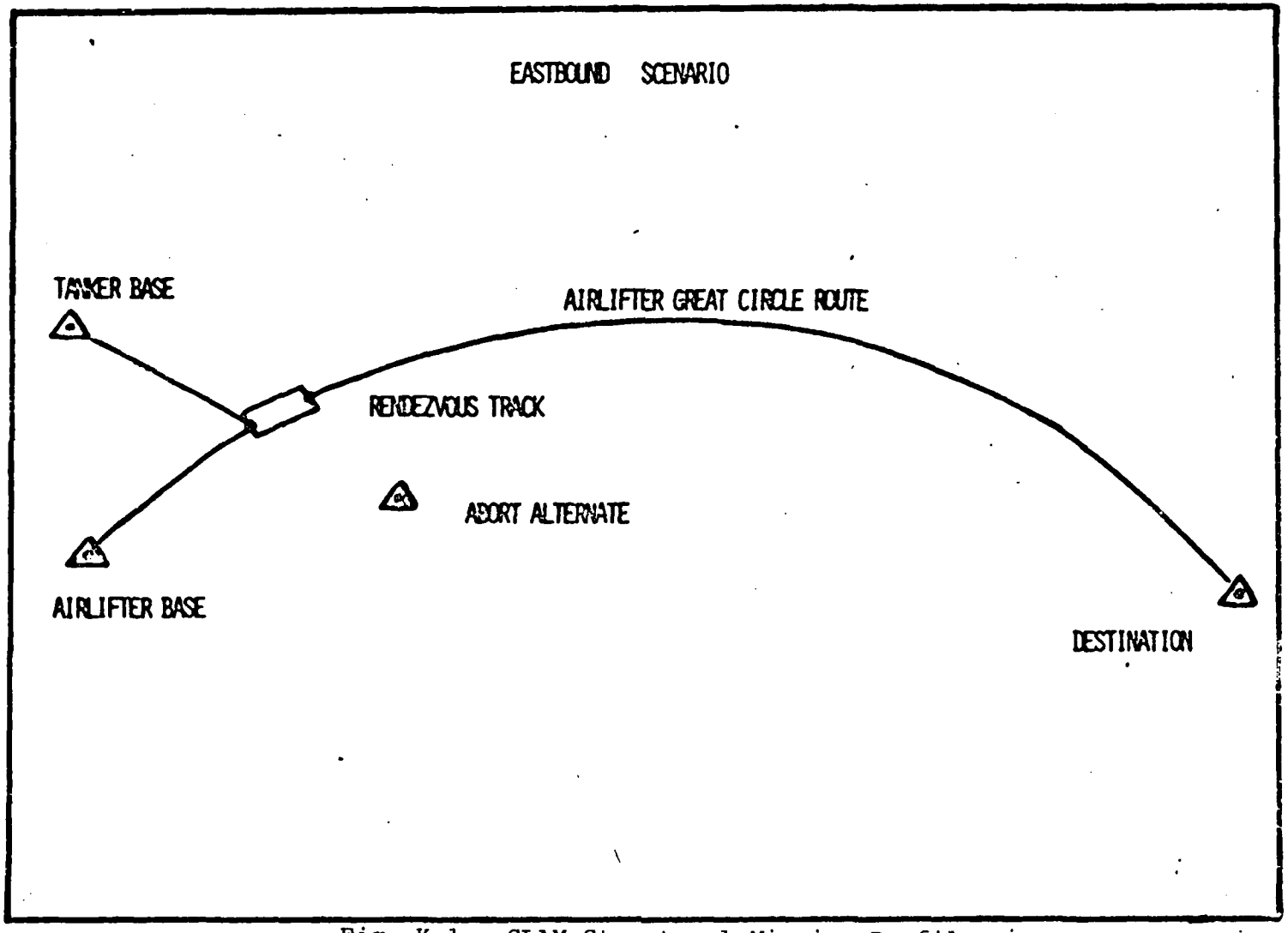


Fig. K-1. SLAM Structural Mission Profile

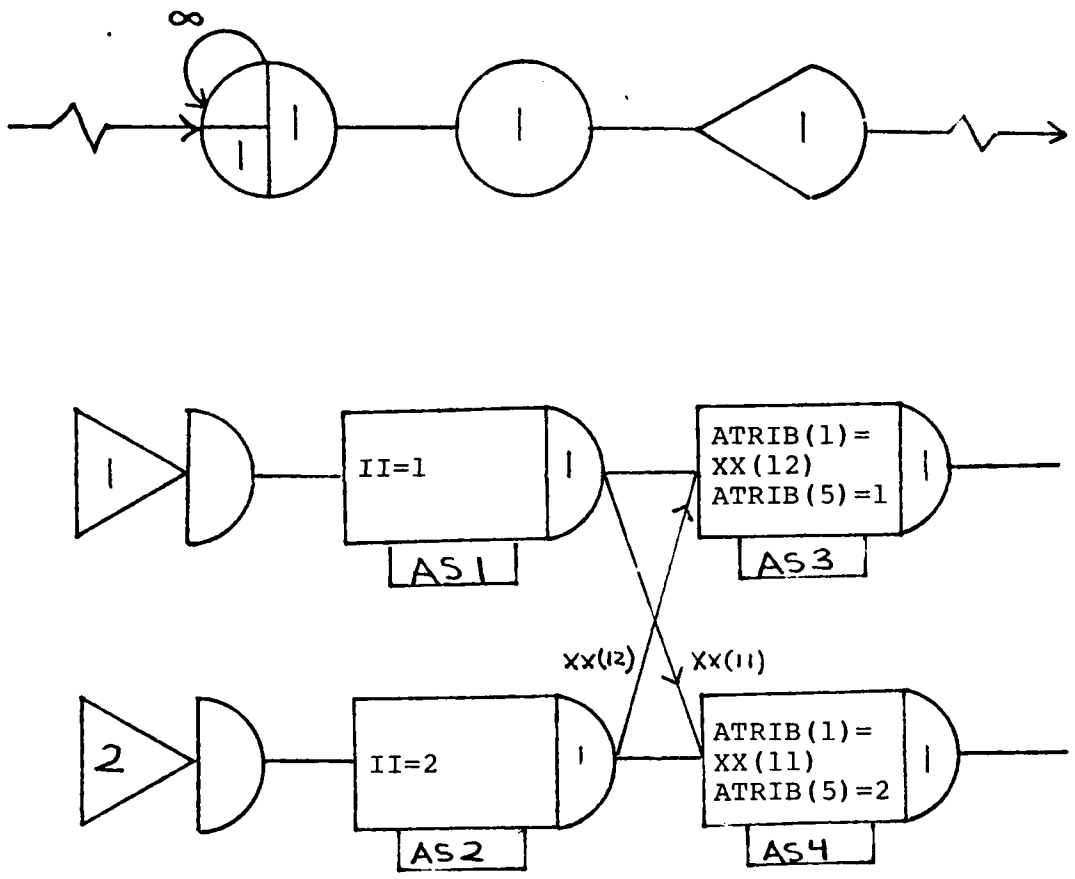


Fig. K-2. SLAM Network

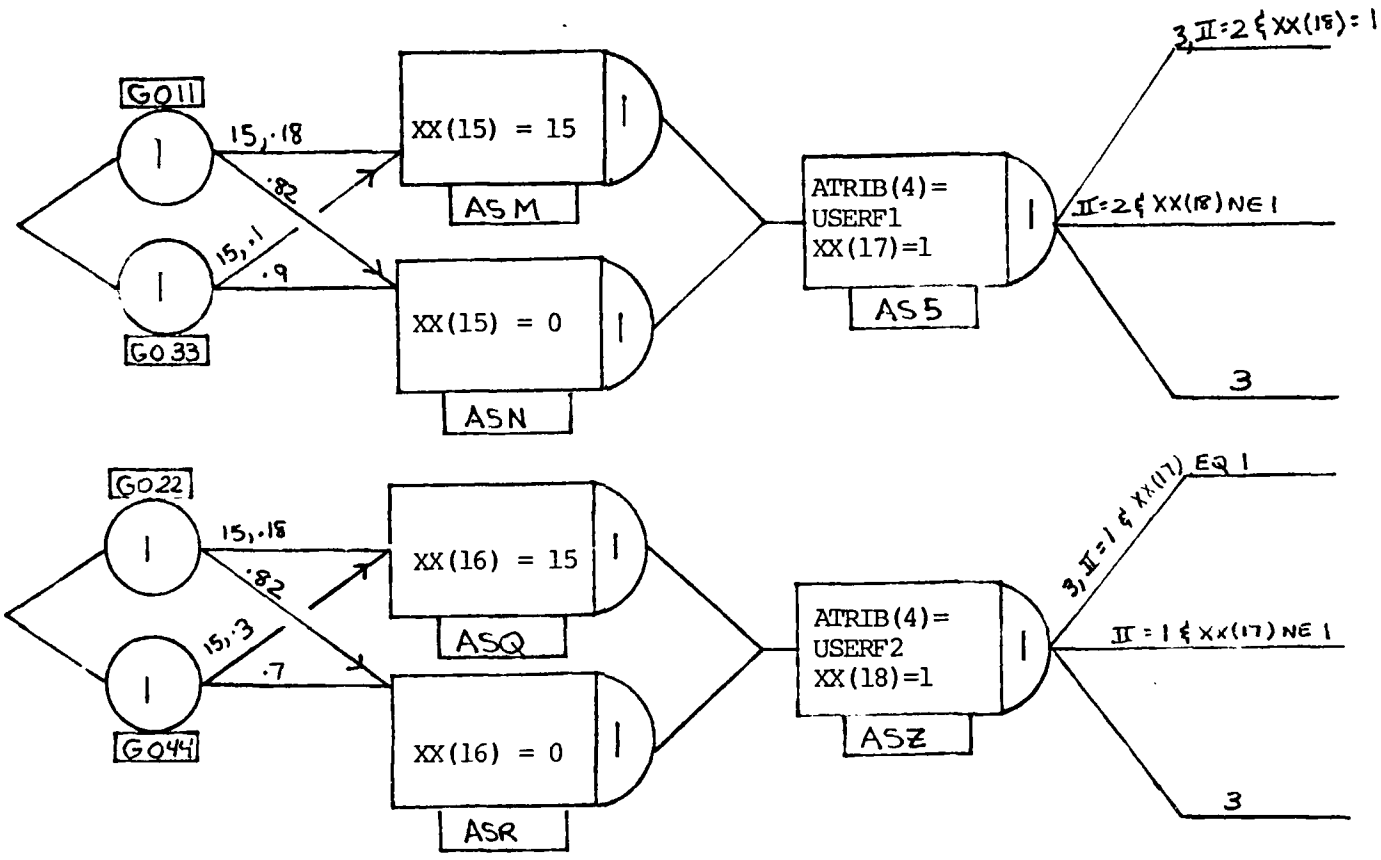


Fig. K-2--Continued

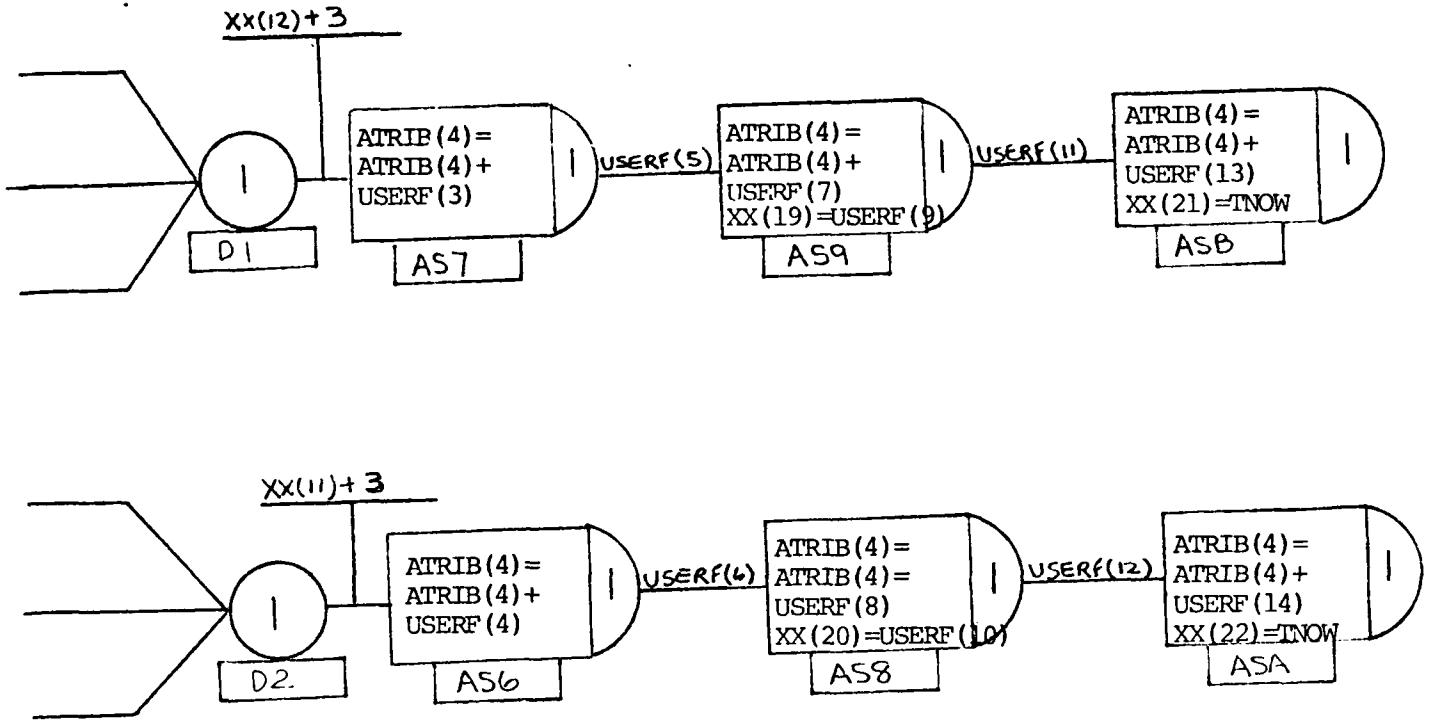


Fig. K-2--Continued

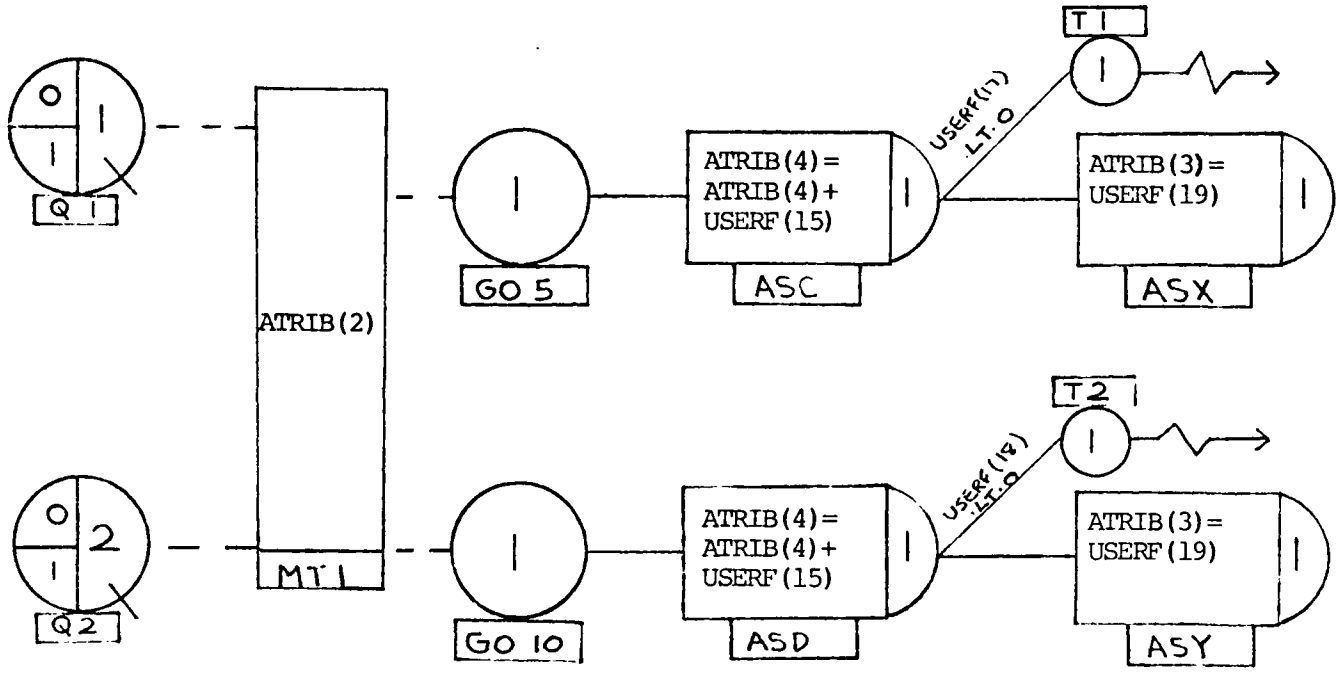
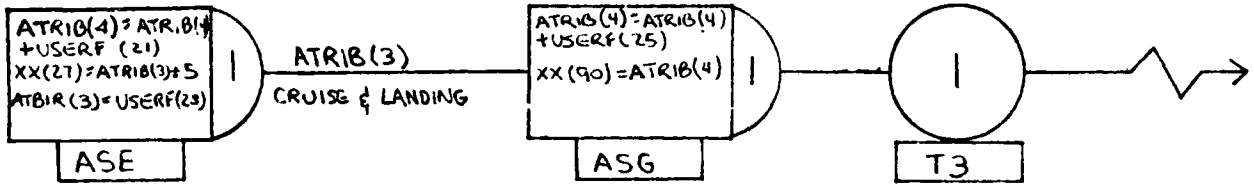


Fig. K-2--Continued



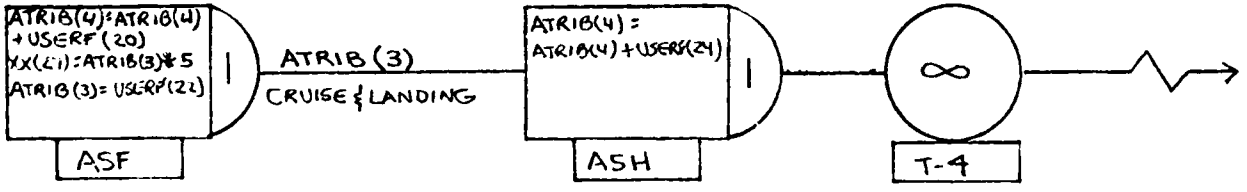
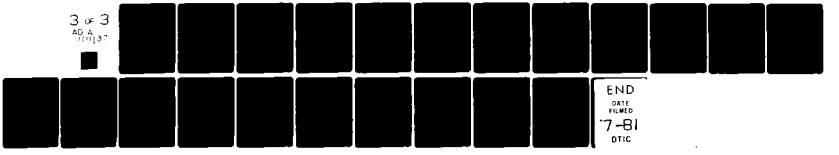


Fig. K-2--Continued

AD-A101 137 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/G 1/2
OPTIMIZATION OF STRATEGIC AIRLIFT IN-FLIGHT REFUELING.(U)
MAR 81 V P BORDELON, J C MARCOTTE
UNCLASSIFIED AFIT/GST/OS/81M-3 NL



See Appendix D for a description of SLAM symbols and concepts. The model uses a combination discrete event-network orientation to simulate the aircraft's flight and consists of two parallel networks representing the flights of the tanker and airlift aircraft. The output variable and measure of effectiveness is fuel consumed by the tanker and airlifter. Only the airlift network is described here and it is broken down into the segments of Figure K-1. However, differences in the tanker network will be noted. An in-depth nodal description follows the general description.

General Description

The SLAM model receives some of the input parameters shown in Figures K-3 and K-4 by calling the flight plan analytic model (FLTPLN). The global variables (XX(i)) contain the initial conditions and other pertinent data. Attributes 1-5 are used as shown in Table K-1.

The first segment of the model represents the start, taxi, and takeoff phase (node AS1 to AS7 for the airlifter and AS2 to AS6 for the tanker). Delays can be incurred by each aircraft. A logic sequence (AS5 to AS7 for the airlifter) prevents the second aircraft from departing until the first scheduled aircraft has departed.

The second segment of the model represents the initial climb from the base to the cruise altitude and the cruise to the rendezvous entry point (AS7 to ASX for the airlifter and AS6 to ASY for the tanker). Included in this

XX(1) = Airlift departure to rendezvous entry point distance.

XX(2) = Airlifter rendezvous exit point to destination point.

XX(3) = Airlifter rendezvous entry point to abort base distance.

XX(4) = Tanker departure to rendezvous entry point distance.

XX(5) = Tanker rendezvous exit point to destination.

XX(6) = Transfer fuel.

XX(7) = Initial fuel load--tanker.

XX(8) = Initial fuel load--airlifter.

XX(9) = Gross weight of the tanker at time (t).

XX(10) = Gross weight of the airlifter at time (t).

XX(11) = Tanker takeoff time.

XX(12) = Airlifter takeoff time.

XX(13) = Aircraft code:

C-5/KC-135 = 1
C-141B/KC-135 = 2
C-5/KC-10 = 3
C-141B/KC-10 = 4

XX(15) = Airlifter takeoff delay.

XX(16) = Tanker takeoff delay.

XX(19) = Initial climb distance airlifter.

XX(20) = Initial climb distance tanker.

XX(21) = Arrival time of airlifter at rendezvous entry point (Q1).

XX(22) = Arrival time of tanker at rendezvous entry point (Q2).

Fig. K-3. Global SLAM Variables

XX(23) = Airlifter fuel consumption from rendezvous entry point to abort base.

XX(24) = Tanker fuel consumption from rendezvous entry point to abort base.

XX(27) = Distance traveled in the refueling track.

XX(31) = Airlifter departure base elevation.

XX(32) = Airlifter initial cruise altitude.

XX(28) = Time required in the refueling track

XX(33) = Airlifter cruise time from leveloff to rendezvous point.

XX(35) = Airlifter initial climb fuel.

XX(40) = Tanker initial climb fuel.

XX(41) = Tanker departure base elevation.

XX(42) = Tanker initial cruise altitude.

XX(45) = Airlifter destination fuel reserves.

XX(46) = Tanker destination fuel reserves.

XX(60) = Tanker post-rendezvous climb fuel.

XX(61) = Airlifter post-rendezvous climb fuel.

XX(62) = Tanker rendezvous exit point to destination time.

XX(63) = Airlifter rendezvous exit point to destination time.

XX(71) = Airlifter cruise altitude to destination.

XX(73) = Airlifter average cruise altitude to destination.

XX(75) = Airlifter ramp fuel.

XX(76) = Tanker ramp fuel.

XX(81) = True course for leg 1.

XX(82) = True course for leg 2.

Fig. K-3--Continued

XX(83) = True course for leg 3.

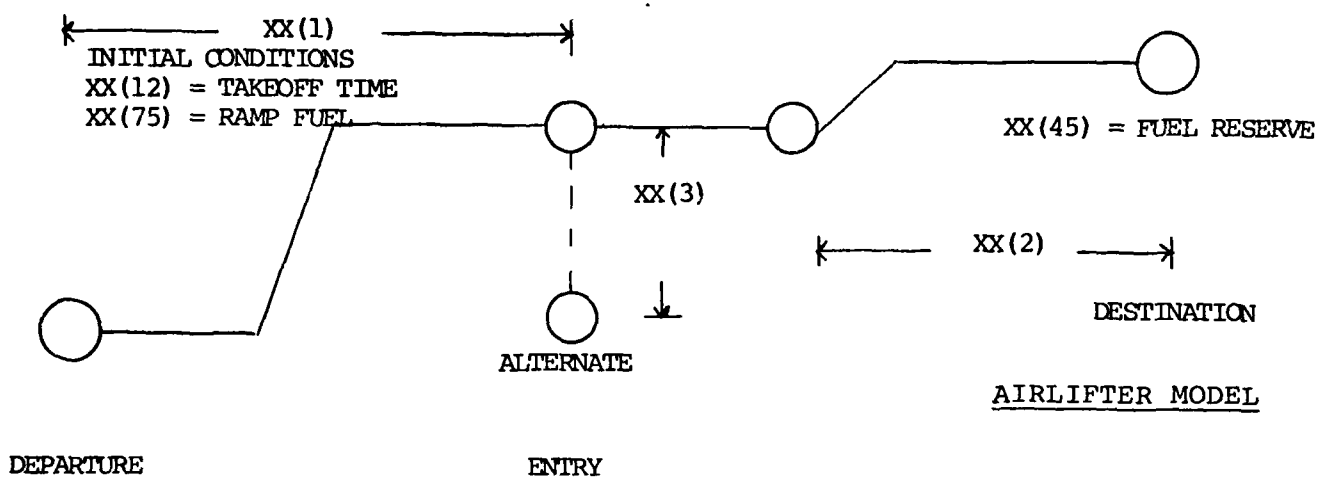
XX(84) = True course for leg 4.

XX(85) = True course for leg 5.

XX(94) = Zero fuel weight of the airlifter.

XX(95) = Zero fuel weight of the tanker.

Fig. K-3--Continued



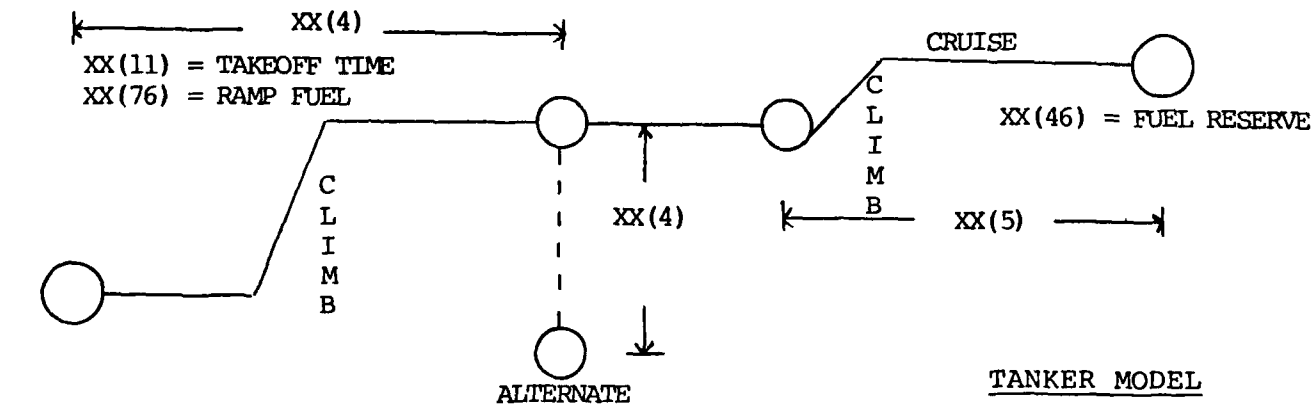


Fig. K-4. SLAM Structural Mission Profile

TABLE K-1

SLAM ATTRIBUTES SUMMARY

ATRIB(i)	Description
(1)	Aircraft takeoff time
(2)	Aircraft combination code
(3)	Cruise time
(4)	Cumulative fuel consumed for a particular aircraft
(5)	Aircraft identifier 1 = Airlifter 2 = Tanker

NOTE: Attributes are numerical characteristics assigned to entities (aircraft) traveling through the network simulation model. These attributes travel with a specific aircraft and are unique to that aircraft. This table shows the attributes used in the SLAM model.

segment are fuel consumption calculations for climb, cruise, and loiter times. The loiter time is the time difference between the arrival of the second and first aircraft at the rendezvous point (Q1 and Q2). The aircraft fuel supply must be sufficient to return from the rendezvous point to a suitable abort base, if the refueling is aborted.

The third segment (ASX to ASE for the airlifter and ASY to ASF for the tanker) represents the refueling maneuver and calculates the time and fuel consumed during the fuel transfer.

The fourth segment (ASE to T3 for the airlifter and ASF to T4 for the tanker) represents the route segment from

the rendezvous exit point to landing. Included in these segments are time and fuel calculations for post-rendezvous climbout, cruise to destination, and approach and landing. At the terminal nodes, T3 and T4, the total fuel consumed respectively by the airlifter and tanker aircraft are printed.

Nodal Description

This section describes the mission profiles through the SLAM model node by node. The discrete flight planning model provides takeoff times for the airlifter and tanker and calls the aircraft network model. (Appendix E is the SLAM computer code.) A logical IF statement in subroutine FLTPLN will call the ENTER1 or ENTER2 node depending on which aircraft takes off first. For simultaneous takeoffs, only one ENTER node will be called so multiple aircraft are not generated. The ENTER node simulates engine start for the first aircraft. If the airlifter takes off first, the ENTER1 node is entered and the next node (AS1) assigns the value of one to global variable II, indicating the airlifter should take off first. II is assigned a value of two in the tanker network if the tanker is scheduled to take off first.

The next event consists of two regular activities, one continues the airlifter to takeoff and one initiates the tanker engine start sequence. The activity from AS1 to AS3 involves no time and at AS3 assigns ATRIB(5) equal

to the aircraft code to facilitate reading the SLAM Output Trace. The second activity leading from AS1 occurs with a completion time from XX(11) which is the takeoff time difference between aircraft. In this way each aircraft is assured of completing the takeoff sequence at the correct time.

The next section models takeoff delays encountered. The fifteen minutes activity from AS3 to either GO11 or GO33 simulates the time for start, taxi, and takeoff. This is a standard value used in flight planning. The decision to go to GO11 or GO33 is based upon the aircraft code in ATRIB(2). If the aircraft is a C-5 the aircraft will delay in accordance with the network following GO11; if the aircraft is a C-141B the aircraft will delay through GO33. If a delay in the scheduled takeoff time for the first aircraft occurs, the second aircraft will remain grounded until the first aircraft is repaired or the mission is cancelled. Stops to prevent the second scheduled aircraft taking off prior to the first are discussed later. The delay occurs probabilistically and always for fifteen minutes. Those delays which do not burn fuel are not modeled. Once the airlift delay is determined, it is assigned to global variable XX(15) which will be used in future fuel computations.

The next segment computes the fuel used in the start, taxi, and takeoff event including the delays.

ATRIB(4) is used as a fuel accumulator for each aircraft. It is initially set at zero and all fuel consumed is added to ATRIB(4) as it is calculated. AS5 calculates the fuel consumed up to that point by calling user function one which assigns the start, taxi, takeoff fuel for the airlifter and calculates the amount of fuel used in any delays. See Appendix F for user function descriptions. AS5 also assigns the value of "one" to XX(17) which will be used in determining takeoff sequences.

To determine when to actually launch the second aircraft, the activity network emanating from AS5 checks three questions in this order:

1. Has the tanker taken off first?

2. Should the tanker take off first and is he delayed?

3. Should the airlifter take off first?

If the first answer is yes, the airlifter takes off and travels to node AS7. If the answer is no and the second answer is yes, the tanker was delayed and the airlifter must also delay to provide the correct takeoff separation between the two aircraft. The airlifter will stay grounded until the tanker is airborne plus the original takeoff time difference. This is accomplished by adding the original takeoff separation to the actual time the first scheduled aircraft departs. If the second answer is no, the third answer is yes and the airlifter departs first. The takeoff maneuver is modeled as three minutes

(brake release to landing gear retraction). The SLAM model uses a conditional take first logic on the three activities, thus allowing only the first "yes" activity to be released. The logic sequence between AS2 and AS6 determines the takeoff time and sequence for the tanker. After the takeoff is accomplished AS7 computes, with USERF3, the takeoff fuel and adds it to ATRIB(4). AS6 performs this function for the tanker.

The next phase of the flight is the initial climb to altitude. The airlift climb time is computed in USERF5. AS9 then calculates the climb fuel and climb distance using USERF7 and USERF9 respectively. USERF8 and 10 calculates the values for the tanker. The climb fuel is added to ATRIB(4) in AS9 for the airlifter and in AS8 for the tanker.

The next phase of flight is the cruise from level-off to the rendezvous entry point. The cruise time for the airlifter is computed in USERF11 and for the tanker, USERF12 is used. ASB computes cruise fuel to the entry point (Q1), adds it to ATRIB(4) and sets XX(21) equal to the entry point arrival time. XX(21) will be used to determine aircraft loiter time. If the tanker arrives first it will hold at Q2.

The next event is the rendezvous maneuver and refueling. The maneuver begins with the arrival of the second aircraft at the rendezvous point Q1 or Q2. When the first aircraft arrives at the queue node, it is

prevented from proceeding further by match node, MAT1. The arrival of the second aircraft releases MAT1 and the refueling maneuver begins. Once through the match node, ASC and USERF15 computes the loiter fuel for the airlifter. ASD and USERF16 perform this function for the tanker.

After each aircraft has arrived at the rendezvous point, but before actual refueling occurs, two conditions must be met:

1. Aircraft must be capable of safely returning to a suitable abort base, if hookup is unsuccessful.

2. Aircraft must be able to fly to the destination base with the fuel available after the transfer.

If these conditions are not met, then unexpected fuel consumption due to excessive loiter fuel, delays, or unforeseen wind changes, have made the refueling event infeasible due to a lack of available fuel. Each aircraft will abort to their respective bases. The abort computation is calculated in USERF17 for the airlifter and USERF18 for the tanker. The SLAM model compares the difference between the fuel available and the fuel required to abort. A difference of less than zero, represents an infeasible situation and the simulation stops by aborting the applicable aircraft to terminal node 1 or 2.

If the aircraft meet the feasible criteria, they proceed with the refueling maneuver. Refueling occurs on the refueling track, prearranged in length by subroutine

FLTPLN. The time in the maneuver is identical for each aircraft and calculated by ASX and USERF19 for the airlifter, and ASY and USERF19 for the tanker. Fuel consumed in the rendezvous maneuver is calculated in ASE and ASF for the airlifter and tanker using USERF21 and 20 respectively.

Once the rendezvous is completed each aircraft departs the exit point to their respective destinations. The time to destination is computed by USERF23 and 22 for the airlifter and tanker respectively and assigned to ATRIB(3). The fuel to reach each destination is computed by USERF25 and 24 for the airlifter and tanker respectively and added to the total fuel consumed in ASG and ASH. Approach and landing fuels and fuel reserves are included in these fuel computations. Fuel reserves used are from the flight plan parameters.

When the airlifter and tanker reach their destinations, they pass through their terminal node T-3 (airlifter) and T-4 (tanker). When both terminal nodes are released, the simulation is stopped and the results are displayed in a SLAM Nodal Trace of the simulation from takeoff to landing. Total fuel consumed by each aircraft is obtained from the column labeled attribute four at T3 and T4. Appendix G lists a typical SLAM nodal trace.

Appendix L

FLTPLN and SLAM Summary of Results

This appendix contains four tables of comparisons between SLAM and FLTPLN fuel consumptions. Table L-1 shows these results for the C-5, Table L-2 for the C-141B, Table L-3 for the KC-10, and Table L-4 for the KC-135. The data in each table represents the combined fuel consumption data for all scenarios (McGuire AFB to Tehran, Iran and Travis AFB to Yokota AB, Japan) for a particular aircraft. The SLAM data was obtained using a normal wind factor variant (μ = 55, σ = 10 KNOTS).

In Tables L-1 to L-4 the first column (Tanker Base) lists the tanker departure base. By specifying only the tanker base the scenario is also fully defined since only the east coast tanker bases are used in the Tehran scenario and only the west coast tanker bases are used in the Yokota scenario. The second column (Complementary Aircraft) defines the aircraft combination. The third column (Airlifter Cargo) represents the airlifter cargo load; those missions which were infeasible at a particular cargo weight are marked "Infeas." The fourth column (Analytical Fuel Consumption) represents the total fuel consumption for the applicable aircraft obtained from the analytical model (FLTPLN). The fifth column (SLAM Fuel Consumption) represents the SLAM fuel consumption sample mean. The sixth column (% Dev) represents the percent deviation of the SLAM mean compared to the analytical model value. For

example, the KC-10 fuel consumption, for the Travis-Yokota scenario, refueling the C-141 with a cargo load of 55,000 lbs, was 138,000 lbs. The SLAM mean fuel consumption was 131,200 lbs. The percent deviation is:

$$\left(\frac{131.2}{138.2} - 1.\right) = -5.5\%$$

A negative value means that the SLAM model used less fuel than the analytical model and a positive value means the SLAM model consumed more fuel. The seventh column shows a 95 percent confidence interval as a total fuel consumption range such that the probability of the true SLAM mean being in that interval is 95 percent. Appendix J contains a sample confidence interval calculation. To obtain a confidence interval, normality must be assumed. Kolmogorov-Smirnov Tests of the SLAM data were used to verify normality and Appendix J contains a normality verification sample calculation using the Vogelbach Computing Center's SPSS Kolmogorov-Smirnov Nonparametric One Sample Test. A "yes" in column eight (SLAM Feasible) indicates that the SLAM total mission fuel consumption for the specific aircraft using the upper limit of the confidence interval as the fuel required for a successful mission, was feasible for the particular scenario. The fuel available for the airlifter is the ramp fuel plus the transferred fuel. The fuel available for the tanker aircraft is the ramp fuel minus the transferred fuel. In Figures 3-6 the percent deviation for each aircraft is plotted.

TABLE L-1

C-5--SLAM VERSUS ANALYTICAL FUEL CONSUMPTION RESULTS

Tanker Base	Complementary Aircraft	Airlift Cargo (1000s lb)	FUEL CONSUMPTION Analytical 1000s lb	FUEL CONSUMPTION SLAM 1000s lb	% Dev	95% Confidence Interval	SLAM Feasible IN CI
McGuire	KC-10	100	277.4	278.9	+ .5	272.1 - 285.6	Yes
		70	274.6	272.9	+ .6	264.7 - 281.2	Yes
Loring		100	277.3	291.3	+5.0	284.5 - 298.1	Yes
		70	269.6	268.1	- .6	260.3 - 275.9	Yes
Charleston		100	285.1	291.8	+2.3	284.9 - 298.7	No
		70	277.3	275.9	+ .5	267.7 - 284.2	Yes
Castle		100	300.6	301.8	+ .4	297.8 - 305.8	Yes
		70	297.5	297.1	- .1	293.2 - 301.0	Yes
Fairchild		100	302.2	307.2	+1.7	303.8 - 310.6	Yes
		70	296.4	298.6	+ .7	294.3 - 302.8	Yes
Eielson		100	303.8	316.9	+4.3	313.3 - 320.5	Yes
		70	273.9	288.1	+5.2	284.5 - 291.7	Yes
McGuire	KC-135	100	285.1	287.2	+ .7	283.7 - 290.7	Yes
		70	267.4	275.6	+3.1	267.3 - 283.8	Yes
Loring		100	285.1	287.3	+ .8	280.5 - 294.1	Yes
		70	269.7	269.5	- .1	254.2 - 284.7	Yes
Charleston	Infeas	100					
		70	277.4	275.6	- .6	267.3 - 283.9	Yes
Castle		100	308.2	312.0	+1.2	305.2 - 318.8	No
		70	302.8	301.9	- .3	297.4 - 306.4	No
Fairchild		100	311.6	319.9	+2.7	312.8 - 327.0	Yes
		70	284.8	294.5	+3.4	291.9 - 297.1	Yes
Eielson		100	316.5	328.4	+3.7	325.4 - 331.4	Yes
		70	280.5	291.8	+4.0	289.5 - 294.1	Yes

TABLE L-2

C-141B--SLAM VERSUS ANALYTICAL FUEL CONSUMPTION RESULTS

Tanker Base	Complementary Aircraft	Airlift Cargo (1000s lb)	FUEL CONSUMPTION Analytical 1000s lb	FUEL CONSUMPTION SLAM 1000s lb	% Dev	95% Confidence Interval	SLAM Feasible IN CI
McGuire	KC-10	55	167.5	176.1	+5.1	172.1 - 180.1	Yes
		40	161.5	168.0	+4.0	165.0 - 171.0	Yes
Loring		55	169.5	157.1	-7.3	154.4 - 159.8	Yes
		40	161.5	168.0	+4.0	163.4 - 172.6	Yes
Charleston		55	170.5	178.8	+4.9	174.7 - 182.9	Yes
		40	161.5	168.3	+4.2	163.7 - 172.9	Yes
Castle		55	175.4	189.8	+8.2	187.8 - 191.7	No
		40	169.6	169.3	- .2	164.8 - 173.8	Yes
Fairchild		55	173.1	188.3	+8.8	186.3 - 190.3	No
		40	169.2	181.9	+7.5	179.6 - 184.2	Yes
Eielson		70	184.0	166.3	-9.6	164.7 - 167.9	Yes
		40	168.7	188.4	+11.7	186.5 - 190.2	Yes
McGuire	KC-135	55	169.5	178.5	+5.3	174.5 - 182.5	Yes
		40	168.6	175.8	+4.3	171.2 - 180.4	Yes
Loring		55	169.5	179.5	+5.9	175.5 - 183.5	No
		40	163.5	170.3	+4.2	165.7 - 174.8	Yes
Charleston	Infeas	55					
		40	167.5	175.9	+5.0	171.3 - 180.5	Yes
Castle		55	175.4	192.1	+9.5	190.0 - 194.1	Yes
		40	173.1	183.0	+5.7	180.7 - 185.2	Yes
Fairchild		55	175.7	185.9	+5.8	182.2 - 189.6	No
		40	172.9	177.1	+3.6	174.7 - 179.5	Yes
Eielson		70	184.0	165.8	-9.9	165.1 - 167.5	Yes
		40	167.8	151.4	-9.8	149.7 - 153.1	Yes

TABLE L-3

KC-10--SLAM VERSUS ANALYTICAL FUEL CONSUMPTION RESULTS

Tanker Base	Complementary Aircraft	Airlift Cargo (1000s lb)	FUEL CONSUMPTION Analytical 1000s lb	FUEL CONSUMPTION SLAM 1000s lb	% Dev	95% Confidence Interval	SLAM Feasible IN CI
McGuire	C-5	100	121.1	123.4	+1.9	121.2 - 125.6	Yes
		70	46.2	44.2	-4.3	42.8 - 45.6	Yes
Loring		100	98.3	95.0	-3.4	93.1 - 96.9	Yes
		70	39.0	37.2	-4.6	35.9 - 38.5	Yes
Charleston		100	146.5	153.0	+4.4	150.5 - 155.5	Yes
		70	78.2	76.4	-2.3	74.7 - 78.1	Yes
Castle		100	102.6	102.0	- .6	100.1 - 103.9	Yes
		70	66.3	63.1	-4.8	61.6 - 64.6	Yes
Fairchild		100	85.6	103.7	+21.1	99.1 - 108.2	Yes
		70	72.3	70.1	-3.0	68.7 - 71.4	Yes
Eielson		100	49.3	49.3	0.0	48.5 - 50.1	Yes
		70	50.1	49.5	-1.0	49.0 - 49.9	Yes
McGuire	C-141	55	133.0	137.6	+3.5	136.3 - 138.9	Yes
		40	92.9	94.1	+1.3	92.1 - 96.1	Yes
Loring		55	108.4	111.5	+2.8	110.8 - 112.2	Yes
		40	71.2	71.4	+ .3	69.0 - 73.8	Yes
Charleston		55	162.9	176.1	+8.1	173.2 - 178.9	Yes
		40	125.5	131.1	+4.5	129.4 - 132.8	Yes
Castle		55	138.8	131.2	-5.5	128.9 - 133.4	Yes
		40	102.9	102.4	- .5	98.1 - 106.7	Yes
Fairchild		55	123.6	117.0	-5.3	115.2 - 118.8	Yes
		40	84.9	81.1	-4.5	80.0 - 82.2	Yes
Eielson		70	64.4	59.5	-7.6	51.8 - 67.2	Yes
		40	41.1	41.1	0.0	40.1 - 42.1	Yes

TABLE L-4

KC-135--SLAM VERSUS ANALYTICAL FUEL CONSUMPTION RESULTS

Tanker Base	Complementary Aircraft	Airlift Cargo (1000s lb)	FUEL CONSUMPTION Analytical 1000s lb	FUEL CONSUMPTION SLAM 1000s lb	% Dev	95% Confidence Interval	SLAM Feasible IN CI
McGuire	C-5	100	79.3	78.5	-1.0	77.7 - 79.3	Yes
		70	28.6	27.5	-3.8	26.4 - 28.6	Yes
Loring		100	63.5	61.8	-2.7	60.8 - 62.8	Yes
		70	24.4	22.4	-8.2	21.6 - 23.2	Yes
Charleston	Infeas	100					
		70	47.3	46.6	-1.5	45.5 - 47.7	Yes
Castle		100	67.2	65.8	-2.0	64.7 - 66.9	Yes
		70	40.6	39.6	-2.5	38.4 - 40.8	Yes
Fairchild		100	55.5	50.0	-9.9	48.4 - 51.6	Yes
		70	61.9	61.0	-1.5	59.4 - 62.6	Yes
Eielson		100	36.1	36.2	+ .3	34.4 - 37.9	Yes
		70	37.5	37.4	- .3	36.1 - 38.7	Yes
McGuire	C-141	55	90.2	90.8	+ .7	89.6 - 92.1	Yes
		40	58.1	57.1	- .7	56.7 - 58.7	Yes
Loring		55	69.2	77.1	+11.4	75.8 - 78.3	Yes
		40	48.8	47.8	-2.1	46.9 - 48.7	Yes
Charleston	Infeas	55					
		40	83.1	80.7	-2.9	79.4 - 81.9	Yes
Castle		55	91.4	91.3	- .1	89.5 - 93.0	Yes
		40	63.5	61.9	-2.5	60.3 - 63.5	Yes
Fairchild		55	80.6	79.8	-1.0	78.5 - 81.0	Yes
		40	54.6	53.2	-2.6	51.8 - 54.6	Yes
Eielson		55	43.3	40.5	-6.5	39.2 - 41.7	Yes
		40	30.7	27.9	-9.1	26.8 - 28.9	Yes

Vitas of the Authors

Vernon Paul Bordelon was born on July 23, 1948, in New Orleans, Louisiana, the son of Vernon P. and Frances N. Bordelon, Sr. He graduated from the University of Southwestern Louisiana in May, 1971, with a Bachelor's Degree in Political Science. Upon receiving his commission in the United States Air Force, he attended Undergraduate Navigator Training at Mather AFB, CA. He served as 15th Military Airlift Squadron standardization navigator and 63rd Military Airlift Wing air operations staff officer in the Combat Tactics and Techniques Office at Norton AFB, CA. A tour at 22nd Air Force (MAC) Combat Operations as an air operations staff officer preceding entering the School of Engineering of the Air Force Institute of Technology.

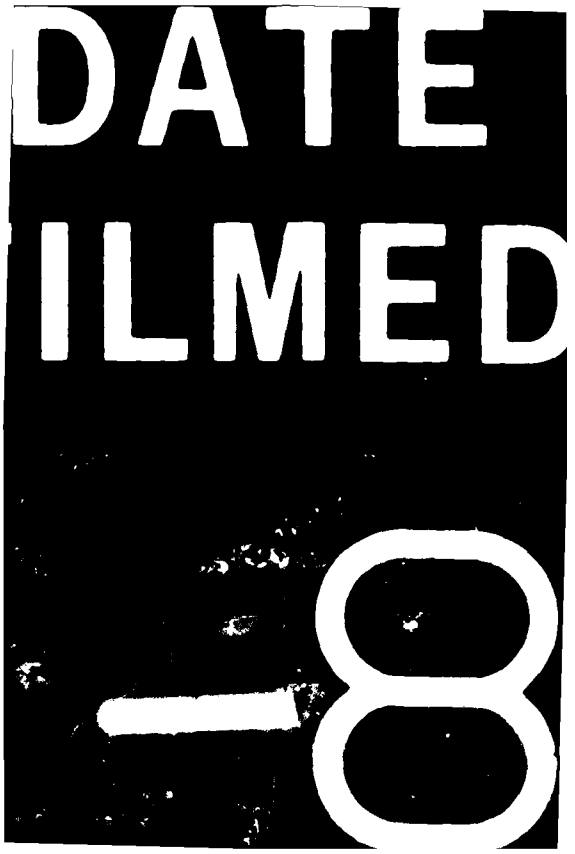
He is married to the former Rebecca Marie Moreau of New Orleans, Louisiana. They have a son, Michael David, and a daughter, Rebecca Kristen.

Permanent Address: 409 Upstream Street
New Orleans, Louisiana

John C. Marcotte, Jr., was born on December 11, 1946, in Camden, NJ, the son of John C. and Virginia L. Marcotte. Upon graduation from Reynolds High School, Troutdale, Oregon, in 1964, he enrolled at Oregon State University, Corvallis, Oregon, from which he received the degree of Bachelor of Science in Mechanical Engineering in June, 1969. Upon graduation he attended Undergraduate Pilot Training at Laredo, Texas, and received his pilot wings in July, 1970. He served at Mather AFB, CA, from July, 1970, to June, 1973, as a T-29 aircraft commander and received a Master's Degree in Business Administration from Golden Gate University, Sacramento, California. Upon graduation he served as the Chief of Contract Programs with the 475th CES, Yokota Air Base, Japan. He served as a C-141A aircraft commander and current operations staff officer with the 63rd MAW, Norton, AFB, CA, until entering the School of Engineering, Air Force Institute of Technology, in August, 1979.

He is married to the former Janis Patricia Bull of Mentor, Ohio. They have two daughters, Monica and Michelle.

Permanent Address: 448 Judy Court
Merced, California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