THE EFFECT OF SCHEDULING ON AIR TRAFFIC DELAY

by

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DEFINITIONS OF TERMS

Airport:	The building, runways, taxiways, and parking facilities which are the center of an air terminal.
Terminal area:	The airspace enclosed by an imaginary circle centered at the airport with radius of approximately forty miles.
Actual terminal:	A terminal which represents one major terminal area in the United States.
"Catch-all" terminal:	A terminal which represents several terminals.
Apron:	The portion of the runway configuration which is used by waiting aircraft.
Gate:	The area at an airport at which aircraft are serviced between flights and where passengers board.
Independent runways:	Runways at the same terminal which may be used simultaneously without any violation of FAA regulations.
Taxi:	The movement of the aircraft while it is on the ground.
Departing:	The status of an aircraft from the time it turns onto the runway to the time it clears the runway.
Landing:	The status of an aircraft between its entry to the glide path and its clearing the runway.
Glide path:	The airspace which extends from a runway in which an aircraft makes its approach to land.
Clearing the runway:	The end of occupancy of the runway and its associated airspace by an aircraft, either on departure or arrival.
Taxiways:	The paved portions of an airport which are used only by taxiing aircraft.
Turnoff:	The paved portions of an airport which are used by aircraft which are clearing the runway on arrival.
Waiting stack:	The aircraft which are waiting to depart or holding to land.

Saturation level:	The largest number of aircraft which the terminal can service during a given time interval.
Movement rate of aircraft:	Speed at which aircraft operations can be serviced.
Flow restrictions:	The restrictions related to the flow of aircraft into and out of a given terminal.
Flight leg:	The components of a daily flight plan, specifying departure terminal, destination, and time of departure.
Peak demand periods:	The periods in which the demands for service by aircraft are the greatest.
Operation:	The departure or arrival of an aircraft.
Parameter:	A variable which can be controlled by the analyst.
Scheduling algorithm:	A method of controlling the departure times of aircraft.
System:	The air terminals and airspace which are under study during a time period.
Class A aircraft:	All jet aircraft requiring runway lengths exceeding 6000 feet.
Class B aircraft:	Piston and turboprop aircraft having a normal loaded weight in excess of 36,000 pounds; jet aircraft not included in Class A but having normal loaded weight in excess of 25,000 pounds.

Chapter 1

INTRODUCTION

At the present time, millions of dollars are being lost by major airlines each year because of the inability of high density air terminals to efficiently service all of the demands placed upon them during peak periods of demand. Eventually, all of the demands will be serviced but not without a vast amount of unscheduled delay which is not indicative of an efficient system. Relative to the air transportation system and high density air terminals, an efficient system would be one that could service all aircraft at their scheduled times without delay. Unscheduled delay is the delay encountered by a flight which causes it to miss its regularly scheduled arrival or departure time. On the other hand, scheduled delay is the delay which is "built in" to a particular flight schedule and which is considered part of the normal flight time. This delay may be due to weather conditions, long taxi times, or conflicts with other aircraft under normal operating conditions. The following statistics relate to unscheduled delay.

For the calendar year 1969 in which three airlines reported, there were 2,239,144 operations of which 855,375 encountered unscheduled delay [14]. This delay totaled 96,149.3 hours at a cost of $37,809,971. This includes the cost of fuel consumed in holding patterns or in departure stacks, crew salaries, maintenance, and the cost of extra ticket agents. Thus, approximately 39 percent of all the operations reported by the three airlines were delayed, with an average delay of 2.58 minutes per operation and an average cost of $6.55 per minute of delay. A study conducted by the Federal Aviation Administration [10] indicated that domestic air carrier terminal delay at 240 airports served by FAA towers totaled 19 million minutes in 1968 at a cost of approximately 118 million dollars. The total delay encountered by all air carriers for the calendar year 1969 was estimated to be 24 million minutes at a cost of 158 million dollars [14]. A comparison between the estimate for 1969 and the estimate for 1968 as reported by the FAA shows an increase in total delay of approximately 26 percent. According to a joint DOT-NASA report [7], the loss to major airlines could grow to about 600 million dollars by 1980 if attempts to reduce delay are not successful. This report also estimates the cost of delay to the passengers involved, in addition to the costs incurred by the airlines, to be approximately 100 million dollars in 1969.

Eighty-nine percent of this delay and its related cost occurred at 35 high activity reports [10]. The top seven terminals, ranked by delay, accounted for 56 percent of the total delay while only handling 27 percent of the total air carrier operations controlled by FAA. For example, in 1967 at Los Angeles, 25 percent of all departures and 34 percent of all arrivals were delayed [16]. Also, 40 percent of all departures and 45 percent of all arrivals were delayed at Atlanta in 1967. These two airports were not considered to be operating at saturation level at the time the study was conducted. Thus, a study which investigates procedures to reduce delay at high density terminals could contribute significantly to alleviating much of the delay discussed in these studies.

The problems concerning delay and its associated cost to airlines and passengers mentioned in the studies above are still just as serious at the present time as they were several years ago and probably more so. For example, consider the ecological effects stemming from the problem of delay. First, there is the effect of air and noise pollution caused by jet engines while aircraft are idling on the ground awaiting departure, or holding in the air waiting to land. In addition, the amounts of fuel consumed by holding aircraft is of prime concern, especially since there is a fuel shortage and a deficiency of fuel producing natural resources. Thus, the delay problem is a very critical one from several different standpoints: the airlines, passengers, ecology and mankind in general. No solution to the problem will totally eliminate delay. However, attempts must be made to reduce delay if the future of air travel is to remain attractive.

Congestion and Capacity

The delay encountered by aircraft is primarily due to congestion at major air terminals, where an air terminal is considered to be the airspace enclosed by an imaginary circle centered at the airport with radius of approximately 40 miles. The causes of this congestion include runway saturation, noise restrictions imposed by environmental regulations, insufficient turnoffs from runways, lack of aprons and holding areas, an insufficient number of gates, and inadequate access to facilities and parking [16]. Relative to delay, inadequate access to facilities and parking causes passengers to park in places which are inconvenient and remote from the gate or ticket agent. Often remote parking causes last minute passengers to arrive at the gate too close to the scheduled departure time. Passenger and luggage checking takes time and in turn causes delay. Similarly, the aircraft also have "parking" problems. Many times there are an insufficient number of available gates to handle the demands of arriving aircraft. When such a situation occurs, aircraft are sent to remote areas of the airport causing longer taxi times and subsequent delay. Over a period of time this delay, although sometimes slight, adds up to an appreciable amount. The lack of aprons and holding areas creates two situations which contribute to delay. First, flights which are scheduled to depart are held at the gate occupying positions which would ordinarily be assigned to arriving aircraft. Thus, arriving aircraft end up going to remote areas of the airport to wait for available gate space. Second, flights which have already departed the gate occupy taxiways which could have been used by arriving aircraft for quicker taxi in. Because of the insufficient number of turnoffs from the runways, arriving aircraft occupy the runway for a longer period of time and, in some cases, have farther to taxi in, both of which contribute to delay. Noise restrictions dictate the runway on which a particular type of aircraft may depart or land. This in turn could lead to longer taxi times, holding times, and waiting times, all contributing to excessive delay. Saturated runways, unable to service aircraft operations expeditiously, cause aircraft demanding service to encounter ground congestion and long waiting periods. Thus, it can be seen that the congestion which causes delay is not only a function of the airport building design and runway configuration but also of parameters not related to aircraft, such as parking facilities and access to airport.

In 1969, the primary causes of congestion at Atlanta were lack of simultaneous approach capability and an inadequate number of runways [21]. At Chicago's O'Hare Airport, the important factors related to congestion were inefficient layout of taxiways, saturated taxiways, and flow restrictions into the air terminals in the New York area. These flow restrictions are due mainly to the competition which airlines flying between New York and Chicago have created. In 1969, four airlines were flying 18,000 seats per day between New York and Chicago of which only 8,500 were occupied [11]. The congestion at Los Angeles was caused not only by saturated runways and the inefficient layout of taxiways, but also by the insufficient number of aircraft gates and noise abatement restrictions [21].

Related to the concept of delay and congestion is the measure of capacity for a given airport and runway configuration. Capacity is usually defined relative to delay, implying that a given aircraft movement rate produces a specific amount of delay [1]. After a maximum acceptable level of delay has been chosen, the capacity is reached when the movement rate results in the chosen level of delay. For example, if the maximum acceptable level of delay were chosen to be four minutes per aircraft, then the capacity of the airport would be reached when the average delay per aircraft reaches four minutes. As with congestion, capacity limitations are not always functions of airport parameters [9]. For instance, man-made objects in the vicinity of the airport as well as natural surroundings influence the capacity. Restricted airspace, caused by several airports being located in the same area, affects the capacity of a given airport. The New York area, containing John F. Kennedy, La Guardia, and Newark Airports, is a good example of the restricted airspace constraint.

The concept of capacity is actually a subjective one since it is based on an acceptable delay level. Some sources use four minutes as the acceptable level of delay. Thus, another measure of aircraft movement rate, not involving subjective judgements and related to the demands of aircraft within the terminal area would be more appropriate in a study concerning delay and congestion at high density terminals. Acceptance rate is such a measure.

Acceptance rate is defined to be the maximum number of operations, arrivals and departures, that an airport can accommodate during a given period of time [6]. Based on the above definition, acceptance rate is greater than the capacity defined by an acceptable level of delay. The reason for this difference is that acceptance rate is based on the maximum technological "capacity" of the airport, including the surrounding airspace [6]. The average delay related to the number of operations per unit time may be given as in Figure 1.1 [6]. Referring to Figure 1.1, acceptance rate would be the number of operations at which the average delay curve becomes vertical [6]. Because acceptance rates are independent of delay, any study involving delay reduction would benefit from the use of this measure of aircraft movement.

As mentioned previously, a study investigating the delay problems at high density terminals would be most beneficial. Considering the causes of congestion at major air terminals, there are not many alternatives

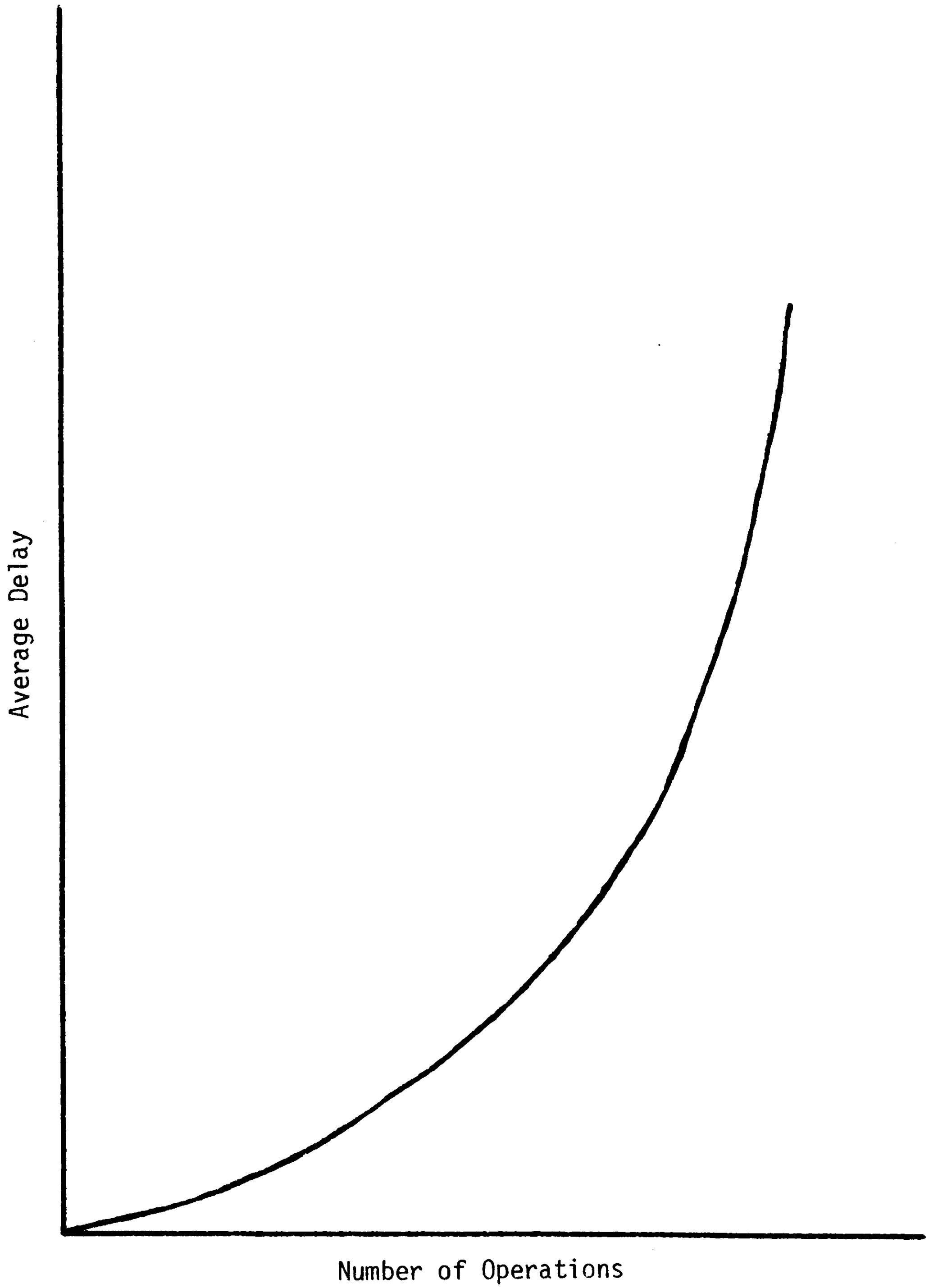

Figure 1.1 Relationship between Average Delay and the Number of Operations

from which to choose. For example, most major airports have been engulfed by the cities which they serve. Thus, plans for additional runways and building expansion at these airports are often infeasible. In addition, noise abatement restrictions imposed by local, state, or federal agencies pose still another constraint on such a study. One approach that would be independent of the above constraints would involve the manner in which aircraft are scheduled in a given system of terminals. Up to the present time, studies involving congestion have been aimed primarily at implementation of computerized techniques to aid the air traffic controller during peak demand periods. However, some studies have considered the use of advanced flow control procedures based on the present schedule of flights, as given in the Official Airlines Guide, but little effort has been expended in attempting to formulate a better method of scheduling flights. By scheduling aircraft in a given system in a different manner, delay could possibly be reduced at high density terminals even more than it has been reduced by using advanced flow control procedures. Thus, the approach which is to be taken in this study involves testing different heuristic scheduling algorithms, based on what has been done previously, to determine to what extent total system delay can be reduced.

Proposed Research

As mentioned previously, the majority of the flights being flown by commercial airlines today are encountering delay other than the planned scheduled delay. Thus, the objective of this research is to test several methods of scheduling aircraft, in a system of terminals, which are intended to reduce the delay time encountered by flights in the system.

In effect, what will be done will be to determine methods which will reduce any delay which is not attributed to uncontrollable factors, such as weather or mechanical breakdowns. The method of approach which will be followed in studying the problem will be based on a simulator which models aircraft movement among N major terminals. Several different heuristic scheduling algorithms will be developed and the operations related to each algorithm will be simulated. For each algorithm, hourly statistics related to the number of operations, average departure delay per aircraft and average arrival delay per aircraft will be calculated along with total system delay times for arriving and departing aircraft. The results obtained from these algorithms will be analyzed and compared. Scheduling algorithms which result in a reduction in delay time will be examined in greater detail to determine whether or not such a schedule would actually be feasible and worthwhile. Thus, from this study methods of reducing delay, based on previous studies, will be explored and the corresponding results analyzed.

Literature Review

Centralized flow control procedures were intended to restrict the number and flow of aircraft to levels which would be compatible with the capacity of the air traffic control (ATC) system [20]. From the studies concerning flow control procedures, advanced flow control procedures emerged. Advanced Flow Control Procedures (AFCPs) were established under FAA Order 7230.9A in late 1968 to estimate delay and distribute it equally among aircraft flying in the system during peak demand periods. By equally distributing delay, no one aircraft would encounter an excessive amount of delay at any time. Essentially, AFCPs are designed to have aircraft absorb inherent system delay on the ground at points of departure rather than in the air at points of destination. This is accomplished by forecasting expected delay for each terminal periodically. AFCPs also help to establish order within the system in an effort to aid the air traffic controller during peak demand periods.

Several sources have explored the delay problem and many beneficial results have been obtained. However, the possibility of more efficient results still remains. The Mitre Corporation [25] has carried out considerable research on the delay problem in conjunction with the FAA. For example, one study by Ziegler, Simmons, and Dawson [25] developed computer program modules which determine allocations to terminals, total delay expected, and maximum ground delay expected for any given flight after implementation of AFCPs. These program modules, in effect, provide automated assistance to the operation of AFCPs.

Another study conducted by Bellantoni, Coonan, and Medeiros [4] evaluated the present AFCPs as developed by the FAA in 1968. This evaluation was an attempt to determine the flow control procedures' effectiveness as well as to explore possible modifications of the procedures. Results from this study indicate that several impediments, primarily related to the control of air delay at the destination, occur when implementing AFCPs. For example, once the capacity for a terminal has been estimated, there is no procedure to revise this estimate. The authors point out that under the present implementation of AFCPs, air delays are uncontrollable and to a certain degree unpredictable. They suggest that by modifying AFCPs, these impediments could be alleviated.

A study by Forys, Heffes, Holtzman, Horing, Messerli, Schwartz, and Stiles [12] develops a traffic flow model which generates the means and variances of delay when arrivals to the terminal area are serviced on a first-come-first-served (FCFS) basis. Kramer [19] developed what he called central flow control based on information obtained from airport reservation offices (ARO) and AFCPs. Developed by FAA the methodology assumes a FCFS service doctrine. It is also suggested that using another service doctrine may lead to a reduction in total system delay. Eyster [8] analyzed AFCPs from a systems viewpoint to determine the degree to which air terminals interact in a closed loop network. He developed an integer linear programming model for scheduling aircraft within the system. While this model for scheduling aircraft produced beneficial results, Eyster felt that a more efficient model could be obtained.

The methods used to schedule aircraft operations during peak periods of demand affect capacity and in turn the amount of delay an aircraft will encounter [1]. Raisbeck, Koopman, Lister, and Kapadim [22] studied the problem of delay from the standpoint of the passengers instead of the aircraft. Consider the situation where delays are attributed to peak demand periods and that to provide flights during these intervals leads to delays in waiting queues. If a decision were made to spread the same flight demands over a longer period of time each flight on the new schedule may experience zero delay. However, the passengers would now experience even more loss of time, due to later departure and arrival times, on the average, than they did before the change in schedule.

Appleby, Blake and Newman [2] developed procedures to produce a timetable for a medium sized school using a digital computer. The solution procedures include the following concepts. A trial solution is developed at random and then examined to determine the number of constraints which were violated. Once this has been done, pairwise interchange is performed to reduce the number of violations. Also, a heuristic approach which begins with a blank timetable in which entries are assigned according to various criteria, if any rules are broken the entry may be rejected. These concepts may be extended to the scheduling of aircraft waiting to enter the terminal area.

Howard and Eberhardt [18], in a study concerning commercial airplane markets, evaluated the economics of routing passenger travel demand. The assumptions concerning the demand generating function were that 1) demand is uniformly distributed, 2) flights are uniformly spread throughout period of scheduling, and 3) passenger demand is normally distributed around a scheduled departure time. They proceeded to simulate various aircraft characteristics to determine the optimum operating conditions. Gacnon [13] considered the flight schedules as defining a network over which passengers flow from a point "A" to point "B." He assumes that the passenger is influenced by the following when choosing a flight: 1) aircraft type, 2) number of stops, 3) frequency of service, 4) time of day, 5) arrival times, and 6) competing airline schedules. Four different models were developed based on the above factors. They were the passenger allocation model, attractive path generator, traffic distribution estimator, and allocation process.

Glenn [15] views a flight schedule as a compromise among the community, airport authorities, government, and customer. Communities dislike airports because of noise and pollution, but they still want to be able to compete with other communities. Airport authorities strive for smooth operations with no peaking of flights or passengers, while the post office wants flights around pick up and delivery times. In the end, the prime task of the scheduler is to meet the customer's desires.

Shaw [24] developed a concept of scheduling which is concerned with the "best schedule of flights." The basis of this concept is the estimation of the proportion of prospective passengers who would be "attracted" to use a flight from the given schedule. Shaw defined the "best schedule" in two ways, the best day-pair schedule and the best weekly-leg schedule. The best weekly-leg schedule is the set of departure times which would attract the largest percentage of gross revenue from all the passengers moving over the network during the week. Whereas, the best day-pair schedule is the set of departure times which would attract the largest percentage of the gross revenue for a given day.

Chapter 2

DEVELOPMENT OF THE SIMULATOR

The basis of comparison of scheduling algorithms will be the statistical results obtained from simulating the movement of aircraft for a given scheduling algorithm. The simulator itself is programmed in Fortran and is a next event simulator which will service aircraft demands and periodically review the status of terminals to determine the point in time at which acceptance rate changes for the terminal.

Assumptions Concerning Aircraft

The following assumptions are concerned not only with characteristics of the aircraft, but also the movement of aircraft in the system.

1) Aircraft speeds for different types of aircraft are random variables and are not dependent on weather conditions, altitudes, and load factors.

This is an approximation to reality but under optimum operating conditions pilots will fly at speeds which approach the best cruise speed of the aircraft which they are flying.

2) Aircraft taxi times and runway occupancy times are equal for all aircraft serviced during a given time period and terminal.

The aircraft which are being used in the system are either Class A or Class B aircraft. Class A aircraft include all jet aircraft which require runway lengths which exceed 6000 feet, whereas Class B includes jet aircraft not included in Class A but having a normal loaded weight in excess of 25,000 pounds [1]. The similarity between the different types of aircraft included in the two classes is the basis for the above assumption.

3) Once an aircraft has entered the waiting stack with the intention of landing, it will remain in the stack until it lands.
4) Similarly, an aircraft never reneges from either entering the waiting stack or landing, no matter how large a stack exists.

The probability of a flight leaving the waiting stack and going to its secondary terminal is so small that it is unnecessary to consider it in this model. Also, reneging, or wave offs, are so rare that they need not be considered. This assumption is based on conversations with FAA personnel at Atlanta.

5) The order in which aircraft enter and leave the waiting stack is strictly on a first-come-first-served service doctrine.
6) The length of time between flight legs is at least 30 minutes.

The basis for this assumption is the fact that servicing the aircraft, unloading and loading baggage, as well as passengers, requires certain actions which are time consuming. A random sample (obtained from the OAG) of the length of time between flight legs indicated that a period of at least 30 minutes duration existed between flight legs, with the average being about 40 minutes.

Assumptions Concerning Terminals

The following assumptions relate to the terminal area as well as the runways and taxiways.

1) Kennedy, Newark, and La Guardia compose one terminal, Chicago's O'Hare and Midway a second, Washington National and Dulles International another, and Dallas-Fort Worth a fourth, with Atlanta, Los Angeles and Denver completing the system.

The above groupings are in accordance with the previous definition of terminal and is based on the conflicts which occur in the airspace around each of the above airports. The system does not need to be composed of the above terminals but may include others depending on the analyst's desires.

2) The acceptance rate for each terminal is reviewed on a periodic basis.

This review is taken to determine the acceptance rate for the following period. The acceptance rate may be increased or decreased depending on weather conditions and the number of runways which will be operational.

3) Depending on the number of independent runways, more than one aircraft operation can occur during the same time span.

At any terminal the number of simultaneous operations which may take place is a parameter which is controlled by the analyst, thereby allowing him flexibility in the use of the simulator.

4) The distances between terminals is taken from the air distances given in the Official Airlines Guide.

These distances are base distances to which vectoring distances are added. These vectoring distances are based on a normal distribution with a mean of 50 miles and a standard deviation of five miles. Several airlines supplied the author with these estimates.

5) Runway occupancy times are based on the acceptance rate of a given terminal.

Runway occupancy times are calculated by dividing the time period for which the acceptance rate has been projected by the projected acceptance rate for that period. For example, if the time period was 60 minutes and the projected acceptance rate for that period was 30 operations, then the runway occupancy time would be equal to two minutes.

6) The acceptance rate for a given terminal is an average plus random error, all of which is based on collected data.
7) The system of terminals is composed of N actual terminals and one "catch-all" terminal.
8) Any flight which originates at one of the N actual terminals going to a terminal which is not one of the actual terminals is sent to the "catch-all" terminal.

9) The "catch-all" terminal has an infinite acceptance rate and the ability to service an infinite number of simultaneous operations.

Simulator Logic

As mentioned previously, the simulator is a Fortran next event simulator which services aircraft operations in a given system of terminals. The basic concept of a next event simulator was obtained from Simulation and Analysis of Industrial Systems [23]. All the necessary variable initialization is performed at the beginning of the simulator and distances between terminals are read in at this time. Referring to Figure 2.1 which depicts the basic logic, it follows that the initial acceptance rate for each terminal is defined and is the time at which the first periodic review will take place. Next, all information pertaining to the flights is read into the simulator. This includes the following: name of airline represented by each aircraft, characteristics of each aircraft (i.e., type and average cruise speed), flight number, number of flight legs which each aircraft flies per day, departure terminal, destination, and departure time for each flight leg. The flight data will then be adapted according to the scheduling algorithm which has been specified. The simulator will enter the process of determining the type of next event which will occur and will continue in a cycle until all aircraft are idle, an aircraft leaves a waiting stack after a prescribed time, or the master clock is equal to 24 hours. The cycle contains the following stages: determine next event type, operate on next event, operate on events which are dependent on next event, return

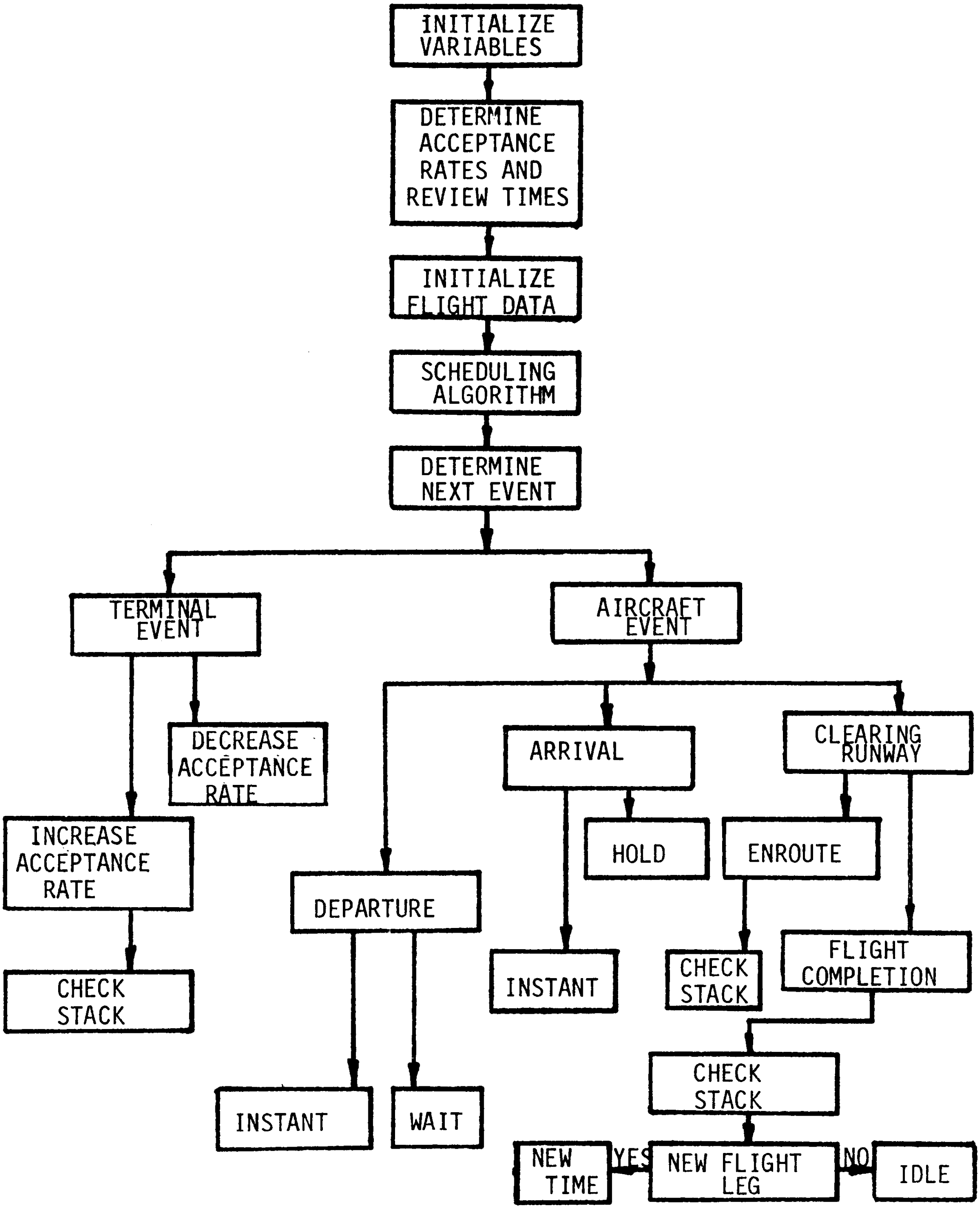

Figure 2.1 Flow Chart of Simulator Logic

to determine the next event. For example, if the next event was an aircraft clearing the runway, then the waiting stack would be checked to determine whether or not an aircraft was waiting for a runway to become available. If one was waiting, then it would be allowed to begin its operation. In this example, the checking of the waiting stack and servicing of any waiting aircraft would be the event which was dependent on the next event, an aircraft clearing the runway.

Referring to Figure 2.1, two types of events may occur. The terminal event is the periodic review of the acceptance rate for each of the N terminals. This event may either be an increase or a decrease in the acceptance rate. In both cases, the runway occupancy time will change for the subsequent period. If the acceptance rate had been zero for any terminal and an increase occurred, then the waiting stack would be checked to determine if an aircraft was waiting for service. If so, that aircraft will begin its operation. This check of the waiting stack will be repeated until all independent runways are occupied or there are no aircraft remaining in the waiting stack.

An aircraft event may be one of three types: departure, arrival, or clearing the runway. First, if the event is a departure, then the aircraft may begin departure service immediately or it may have to wait. For the aircraft to begin immediate departure, three conditions must prevail:

1) The acceptance rate at the departure terminal must not be zero.
2) A waiting stack must not exist at the departure terminal.
3) There must be at least one independent runway which is not being occupied.

If any one of the above conditions is violated, then the aircraft must be put into the waiting stack and wait until conditions allow it to begin its departure. To clarify this concept, when an aircraft demands departure service and finds all the runways occupied, it is put into the waiting stack. It must then wait for a runway to become available before it is allowed to depart. Thus, the two conditions that will allow an aircraft to leave the stack are 1) it is occupying the first position in the waiting stack, and 2) an aircraft has just cleared the runway. Along these same lines, if the event corresponds to an arrival, the above three conditions must be prevalent at the aircraft's destination if the arrival is to begin landing immediately. Otherwise, the aircraft will be forced to hold until conditions permit it to begin its landing. When the aircraft event corresponds to an aircraft clearing the runway, one of two situations will occur, either the aircraft is clearing the runway on take-off or it is clearing the runway after landing. If the aircraft is clearing the runway on take-off, it will be put enroute to its destination. Its next event time will be equal to the present time plus the calculated flying time and random error. As indicated in the example given previously, the waiting stack will be checked to determine if any aircraft is waiting for an available runway. On the other hand, if the aircraft is clearing the runway after landing a check will be made as to the number of flight legs which that aircraft has completed. If it has completed all of the required daily flight legs, then it will be classified as an idle aircraft and will be removed from the system. If it has not completed all of the required flight legs then that aircraft will be assigned a new departure time and will remain in the system.

As before, the waiting stack will be checked to determine if any aircraft is waiting for an available runway.

The above events are the primary events on which the simulator operates. Any one event does not necessarily have to have a distinct time associated with it. More than one event, either aircraft, terminal, or both, may occur at the same instant in time with all being serviced in the appropriate manner. Also, when any aircraft enters or leaves a waiting stack the appropriate times are recorded and later used in calculating the arrival and departure statistics concerning delay. In addition, whenever a demand for departure service or a demand for arrival service occurs, the appropriate values corresponding to the number of departures or arrivals at a given terminal are incremented by one.

The following hourly statistics based on the results of the simulation are calculated: the total number of aircraft departing each terminal, the total number of aircraft which wait at each terminal, the total number of aircraft landing at each terminal, the total number of aircraft holding at each terminal, total waiting time, average waiting time and standard deviation of waiting time, total holding time, average holding time and standard deviation of holding time for each terminal. Based on these statistics, a statistical test will be carried out to determine whether or not a difference exists among the algorithms tested.

Extensions of the Simulator

The simulator may be extended with minor modifications to provide the analyst with more than N actual terminals. Also, the N actual terminals which were used in this research could be replaced by others.

The number of aircraft operations which are simulated can also be increased. This increase would provide the analyst with a means of determining the effect of more operations on both arrival and departure delay in the system. Other possible areas of study include having a terminal become inoperative, unable to service aircraft demands, and having independent runways become unavailable for service to determine the effect on system delay.

Chapter 3

INTRODUCTION TO SCHEDULING

As mentioned previously, millions of dollars are being lost by major airlines each year because of delay in and around the terminal area. Efforts have been made to alleviate the problem of delay, everything from computer aided AFCPs to increasing airport capacity. The method to be used in this research will be based on the concept of scheduling aircraft flying in the system in a different manner. The method assumes that air terminals could handle all demands placed them up to the saturation level, after which delays will be encountered. With this in mind, algorithms aimed at scheduling aircraft into a terminal in such a way as to not exceed the saturation level at any time will be examined.

Scheduling Algorithms

There are six basic scheduling algorithms which will be discussed in detail in this chapter. One of the six schedules is actually the present schedule of flights as given in the Official Airline Guide, North American Edition. This schedule was used for two reasons: 1) to aid in the validation of the simulator, and 2) to use as a basis of comparison for the developed algorithms. Thus, this schedule has the departure time for each flight leg as the time given in the airline guide.

Uniform Scheduling Algorithm

One factor which must be considered in scheduling is that of meeting the passengers' desires with respect to the time at which they wish to travel. The trend at the present time is for the majority of the passengers to travel between the hours of eight o'clock and ten o'clock in the morning and five o'clock and eight o'clock in the evening. Thus, if any change is made in the present schedule it should remain as sensitive to the passengers' desires as possible. With this in mind, the uniform scheduling algorithm is designed to schedule aircraft departures from a major terminal during the same hour in which they are presently departing.

The time between departure demands at a terminal using this method of scheduling will be equal to the length of the period for which the acceptance rate has been projected divided by the projected acceptance rate for that terminal. For instance, if the acceptance rate is 60 operations per hour, then aircraft demanding departure service during that hour would be spaced one minute apart. If a flight plan presently has a scheduled departure time of 9:45 a.m. it is possible under this algorithm for that flight to depart earlier depending on the number of aircraft demanding departure service. In a later section, the consequences of a flight departing earlier will be discussed. If nine aircraft had demanded service before the one given above and the acceptance rate was 30, then the above aircraft would be scheduled to depart at 9:18 a.m. Flights which arrive during a given hour and which have another flight leg will be assigned a new departure time based on the number of flights already scheduled for departure service at that terminal. Also, if the number of demands exceeds the acceptance rate for a given hour, the excess will be carried over into the next hour. The basic step-by-step procedure is as follows:

1) Determine the number of departure demands during a given time period.
2) Calculate time interval between departures $\left(\frac{\text{length of period}}{\text{acceptance rate}}\right)$.
3) Assign departure times to aircraft on a first-come-first-served basis.

This algorithm is based on the principle of having one aircraft occupying one distinct time slot. The following algorithm is based on the concept of having more than one aircraft occupying a distinct time slot.

Simultaneous Uniform Scheduling Algorithm

Like the uniform scheduling algorithm, the simultaneous uniform scheduling algorithm has the time between departures based on the acceptance rate at a given terminal. As before the passengers' desires were considered in the development of this algorithm and thus no flight departs more than an hour from its presently scheduled time. Most major terminals have more than one independent runway, which implies that more than one aircraft may be serviced during a given time interval. With this in mind, the simultaneous uniform algorithm schedules aircraft such that two or more aircraft have the same departure time. The number of aircraft having the same departure time is based on the number of independent operations a given terminal can service simultaneously. For example, if a terminal has two independent runways then it can service two aircraft simultaneously. Therefore, according to this algorithm, two aircraft may have the same departure time.

This scheduling algorithm is similar to the uniform scheduling algorithm which uses the acceptance rate of each terminal to calculate the time interval between departures. However, with this algorithm, departure slots are established and then M aircraft are assigned to each slot, with M representing the number of simultaneous operations which may occur at a given terminal. The other conditions concerning arrivals and excessive departure demands are processed in the same manner as described in the uniform algorithm. The procedure used for this algorithm may be given as:

1) Determine the number of demands for each time period.
2) Calculate the time interval between departure time slots. $\left(\frac{\text{length of period}}{\text{acceptance rate}}\right)$
3) Determine the number of simultaneous operations, M, which can be serviced at a given terminal.
4) Assign M aircraft to each departure slot.

Peak Demand Uniform Scheduling Algorithm

This algorithm resembles the previous two algorithms in that the times for departures are based on the acceptance rate of each terminal. Basically, this algorithm schedules flights uniformly throughout a period of known peak demand while allowing flights not demanding service during that period to depart according to the present Official Airline Guide schedule. This algorithm will schedule flights during the peak demand period either according to the uniform scheduling algorithm or the simultaneous uniform scheduling algorithm, both of which have been described in previous sections. Thus, with this algorithm flights may be scheduled in one of two ways. They are

1) Peak demand uniform scheduling based on the acceptance rate for each terminal.
2) Peak demand simultaneous uniform scheduling based on the acceptance rate for each terminal.

These two algorithms are very similar to the algorithms described previously. The only dissimilarity is that the algorithm is enforced only during certain periods of the day. Hence, the step-by-step procedure for each of the two methods are given below.

Peak Demand Uniform Scheduling Based on Acceptance Rate

1) Based on present operations and passenger desires, establish the peak demand periods of the day.
2) Calculate the time interval between departure demands. $\left(\frac{\text{length of period}}{\text{acceptance rate}}\right)$
3) Assign departure times to the aircraft demanding departure service during peak periods.
4) Schedule remaining aircraft according to the present schedule.

Peak Demand Simultaneous Uniform Scheduling Based on Acceptance Rate

1) Establish peak demand periods of the day.
2) Calculate the time interval between departure demand slots for peak periods.
3) Determine the number of operations, M, which each terminal can service simultaneously during peak periods.
4) Assign departure times to aircraft demanding departure service during peak periods, with up to M aircraft assigned to each departure slot during peak periods.
5) Remaining aircraft will be scheduled according to the present schedule.

The advantage of the above procedures given is that it does not restrict the present schedule for the entire day.

Aircraft Tagging Method

This method of scheduling aircraft is actually only a means for controlling the present schedule. The basic concept is to calculate the expected arrival time interval for each departing flight and then based on this time interval and the projected number of flights previously scheduled for service at a destination terminal during the time interval, determine whether or not each flight should be allowed to depart at its scheduled time. If the number of flights is less than the number which that terminal can service, then the flight is allowed to depart. A more concise step-by-step procedure will aid the reader in understanding the concept on which the tagging algorithm is based.

1) Flight's departure time occurs.
2) Expected time of arrival at destination is calculated for that flight (present + enroute time + runway occupancy time).
3) The expected time of arrival is used to compute the time interval, T, in which the flight will arrive at its destination.
4) Acceptance rate for time interval, T, is calculated, hourly acceptance rate times T divided by 60.
5) The number of flights already scheduled for service during that time interval is compared to calculated acceptance rate.
6) If the projected number of flights scheduled for service is less than the acceptance rate, then the flight is allowed to depart as scheduled.
7) If the projected number of flights scheduled for service is greater than the acceptance rate, the flight is not allowed to depart. The acceptance rate for successive T minute intervals is reviewed to determine in which interval the flight could be serviced.
8) Once an interval has been found a new departure time will be assigned to the aircraft.

An example will aid in understanding the above procedure. Consider a flight which has 9:10 a.m. as its departure time and an enroute time of 45 minutes. Thus, the expected time of arrival would be 9:55 a.m. which would occur during the 15 minute time interval 9:45 a.m. to 10:00 a.m.

Assuming that the acceptance rate for that interval is 15, and 15 flights have already been scheduled for service during that interval, then the flight under consideration would be delayed. Thus, the acceptance rate for successive 15 minute intervals (10:00-10:15, 10:15-10:30, etc.) would be compared with the corresponding number of scheduled flight services until an interval with an acceptance rate greater than the number of flights scheduled for service is found. Assuming that this situation occurs for the interval 10:00 a.m. to 10:15 a.m., then the above flight would be delayed for 15 minutes. Hence, departure time would become 9:25 a.m. and the expected time of arrival would become 10:10 a.m. It is possible that at 9:25 a.m. the flight may not be able to depart due to the existence of a waiting stack, or weather conditions; however, by assigning the aircraft a special status, attempts are made to see that it does.

Summary of Scheduling

In all of the above scheduling algorithms an effort was made to have them sensitive to passenger desires since airlines wish to satisfy their passengers. However, in some cases a scheduling algorithm may have a flight departing at a time earlier than its present departure time. An example would be the uniform algorithm. This would require that the passengers arrive at an earlier time in order to meet the flight. Initially, this would cause some inconvenience for the passengers; however, as the new departure time was accepted by the public this inconvenience would diminish. It should be pointed out that for the uniform algorithm departure times were never adjusted more than an hour earlier or an hour later than the present schedule. Thus, the passengers would not have to arrive at the airport more than an hour earlier. On the other hand, a scheduling algorithm may cause a flight to depart later than its present departure time. An example would be the tagging algorithm. Later departure times could cause passengers to miss their connections; however, delay encountered while holding in the air could also cause passengers to miss their connections. As far as the passengers are concerned, a 20 minute departure delay is equal to a 20 minute arrival delay. From the airlines point of view, it is a lot more economical and safer to have the aircraft waiting on the ground instead of holding in the air. All of the steps of each scheduling algorithm are carried out within the simulator, based on the algorithm which is specified for a particular simulation.

Chapter 4

VALIDATION AND RESULTS

Before any statistical tests can be performed and conclusions drawn, it is necessary to validate the simulation model. In order to validate the simulation model, it is essential that it meet the objectives for which it is intended to achieve. The basic objective of the simulator was to simulate the operations of M aircraft in a system of N terminals in a realistic manner so that various scheduling algorithms could be compared. In other words, the simulator was to allow aircraft to "fly" in a system of terminals according to various scheduling algorithms and have the terminals service these aircraft. The simulator is able to simulate various numbers of aircraft in the system using different scheduling algorithms in an attempt to obtain a reduction of departure delay and arrival delay. The simulator records the various delay statistics needed for comparing the different scheduling algorithms. The sample output given in Appendix C gives an indication of the ability of the simulator to simulate aircraft operations in the system. The most significant validation step was in the comparison of actual data to results from the simulator in order to determine whether or not the simulator is realistic. Table I gives the delay time per aircraft for each hour of the day during February 1973 at Hartsfield Atlanta International Airport. Table II gives the delay time per aircraft for each hour of the day obtained from the results of simulating the operations of 1750 aircraft scheduled according to the OAG. While Figure 4.1 is a graph of the actual data points and the data points obtained from the simulator.

Table I

Delay Time per Aircraft
from Hartsfield Atlanta International Airport

Hour	Total Delay (hours, minutes)	Delay/Aircraft
00 - 01	4 + 29	0.203
01 - 02	+ 32	0.038
02 - 03	+ 00	0.000
03 - 04	+ 00	0.000
04 - 05	+ 02	0.006
05 - 06	5 + 17	0.269
06 - 07	12 + 03	0.496
07 - 08	+ 44	0.071
08 - 09	1 + 37	0.111
09 - 10	12 + 54	0.476
10 - 11	12 + 22	0.335
11 - 12	11 + 06	0.290
12 - 13	11 + 08	0.420
13 - 14	+ 47	0.044
14 - 15	8 + 39	0.294
15 - 16	6 + 64	0.212
16 - 17	2 + 06	0.074
17 - 18	16 + 32	0.478
18 - 19	12 + 35	0.396
19 - 20	23 + 24	0.642
20 - 21	10 + 40	0.374
21 - 22	2 + 25	0.101
22 - 23	+ 56	0.052
23 - 24	9 + 53	0.371

Table II

Delay Time per Aircraft from Simulation

Hour	Total Delay (hours, minutes)	Delay/Aircraft
00 - 01	+ 05	0.028
01 - 02	+ 01	0.004
02 - 03	+ 00	0.000
03 - 04	+ 00	0.000
04 - 05	+ 01	0.002
05 - 06	+ 16	0.064
06 - 07	+ 56	0.341
07 - 08	+ 00	0.000
08 - 09	+ 09	0.073
09 - 10	+ 59	0.192
10 - 11	3 + 02	0.495
11 - 12	2 + 54	0.536
12 - 13	1 + 18	0.274
13 - 14	+ 22	0.138
14 - 15	+ 42	0.154
15 - 16	2 + 47	0.534
16 - 17	+ 12	0.045
17 - 18	1 + 15	0.293
18 - 19	2 + 30	0.399
19 - 20	+ 19	0.077
20 - 21	2 + 47	0.481
21 - 22	+ 23	0.120
22 - 23	+ 11	0.091
23 - 24	+ 16	0.075

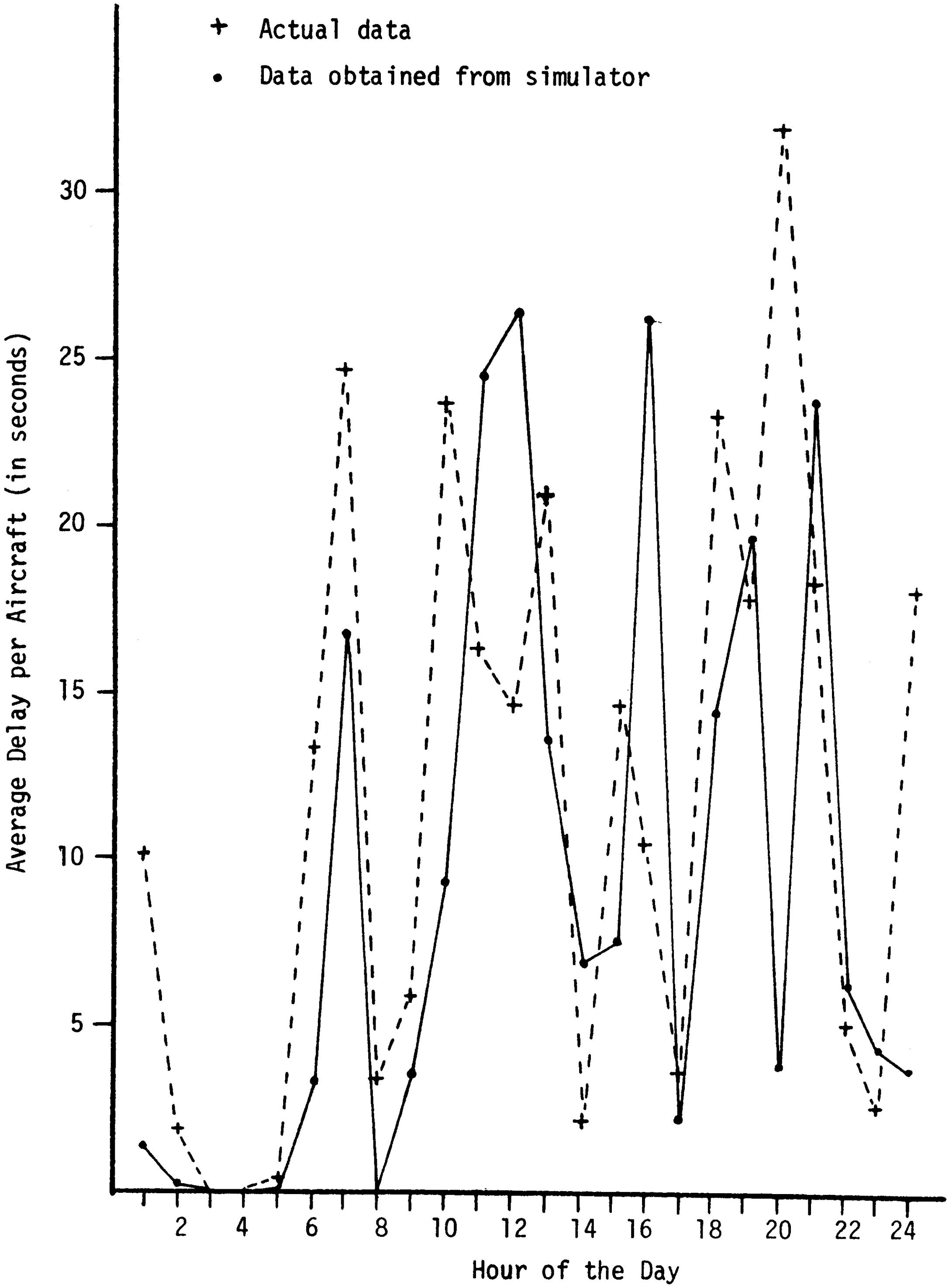

Figure 4.1 Actual Data vs. Data Obtained from Simulator

As can be seen, there appears to be a reasonable degree of similarity between the actual data and the data obtained from the simulator. Thus, it was concluded that the simulator did indeed meet its objectives.

Analysis of Results

Once it had been determined that the simulator met its objectives, the operations of the various scheduling algorithms were simulated. To determine the effect on delay of an increase in the number of aircraft in the system, the operations 1750, 2250, and 2750 aircraft were simulated for each scheduling algorithm. Actual data was extracted from the Official Airlines Guide for 1750 flights in the system, while the additional flights were synthesized within the simulator. The departure delay and arrival delay statistics were calculated for each combination of the number of aircraft and scheduling algorithm. These statistics were then analyzed and compared to determine which algorithms were able to handle an increase in the number of daily operations with only a minimum increase in delay. The results obtained from simulating the operations of 1750, 2250, and 2750 aircraft scheduled by the airlines guide served as a basis for comparing the results of the other algorithms. Table III gives the average departure delay per aircraft and the average arrival delay per aircraft for each scheduling algorithm. It should be pointed out that the average departure delay per aircraft scheduled by the tagging algorithm is somewhat higher than the other algorithms. However, this is in accordance with the basic concept of having aircraft absorb delay at their departure terminals instead of their destination. Also, the complete results for three of the algorithms are not included

Table III

Results Obtained from Simulation Concerning Average Delay

Schedule		Departure Delay	Arrival Delay	Weighted Average
OAG	1750	21.29	8.71	15.40
	2250 a.m.	42.84	38.26	40.67
	2250 p.m.	53.89	56.18	54.98
	2750 a.m.	359.60	627.03	487.60
	2750 p.m.	424.26	795.85	601.38
Uniform	1750	1.81	4.32	2.97
	2250 a.m.	22.90	32.70	27.54
	2250 p.m.	30.68	43.45	36.73
	2750 a.m.	413.24	611.53	508.21
	2750 p.m.	388.43	623.51	501.03
Tagging	1750	39.87	7.21	24.03
	2250 a.m.	1429.03	12.72	758.48
	2250 p.m.	1262.46	14.74	655.76
	2750 a.m.	4683.04	48.72	2464.34
	2750 p.m.	3870.87	107.52	2073.72
Peak Demand Uniform	1750	13.11	8.04	10.75
	2250 a.m.	-	-	-
	2250 p.m.	37.84	45.95	41.68
	2750 a.m.	-	-	-
	2750 p.m.	-	-	-
Simultaneous Peak Demand Uniform	1750	33.43	12.77	23.84
	2250 a.m.	-	-	-
	2250 p.m.	-	-	-
	2750 a.m.	-	-	-
	2750 p.m.	-	-	-
Simultaneous Uniform	1750	50.81	13.24	29.50
	2250 a.m.	-	-	-
	2250 p.m.	-	-	-
	2750 a.m.	-	-	-
	2750 p.m.	-	-	-

in the table due to the fact that each one resulted in an increase in unscheduled delay over the present method of scheduling 1750 aircraft. The uniform peak demand algorithm did indicate a slight decrease in average delay; however, it was felt that it was insignificant. Thus, in an effort to minimize computation costs, this algorithm was not investigated in further detail. Hence it was decided to determine whether or not there existed a difference among the remaining three algorithms.

The method used in comparing the three scheduling algorithms was a three-way analysis of variance which tested for the equality of means among the effects, schedule, terminal and hour of the day. The development of the three-way analysis of variance model is based on the model developed in Statistical Theory and Methodology in Science and Engineering by Brownlee [5]. Let row index i correspond to the various scheduling algorithms, column index j correspond to the terminals, and array index k correspond to the hour of the day. Thus, since there are three, $r = 3$, scheduling algorithms, seven, $t = 7$, terminals, and 24 hours, $u = 24$, there will be 504 cells in the three-dimensional lattice. Now let ℓ correspond to the index of the observation in each cell, where $\ell = 1, 2, 3$. For the model given above, all of the effects will be tested using the within-cell mean square. Table IV gives the source of variation, degrees of freedom, sum of squares, and the expected mean square for the model to be used. In other words, the null hypothesis was

$$H_0: \mu_1 = \mu_2 = \mu_3$$

$$H_0: \gamma_1 = \gamma_2 = \cdots = \gamma_7$$

$$H_0: \alpha_1 = \alpha_2 = \cdots = \alpha_{24}$$

Table IV

Three-Way Analysis of Variance

Source of Variance	Sums of Squares	Degrees of Freedom	E[M.S.]
A	$ntu \sum_{i}^{r} (\bar{x}_{i\cdot\cdot} - \bar{x}_{\cdot\cdot\cdot})^2$	(r-1)	$\sigma^2 + ntu\sigma^2_{A}$
B	$nru \sum_{j}^{t} (\bar{x}_{\cdot j\cdot} - \bar{x}_{\cdot\cdot\cdot})^2$	(t-1)	$\sigma^2 + nru\sigma^2_{B}$
C	$nrt \sum_{k}^{u} (\bar{x}_{\cdot\cdot j} - \bar{x}_{\cdot\cdot\cdot})^2$	(u-1)	$\sigma^2 + nrt\sigma^2_{C}$
AB	$nu \sum_{i}^{r} \sum_{j}^{t} (\bar{x}_{ij\cdot} - \bar{x}_{i\cdot\cdot} - \bar{x}_{\cdot j\cdot} + \bar{x})^2$	(r-1)(t-1)	$\sigma^2 + nu\sigma^2_{AB}$
AC	$nt \sum_{i}^{r} \sum_{k}^{u} (\bar{x}_{i\cdot k} - \bar{x}_{i\cdot\cdot} - \bar{x}_{\cdot\cdot k} + \bar{x}_{\cdot\cdot\cdot})^2$	(t-1)(u-1)	$\sigma^2 + nr\sigma^2_{BC}$
BC	$nr \sum_{j}^{t} \sum_{k}^{u} (\bar{x}_{\cdot jk} - \bar{x}_{\cdot j\cdot} - \bar{x}_{\cdot\cdot k} + \bar{x}_{\cdot\cdot\cdot})^2$	(t-1)(u-1)	$\sigma^2 + nr\sigma^2_{BC}$

Table IV (continued)

Source of Variance	Sums of Squares	Degrees of Freedom	E[M.S.]
ABC	$n\sum_{i}^{r}\sum_{j}^{t}\sum_{k}^{u}(\bar{x}_{ijk}-\bar{x}_{ij\cdot}-\bar{x}_{i\cdot k}-\bar{x}_{\cdot jk}+\bar{x}_{i\cdot\cdot}+\bar{x}_{\cdot j\cdot}+\bar{x}_{\cdot\cdot k}-\bar{x}_{\cdot\cdot\cdot})^2$	(r-1)(t-1)(u-1)	$\sigma^2 + n\sigma^2_{ABC}$
Within cells	$\sum_{i}^{r}\sum_{j}^{t}\sum_{k}^{u}(x_{ijk}-\bar{x}_{ijk})^2$	rtu(n-1)	σ^2
Total	$\sum_{i}^{r}\sum_{j}^{t}\sum_{k}^{u}(x_{ijk}-\bar{x}_{\cdot\cdot\cdot})^2$	rtun - 1	

where μ_i is the true mean for the ith schedule, γ_i is the true mean for terminal i, and α_k is the true mean for hour k. In effect, this statistical test was performed to determine whether or not a difference in average delay among the three scheduling algorithms exists. Due to the fact that there are such a large number of observations, the aid of a computerized analysis of variance solution procedure, SAS [3], was used. The tables in Appendix D give the results obtained from SAS. The main effects which were tested for significance were the scheduling algorithms, the terminal, and the hour of the day. As can be seen by referring to Appendix D, all of the main effects proved to be significant when tested. Thus, it was concluded that the mean delay associated with each of the three scheduling algorithms was not equal. Even though there was a significant difference in the mean delays, it was still not clear as to which scheduling algorithm showed the greatest reduction in unscheduled delay.

The uniform scheduling algorithm showed the greatest reduction over the present schedule in departure delay and arrival delay. Uniform scheduling implies that only one aircraft should be departing a given terminal at any point in time. Thus, if a terminal can service N simultaneous operations, then (n-1) runways would be available for arriving aircraft to use. Hence, arriving aircraft would encounter little or no delay, while departing aircraft would experience little or no delay since there should always be, at worst,one runway which is not being occupied by another aircraft. This algorithm would be quite effective in reducing the total system delay. However, it would require a complete change in the present schedule.

Based on the present schedule, the tagging algorithm showed a reduction in unscheduled arrival delay but showed an increase in departure delay. This is in accordance with the basic concept of having aircraft absorb delay on the ground at their departure terminal instead of in the air at their destination. Nevertheless, from the standpoints of safety and ecology, the tagging algorithm would be most effective in that the aircraft would not be consuming fuel holding in the air, but instead would be on the ground conserving fuel. Also, no changes would need to be made in the present schedule. Figures 4.2 through 4.11 are graphs of the average hourly delay per aircraft for each hour of the day at the terminal which corresponds to Atlanta for the three algorithms compared above.

One can conclude from the results given above that unscheduled delay can be reduced by scheduling aircraft in the system in a manner different from the present schedule. To state which scheduling algorithm is the best and most effective would be difficult without further study. However, the objective of this research was to determine whether or not unscheduled delay could be reduced by modifying, or changing, the present scheduling procedure. Thus, the objective was accomplished.

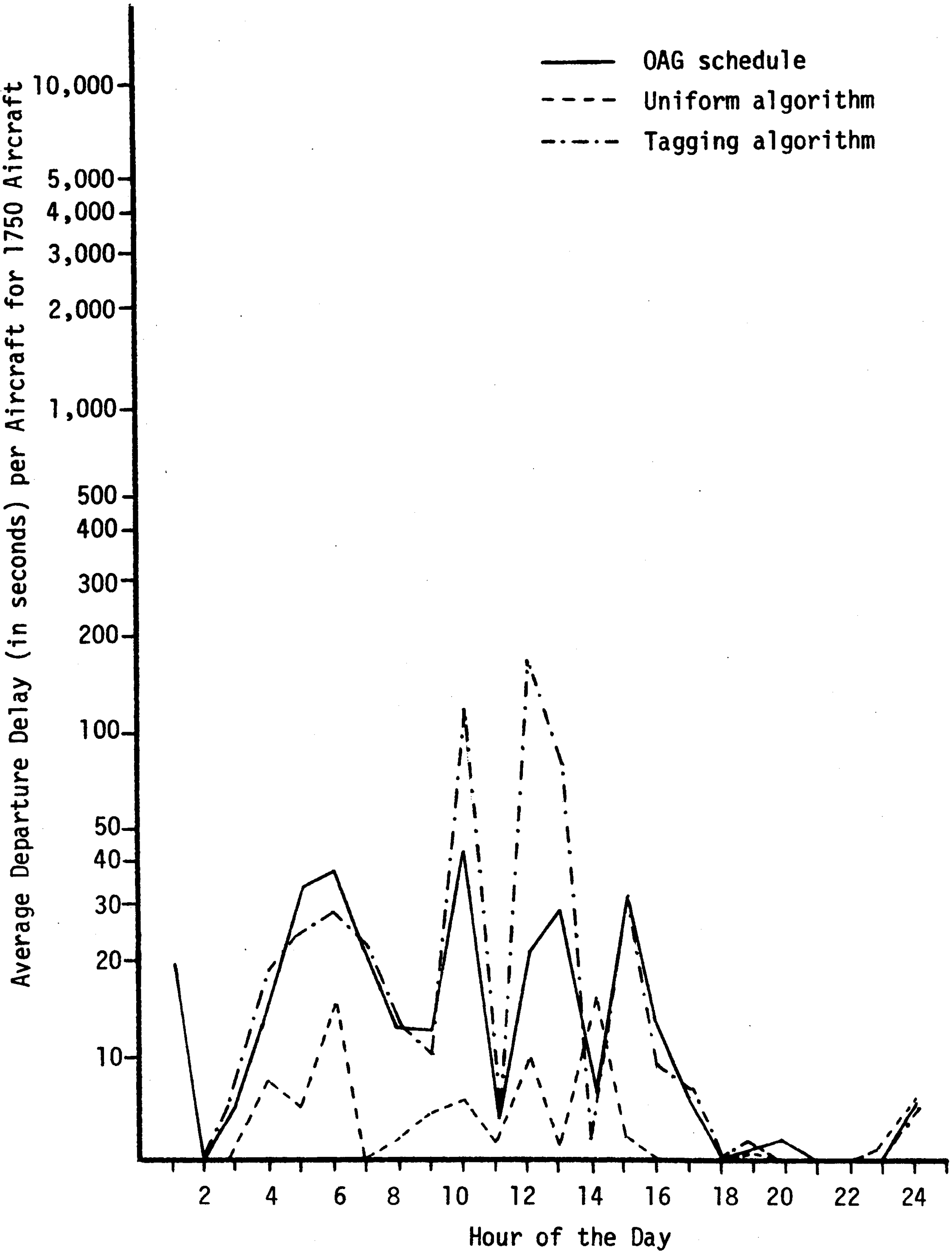

Figure 4.2 Average Departure Delay per Aircraft for 1750 Aircraft

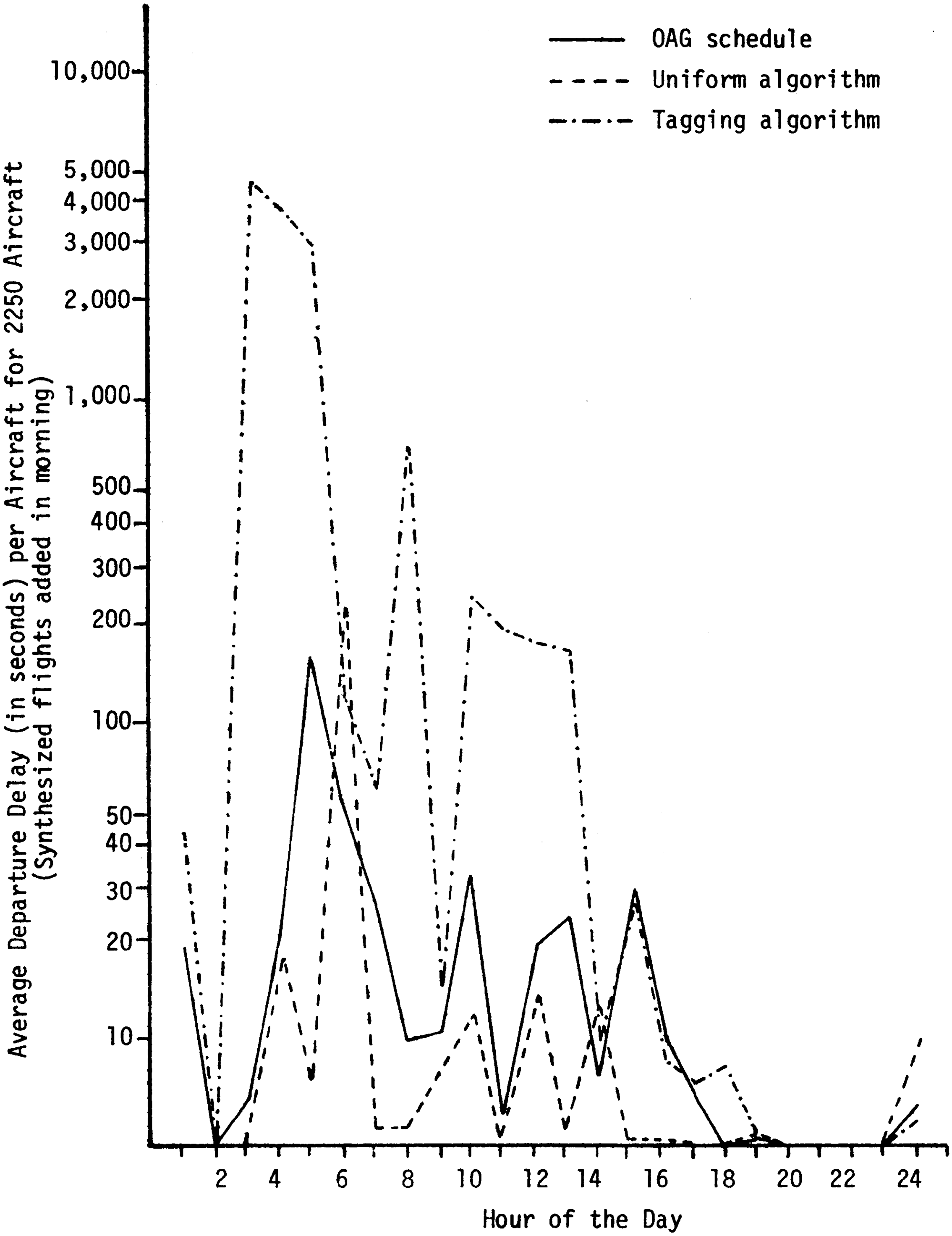

Figure 4.3 Average Departure Delay per Aircraft for 2250 Aircraft (Synthesized flights added in morning)

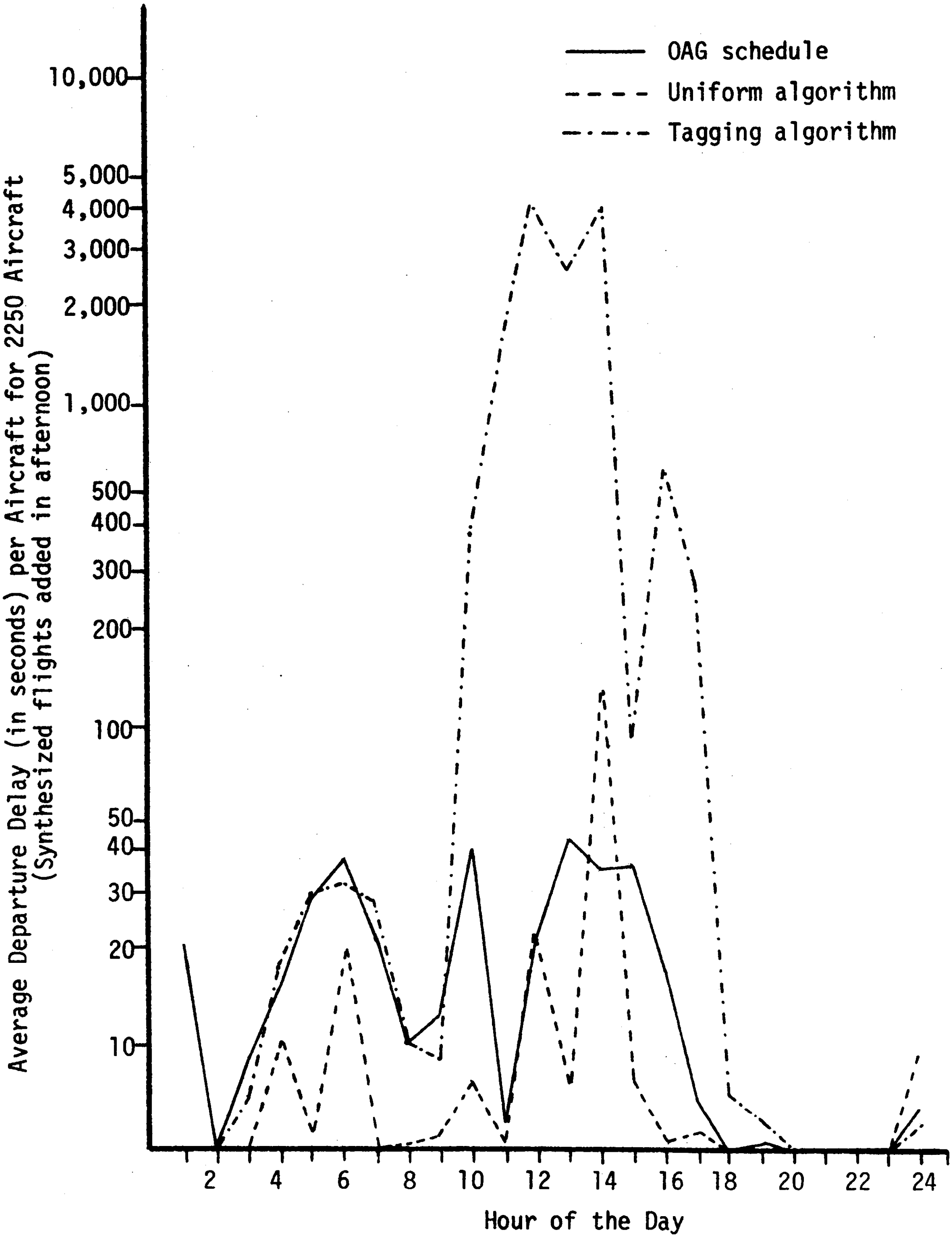

Figure 4.4 Average Departure Delay per Aircraft for 2250 Aircraft (Synthesized flights added in afternoon)

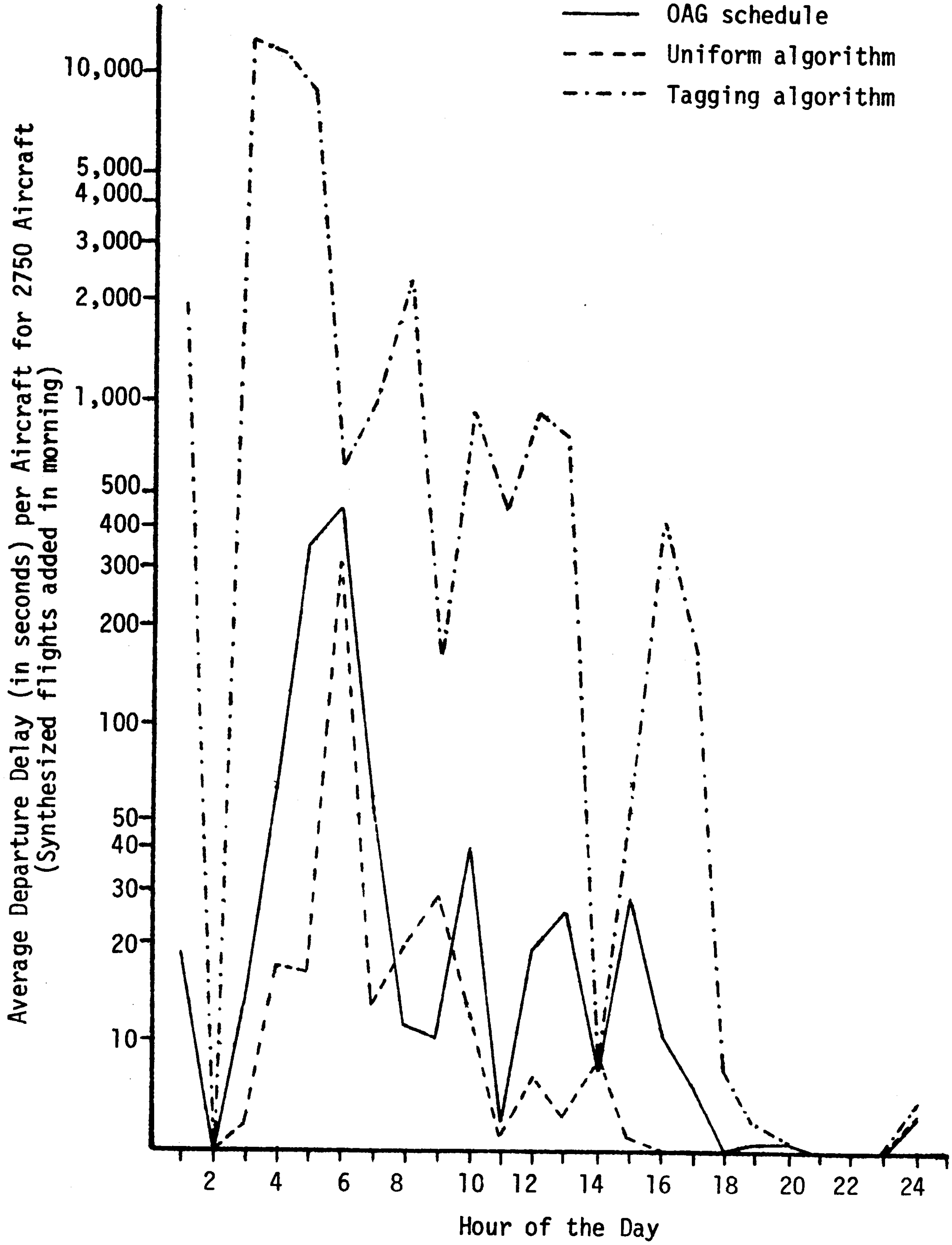

Figure 4.5 Average Departure Delay per Aircraft for 2750 Aircraft (Synthesized flights added in morning)

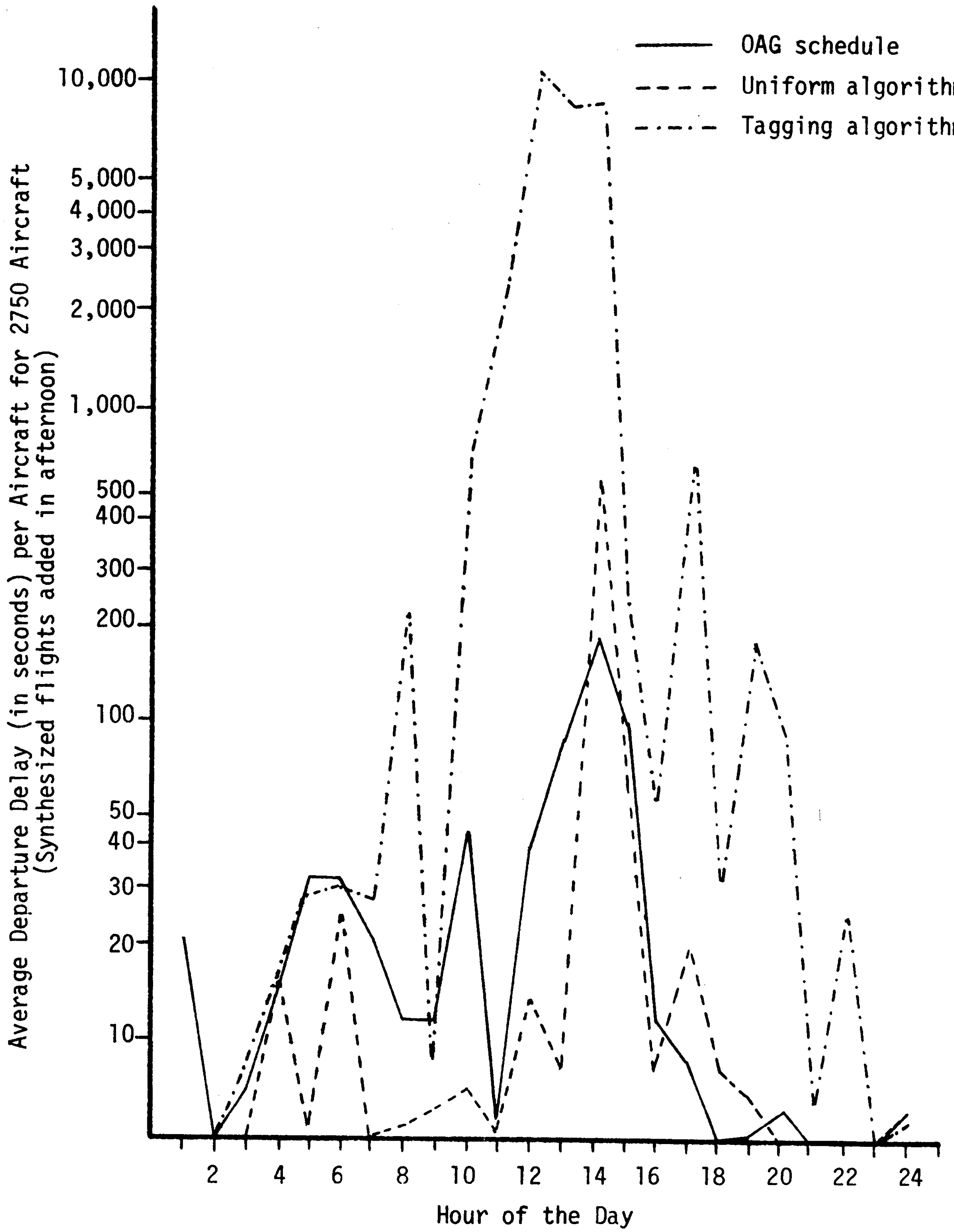

Figure 4.6 Average Departure Delay per Aircraft for 2750 Aircraft (Synthesized flights added in afternoon)

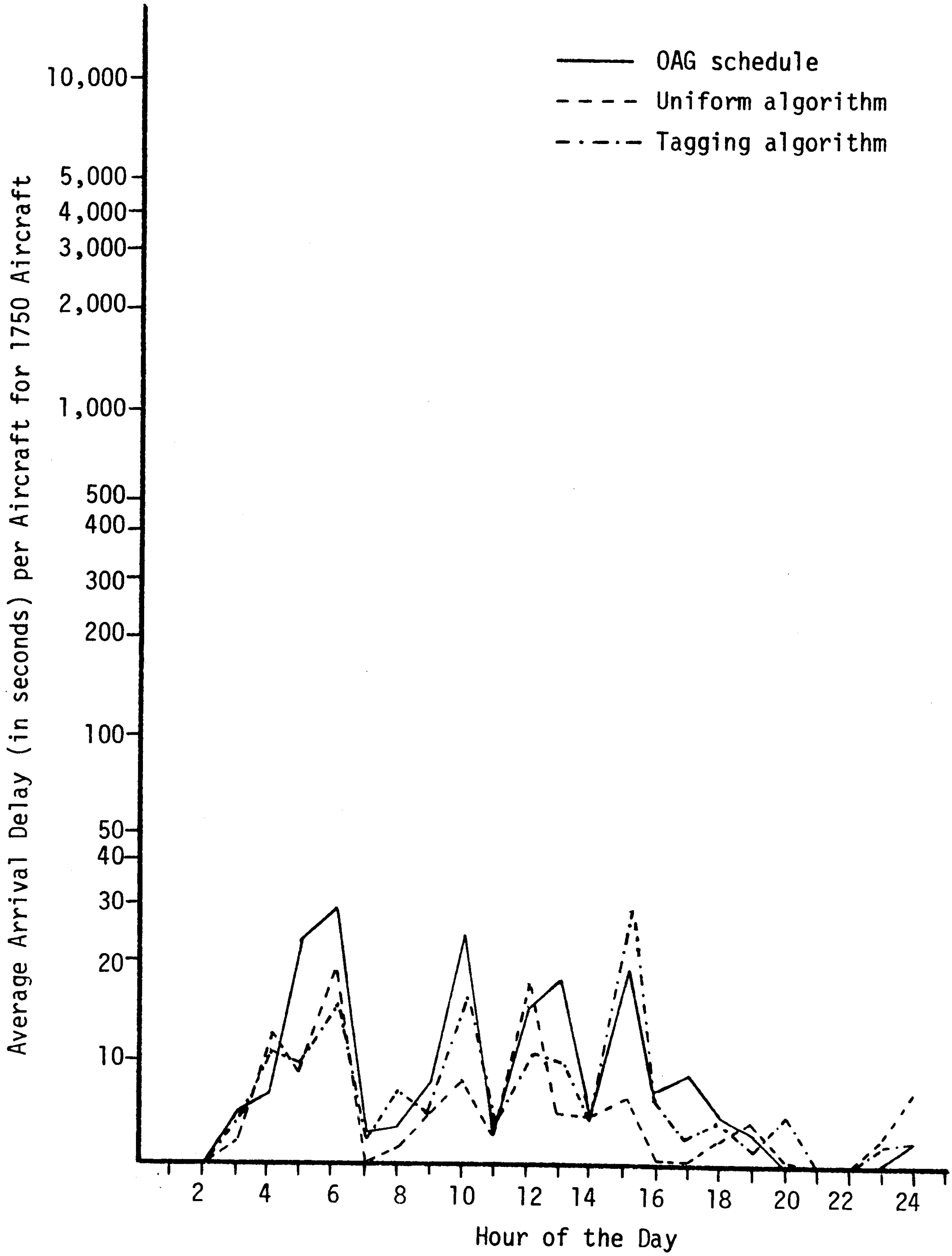

Figure 4.7 Average Arrival Delay per Aircraft for 1750 Aircraft

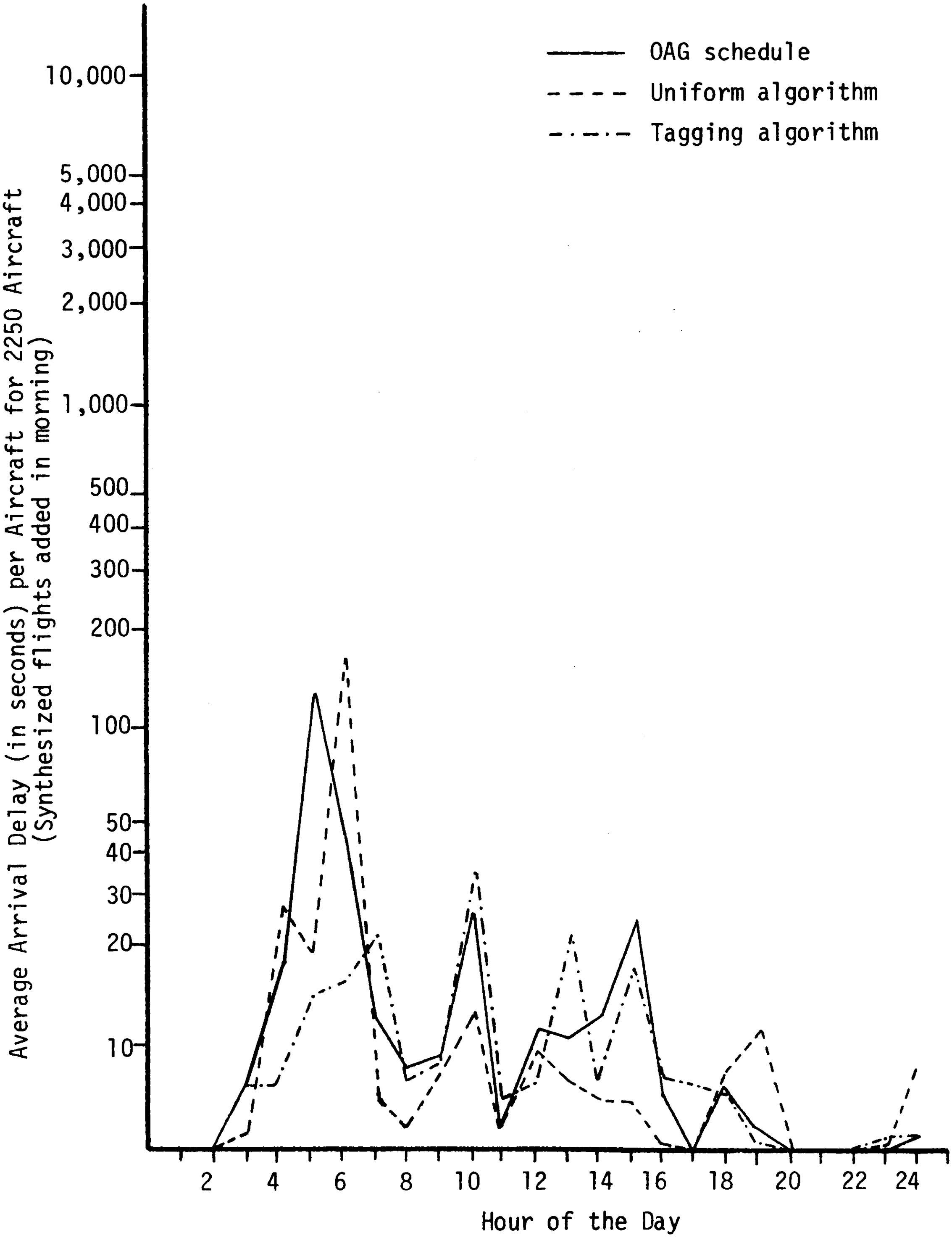

Figure 4.8 Average Arrival Delay per Aircraft for 2250 Aircraft
(Synthesized flights added in morning)

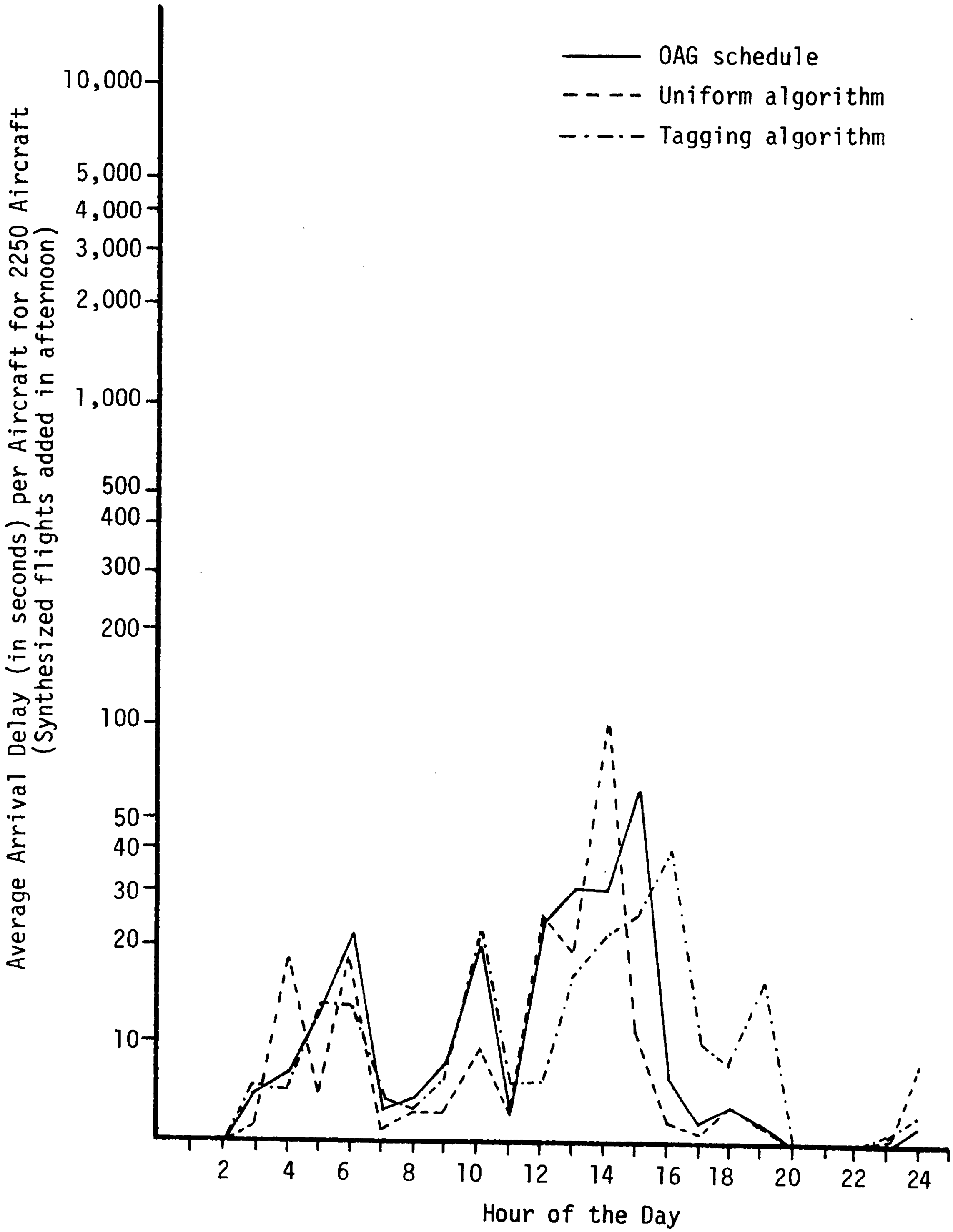

Figure 4.9 Average Arrival Delay per Aircraft for 2250 Aircraft
(Synthesized flights added in afternoon)

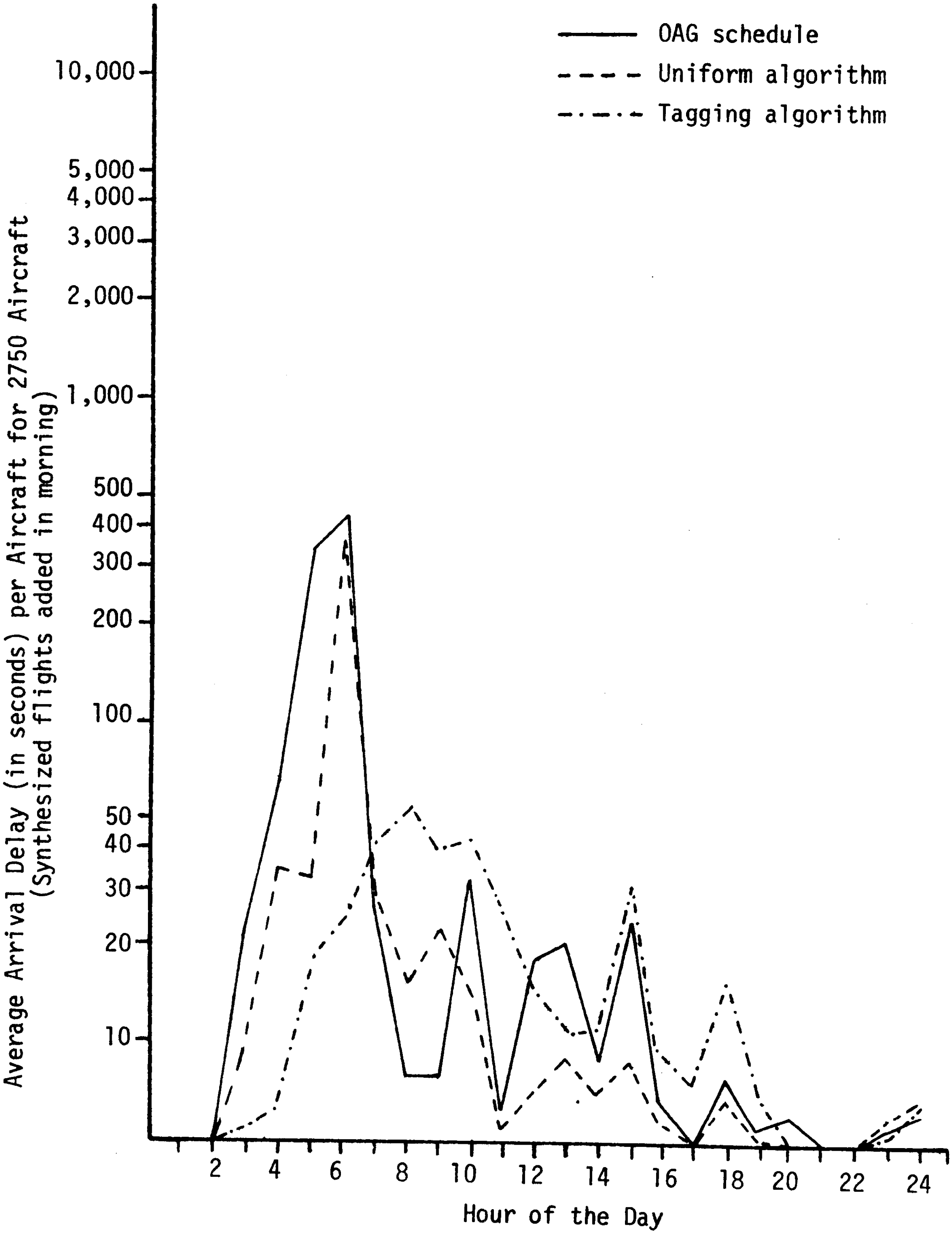

Figure 4.10 Average Arrival Delay per Aircraft for 2750 Aircraft (Synthesized flights added in morning)

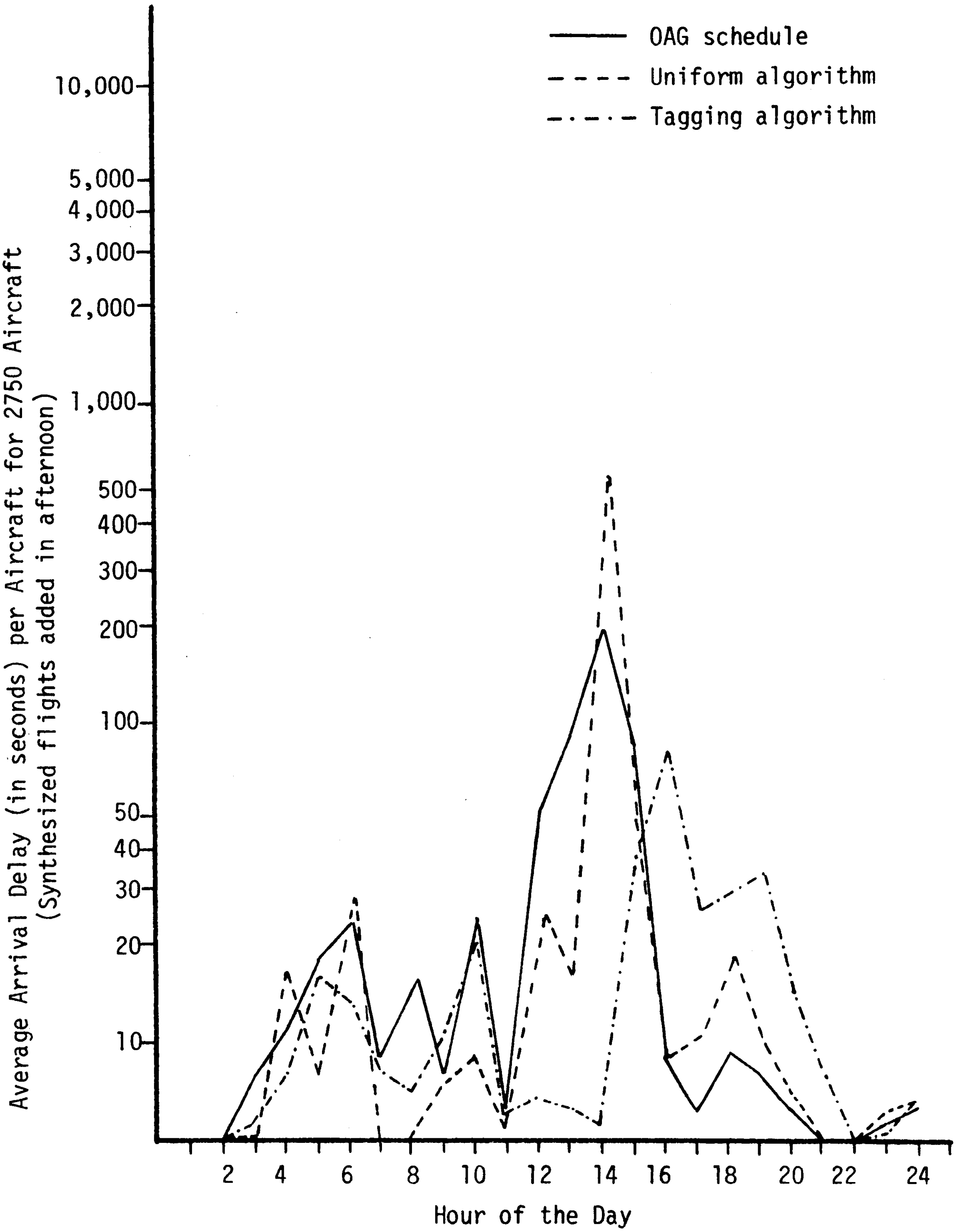

Figure 4.11 Average Arrival Delay per Aircraft for 2750 Aircraft (Synthesized flights added in afternoon)

Chapter 5

SUMMARY AND RECOMMENDATIONS

The purpose of this research was to determine the effect of scheduling an air traffic delay. The airlines are losing millions of dollars each year because of unscheduled delay which aircraft encounter at high density air terminals during peak periods of demand. Efforts have been made to reduce this unscheduled delay by attempting to control the flow of aircraft in the present system. For example, Advanced Flow Control Procedures developed by the FAA control the flow of aircraft in the system by having aircraft absorb delay at their departure terminals instead of their destination. It was felt that delay could be reduced even more if other methods of scheduling were developed and studied.

The scheduling algorithms developed are heuristic and were based on the acceptance rates of the terminals in the system. It was assumed that there exists a given saturation level for an air terminal at which it can service the demands without unscheduled delay. Based on this assumption, the algorithms were designed to schedule aircraft in such a way as to not exceed the saturation level at a given terminal. Each algorithm was intended to reduce delay and as seen in the previous chapter, several of the algorithms did indeed reduce the delay.

Although the research showed that delay could be reduced by scheduling aircraft in a different manner, the "optimum" scheduling policy was not developed as such. Thus, the need still exists for further investigation in the area of flight scheduling. Possible extensions of the research preferred in this study include:

1) Determining the effect on the scheduling algorithm and delay of having the acceptance rate at a terminal become zero.
2) Determining the effect of having the number of simultaneous operations at that terminal be decreased during the simulation.
3) Gathering and analyzing data on a consistent basis for all major terminals.
4) Gathering and analyzing on a consistent basis data for various flights throughout U. S.
5) Gathering and analyzing on a consistent basis data on runway operation, maintenance, etc.

One of the major problems encountered in this research was the lack of accurate data concerning runway availability. It was difficult to obtain any information concerning runway maintenance and the percentage of time runways are available. Thus, it was difficult to determine each one's effect on terminal acceptance rate. The need exists for a more accurate and consistent method of collecting and analyzing data concerning the runways. There is also a need for more detailed and consistent data concerning the various flights in the United States. This data would be concerned with departure delay, enroute delay, arrival delay, taxi out delay, and taxi in delay. It was most difficult to validate the simulator due to the lack of this kind of data. Several airlines did supply the author with some of this data, but it was not complete. Also, there was no information concerning the number of flights which actually reported that they encountered delay. Finally, there exists a need for major terminals to record data concerning acceptance rates, the effect of weather on aircraft operations and the delay which aircraft encounter while in the terminal area. The lack of this kind of data also proved to be a factor in the validation of the simulator. Atlanta does, however, record information concerning the total number of operations, the total delay encountered, and the hourly acceptance rates which the author used in validating the simulator. Other major terminals need to record accurate information similar to that obtained from Atlanta.

Also, combinations of the scheduling algorithms developed in this research or other scheduling algorithms could be investigated to determine the effect on unscheduled delay. For example, combine the uniform algorithm and the tagging algorithm. Thus, the area of scheduling appears to be a lucrative one in terms of reducing unscheduled delay, one which should be investigated in more detail.

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APPENDICES

Appendix A

DESCRIPTION OF COMPUTER PROGRAM

Variable Definitions

NA1 - the number of actual flights in the system.

NT - the number of terminals in the system.

NTIM - conversion factor converting minutes to seconds.

NSTOP - variable controlling the termination of the simulator.

IWRIT - variable controlling the write statements in the simulator.
= 0, written
= 1, not written

ISS - variable controlling which scheduling algorithm will be used.
= 0, OAG
= 1, uniform
= 2, simultaneous uniform
= 3, peak demand uniform
= 4, tagging

NREPS - the number of days to be simulated.

IADD - the number of synthesized flights in the system.

IAD1 - the variable controlling the time interval when the synthesized flights will be added.
= 0, morning
$\geq$ 0, afternoon

ENDEL - total enroute delay.

SENDEL - the sum of squares for enroute delay.

NEN - the number of aircraft which actually go enroute.

NDAY - the present day being simulated.

NA - the total number of aircraft in the system.

ISZ - variable related to tagging algorithm which indicates whether or not an aircraft gets tagged when its initial demand for departure occurs.
= 0, tagged
= 1, allowed to depart

ISU - variable controlling when the number of aircraft that must wait is incremented in subroutine FUTCAP.
= 0, increment number by one
= 1, do not increment

IX	- seed for random number generator.
MSTOP	- variable controlling the termination of the simulator, associated with NSTOP.
MBEGPD	- variable controlling beginning of peak demand period in the morning.
MENDPD	- variable controlling the ending of the peak demand period in the morning.
NBEGPD	- variable controlling the peak demand period in the evening.
NENDPD	- variable controlling the end of the peak demand period in the afternoon.
ITHDEL	- total arriving delay for aircraft in the system.
ITWDEL	- total departing delay for aircraft in the system.
DIST(I,J)	- distance between terminal I and terminal J.
KFA	- variable used in controlling which algorithm will be used in in conjunction with the peak demand uniform algorithm. = 1, uniform = 2, simultaneous uniform
NAI	- counter used in determining the number of idle aircraft in the system.
NAM(I,J)	- array containing the airlines corresponding to aircraft I.
CHAR(I,J)	- array containing the characteristics of aircraft I. J = 1, type J = 2, cruise speed
NFN(I)	- flight number corresponding to aircraft I.
NDF(I)	- number of flight legs which aircraft I has each day.
NADF1(I,J)	- departure terminal for Jth flight leg of aircraft I.
NADF2(I,J)	- destination terminal for Jth flight leg of aircraft I.
NADF3(I,J)	- departure time for Jth flight leg of aircraft I.
CSA	- random error associated with cruise speed.
NDDF(I)	- current flight leg of aircraft I.
NTAG(I)	- variable controlling whether or not aircraft I has been tagged. = 0, has not been tagged = 1, has been tagged.

NACFT(I,J) - array storing present information concerning aircraft I, used as a "working" array which changes with time.
J = 1, departure terminal
J = 2, destination terminal
J = 3, status of aircraft

NACTM(I) - array storing next event time of aircraft I.

NTER - terminal under consideration at any given time.

NUST(L,K) - stores the number of departure demands already scheduled at terminal L during Kth hour.

NHAC(L,K) - stores the acceptance rate for terminal L during Kth hour.

NST - time between departure time slots.

NSOP(L) - the number of simultaneous operations which can occur at terminal L.

NFCAP(L,M) - the number of aircraft scheduled for service at terminal L during the Mth fifteen minute interval of the day.

TNEXT - next event time.

NCCAP - time interval between periodic reviews of terminal.

NDT(L,K) - number of departures from terminal L during Kth hour.

NAT(L,K) - number of arrivals at terminal L during Kth hour.

NHT(L,K) - number of arrivals which hold at terminal L during Kth hour.

NWT(L,K) - number of departures which wait at terminal L during Kth hour.

IWDEL(L,K) - total departure delay at terminal L during Kth hour.

IHDEL(L,K) - total arrival delay at terminal L during Kth hour.

SSQUD(L,K) - sum of squares of delay time for departures at terminal L during Kth hour.

SSQUA(L,K) - sum of squares of delay time for arrivals at terminal L during Kth hour.

NACAP(L) - number of aircraft actually occupying runways at terminal L at any given time.

NWS(L) - number of aircraft in waiting stack at terminal L.

NCHCAP(L) - time of next periodic review at terminal L.

INEXT(J) - array storing smallest time associated with terminals and aircraft.
J = 1, aircraft
J = 2, terminal
J = 3, end of simulation

NUEV(J) - variable corresponding to whether or not an aircraft and terminal event occurred simultaneously.
J = 1, either type occurred
J = 2, both types occurred
J = 3, end of day's operation

NV - number of aircraft having the same next event time.

NFFP(N) - array storing aircraft number associated with the Nth aircraft having the present next event time.

NIAT - number of terminals having the same next event time.

IDMT(N) - array storing terminal number associated with the Nth terminal having the same next event time.

NKN - aircraft number associated with Nth event.

NCAPTR(L) - present acceptance rate for terminal L.

EDIS - random error associated with distances between any two terminals.

ENRT - enroute time.

EX - random error added to enroute time.

DISTAN - distance presently being considered.

NCSAV(L) - variable used to indicate whether or not the acceptance rate at terminal L has increased from zero.

NCE - random error associated with the acceptance rate of a given terminal.

NEARTM - expected arrival time used in tagging algorithm.

NFMAC - acceptance rate associated with the expected time of arrival and the 15 minute interval in which it occurs.

NWSO(M,L) - aircraft number corresponding to Mth position in waiting stack at terminal L.

NDEL(I) - time at which aircraft I demanded service.

NDUM(M,L) - dummy array used in moving aircraft up in the waiting stack once an aircraft leaves the stack.

AWT - average waiting time.

SDWT - standard deviation of waiting time.

AHT - average holding time.

SDAT - standard deviation of holding time.

RAND - uniformly distributed random number.

NTT - the number of terminals in system minus one.

IKEY - variable controlling when the number of aircraft that must wait, or hold, is incremented.
= 0, increment by one
= 1, do not increment

LF - departure terminal.

LT - destination.

NEN - number of aircraft which actually go enroute.

XLAM - mean of normal distribution.

SIG - standard deviation of normal distribution.

NXTD - total number of aircraft that depart.

NXTA - total number of aircraft that land.

XNTT - total holding time for arriving aircraft.

XWTT - total waiting time for departing aircraft.

WTT(L) - total waiting time at terminal L.

NTDT(L) - total number of departures at terminal L.

NTWT(L) - total number of aircraft that must wait at terminal L.

NTAT(L) - total number of arrivals at terminal L.

NTHT(L) - total number of aircraft that must hold at terminal L.

SDSQ(L) - sum of squares for total departure delay at terminal L.

SHSQ(L) - sum of squares for total arrival delay at terminal L.

XWTT - total system departure delay.

XHTT - total system arrival delay.

AEND - average enroute delay.

AXWTT - average departure delay per aircraft in system.

AXHTT - average arrival delay per aircraft in system.

Main Program

The purpose of this portion of the simulator is to control the basic operations of the simulator. From it the subroutine to read in the flight plan data, the subroutine to initialize variables associated with the terminals, the subroutine to determine the next event, and the subroutine to calculate the statistics concerning delay are called. Also, the matrix containing the distances between terminals, variables associated with the different scheduling algorithms and variables related to the termination of the simulator are initialized. In the cycle of determining the next event, the main program acts as the beginning and the end of the process which determines and services the next event. In other words, the subroutine that determines the number of idle aircraft in the system is reviewed. If all aircraft are idle then the simulator terminates and the hourly delay statistics are calculated. Otherwise, the minimum next event time is found and is operated upon, until the day's operations have been simulated. At this time the hourly delay statistics are accumulated. (For flow chart see Figure A.1.)

Subroutine FLIGHT

The purpose of this subroutine is to read into the simulator the daily flight plans for each aircraft in the system. The following parameters are given for each aircraft in the system:

1) Airline associated with each flight
2) Aircraft characteristics
    a) Type (i.e., 707, 727, 747, DC8)
    b) Best cruise speed

3) Flight number

4) Number of daily flight legs

5) Departure terminal, destination terminal, and departure time for each flight leg.

After all the parameters given above are read into the simulator for any given aircraft, the ones associated with the initial flight of the day are stored in the corresponding arrays which will be used in determining the next event. Thus, the original data is not used in determining the next event but instead "working" arrays which are continuously changing are used. (See Figure A.2 for flow chart.)

Subroutine ADFLT

This subroutine will synthesize N additional flights during a given time interval during the day. This includes departure terminal, destination, and departure time for each flight synthesized. These flights are synthesized to determine the effect of more aircraft in the system on the various scheduling algorithms. (For flow chart see Figure A.3.)

Subroutine UNIFM

This subroutine is used to schedule aircraft either according to the uniform scheduling algorithm or the simultaneous uniform scheduling algorithm. The method used is based on the following concept. First, determine the departure terminal of the aircraft under consideration. Second, determine in which hour of the day that aircraft demands departure service. Third, calculate the time interval between departure time slots using the acceptance rate of the departure terminal for the hour calculated above. Finally, based on the hour of the day and the number of aircraft previously scheduled at the departure terminal under consideration, assign the aircraft being considered a departure time. (For flow chart see Figure A.4.)

Subroutine PDUNIF

Subroutine PDUNIF schedules aircraft either according to the uniform algorithm or the simultaneous uniform algorithm during the peak demand periods of the day. The basic procedure is given below. First, determine if the aircraft under consideration has a departure time for its first flight leg during one of the peak demand periods. Second, determine the departure terminal for the aircraft being considered. Third, calculate the hour of the day in which the departure demand occurs. Finally, assign a departure time to the aircraft based on the number of aircraft previously scheduled at the same terminal and the terminal's acceptance rate. (For flow chart see Figure A.5.)

Subroutine TAGSCH

Subroutine TAGSCH is used in conjunction with the tagging scheduling algorithm. At the beginning of the simulation it calculates the projected number of flights departing each terminal during any given time interval. This is only done for the initial flight leg of the day for each aircraft. When an aircraft completes its first flight leg and has remaining flight legs, the projected number of flights departing a terminal is incremented during the appropriate time interval, which is based on the new departure time. (For flow chart see Figure A.6.)

Subroutine TERCAP

This subroutine will read in the time interval between periodic reviews at each terminal, the number of simultaneous operations each terminal can service, and the average hourly acceptance rate for each hour of the day. Also, it initializes all variables associated with the terminals concerning the number of departures, the number of arrivals, the number of aircraft that must wait, and delay time. (For flow chart see Figure A.7.)

Subroutine NEXT

This subroutine controls the steps for determining the next event time. The steps involved are finding the smallest next event time among all aircraft, finding the smallest time among periodic review times for the terminals, setting the end of simulation time and choosing the minimum time among the above times. Once this has been done the appropriate subroutine, which will operate on the next event, will be called. (For flow chart see Figure A.8.)

Subroutine ACNEXT

Subroutine ACNEXT determines the minimum next event time among all the aircraft in the system. It is called from subroutine NEXT and returns INEXT (1) to subroutine NEXT. (For flow chart see Figure A.9.)

Subroutine TERNEX

Subroutine TERNEX determines the minimum next event time among the terminals in the system, where the event would be a periodic review of the acceptance rate. This subroutine is called from subroutine NEXT and returns the value of INEXT (2) to subroutine NEXT. (For flow chart see Figure A.10.)

Subroutine AOPER

Subroutine AOPER services the aircraft next events according to the status of a given flight. Depending on the status of the flight under consideration, the aircraft will either be allowed to occupy a runway, either departing or arriving, will clear the runway and start its enroute portion of the flight, or become idle, or be put into the waiting stack to wait for conditions to permit its service. (For flow chart see Figure A.11.)

Subroutine ENROUT

This subroutine calculates the enroute time for any given flight based on the distance to be travelled, vectoring distance, and best cruise speed. (For flow chart see Figure A.12.)

Subroutine ERDEL

This subroutine is associated with determining the amount of enroute delay an aircraft will encounter for a given flight leg. It generates this delay time from a normal distribution using a mean and a variance selected by the analyst. It uses the normal process generator as given in Simulation and Analysis of Industrial Systems by Schmidt and Taylor. (For flow chart see Figure A.13.)

Function VECT

This function is associated with calculating the vectoring distance for a given flight once it departs. It generates this distance from a normal distribution using a mean and a variance selected by the analyst. It also uses the normal process generator as described by Schmidt and Taylor. (For flow chart see Figure A.14.)

Subroutine SERDES

This subroutine will assign an aircraft a position in the waiting stack at a given terminal and perform the necessary adjustments to aircraft's status and next event time. The subroutine will also increase the number of aircraft that must wait, or the number of aircraft that must hold, based on the previous status of the aircraft. (For flow chart see Figure A.15.)

Subroutine UNSTAC

Subroutine UNSTAC will service an aircraft which leaves the waiting stack after an aircraft has cleared the runway. In effect, this subroutine will remove the first aircraft from the waiting stack and allow it to occupy a runway. In addition, it will call subroutine DELAY to calculate delay statistics for their aircraft. (For flow chart see Figure A.16.)

Subroutine DELAY

This subroutine calculates the amount of delay which an aircraft may encounter while waiting for service, either departure or arrival. The basic concept is that the amount of delay encountered will be equal to the difference between the actual time of service and the desired time of service. (For flow chart see Figure A.17.)

Subroutine FUTCAP

This subroutine is associated with the tagging scheduling algorithm. It estimates the enroute time for a flight and then predicts the time interval, T, in which that flight will arrive at its destination. Based on the terminal's hourly acceptance rate, it will determine if the flight would be allowed service during that time interval, T. If so, the flight is allowed to depart at the present time; otherwise, the flight will be tagged and must wait. (For flow chart see Figure A.18.)

Subroutine OPWRIT

Subroutine OPWRIT will write the appropriate information relative to the present aircraft event. This subroutine is only called when the IWRIT parameter is equal to zero. (For flow chart see Figure A.19.)

Subroutine WRIDEL

Subroutine WRIDEL calculates hourly delay statistics for each terminal at the end of the simulation. This includes the number of aircraft that demand departure (arrival) service, the number of aircraft that wait (hold), and the average delay encountered by an aircraft and standard deviation. (For flow chart see Figure A.20.)

Subroutine TODEL

Subroutine TODEL accumulates the total delay statistics for each terminal at the end of the simulation. Also, it gives total departure delay, total arrival delay, and average enroute delay. (For flow chart see Figure A.21.)

Subroutine TWRIT

Based on whether or not all "write" statements are being written, this subroutine will write the appropriate information each time a periodic review is taken. This subroutine is called only when IWRIT is equal to zero. (For flow chart see Figure A.22.)

Subroutine PUSHUP

Subroutine PUSHUP will advance all aircraft occupying positions in the waiting stack at a given terminal one position. This advancing will occur after the aircraft occupying the first position has been removed from the waiting stack and allowed to occupy the runway. (For flow chart see Figure A.23.)

Subroutine NEXFLI

Subroutine NEXFLI is used to determine the information relative to an aircraft's subsequent flight leg once that aircraft has completed its previous flight leg. The subroutine determines the departure terminal, the destination, and the time at which the aircraft will demand departure service. (For flow chart see Figure A.24.)

Subroutine TCAPY

Subroutine TCAPY controls the steps in reviewing the acceptance rate of the terminals when a periodic review is found to be the next event. It controls the calling of the subroutine CHANG, which determines the new hourly acceptance rate when appropriate. (For flow chart see Figure A.25.)

Subroutine CHANG

This subroutine determines the new hourly acceptance rate for a given terminal at each periodic review. (For flow chart see Figure A.26.)

Function RAND

This function generates a uniformly distributed random number between zero and one. It is taken from Simulation and Analysis of Industrial Systems by Schmidt and Taylor. (For flow chart see Figure A.27.)

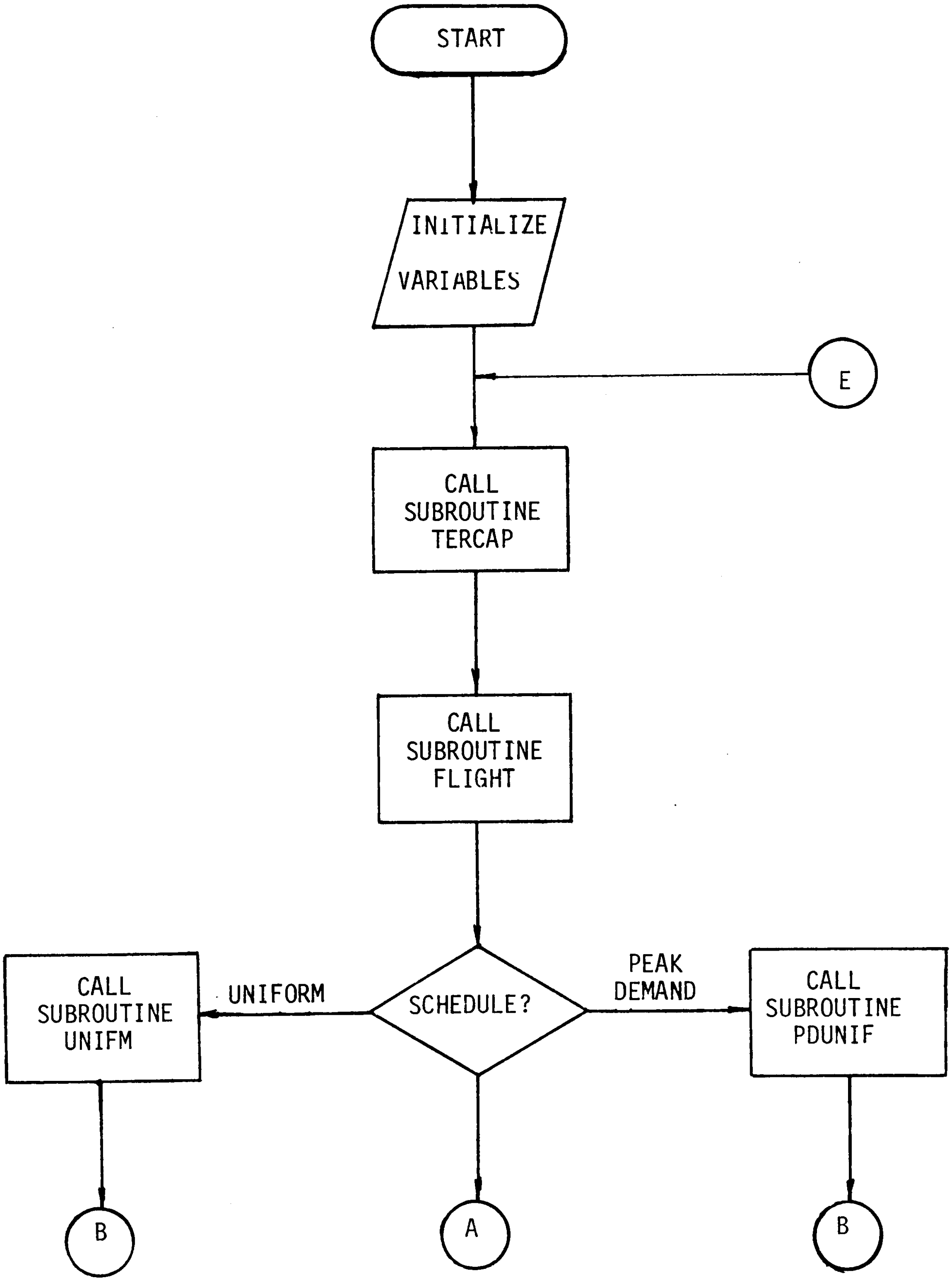
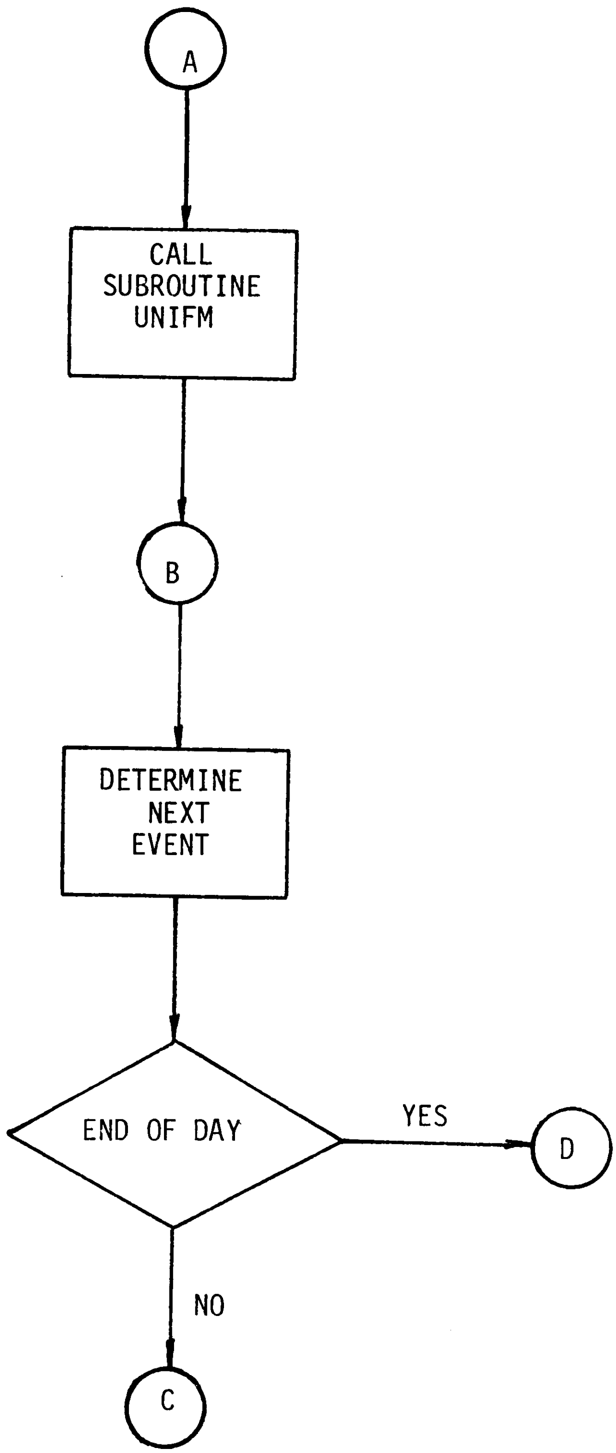


Figure A.1 Macro Flow Chart of Main Program



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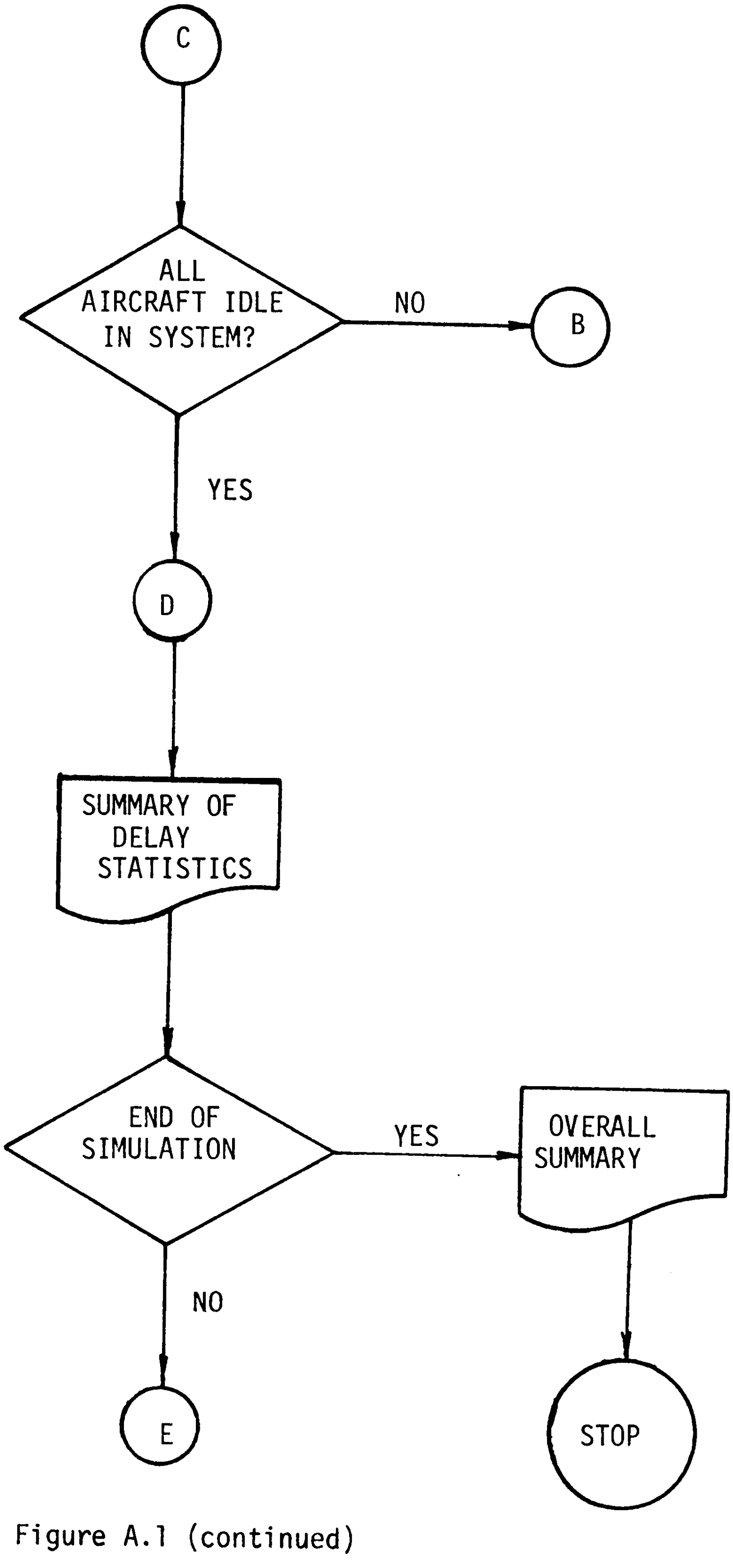

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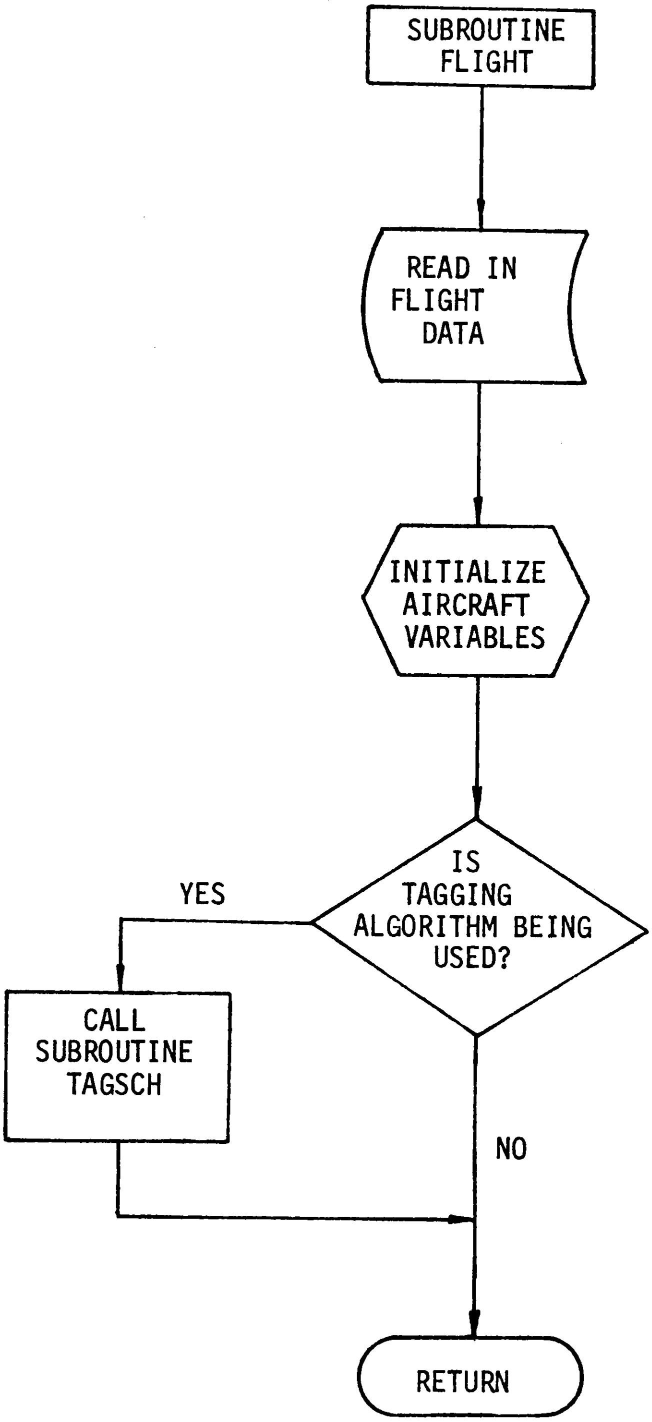


Figure A.2 Macro Flow Chart of Subroutine FLIGHT

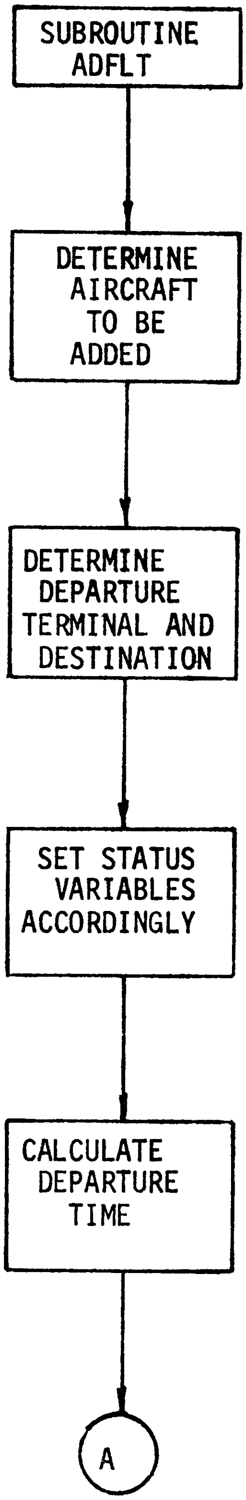
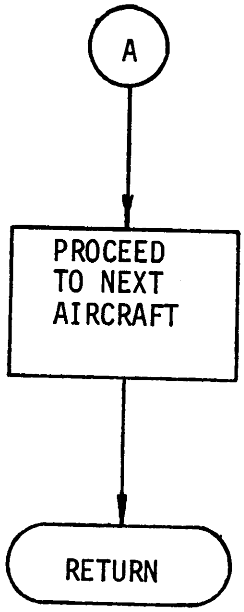


Figure A.3 Macro Flow Chart of Subroutine ADFLT



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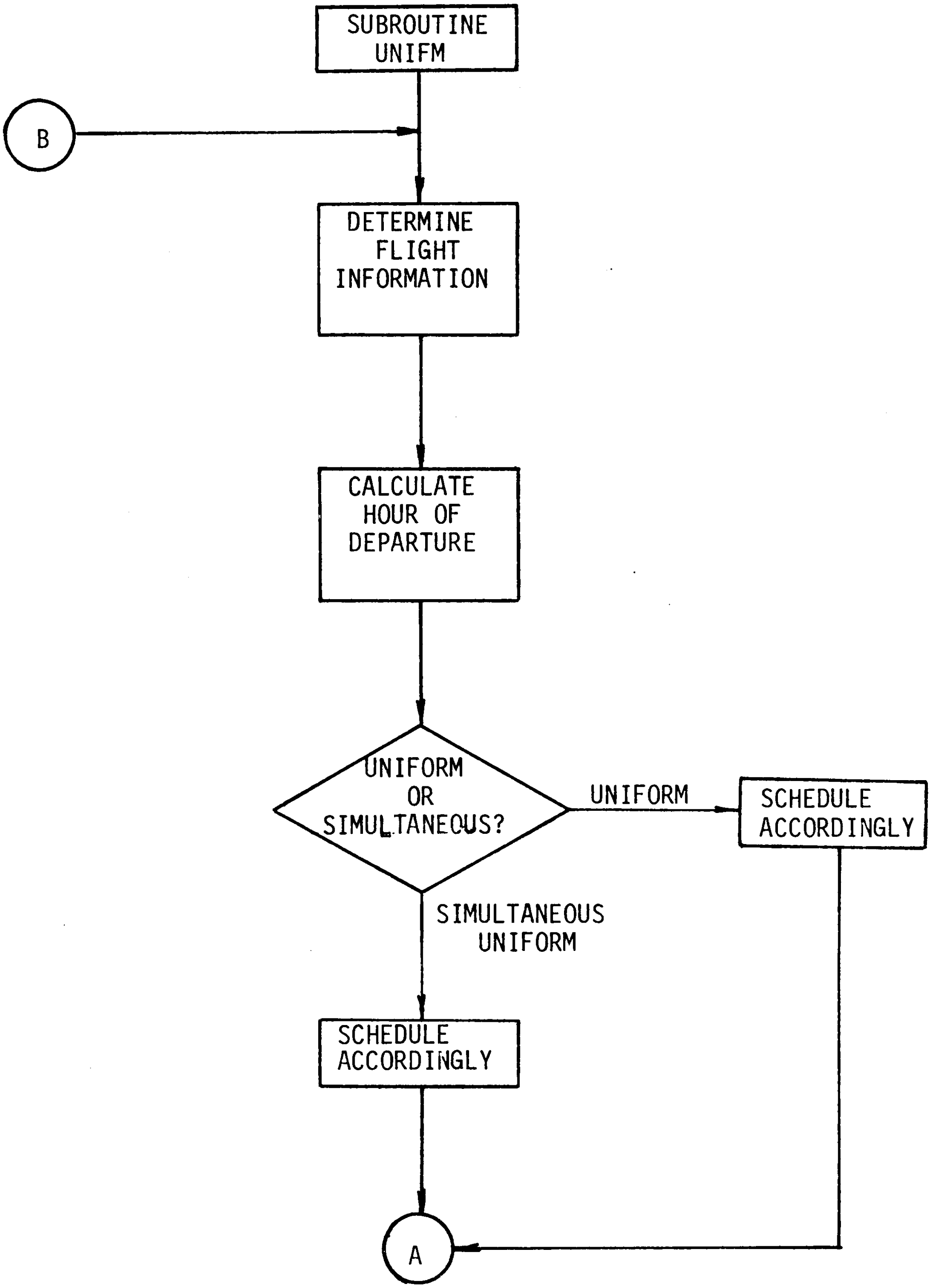
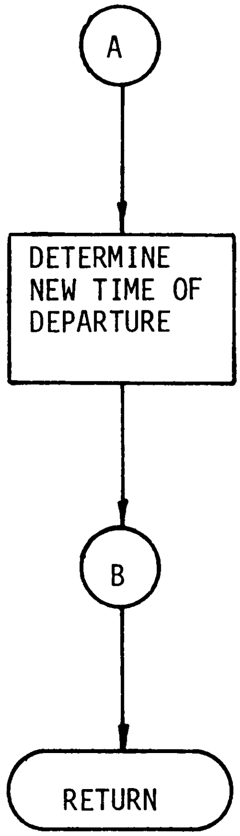


Figure A.4 Macro Flow Chart of Subroutine UNIFM



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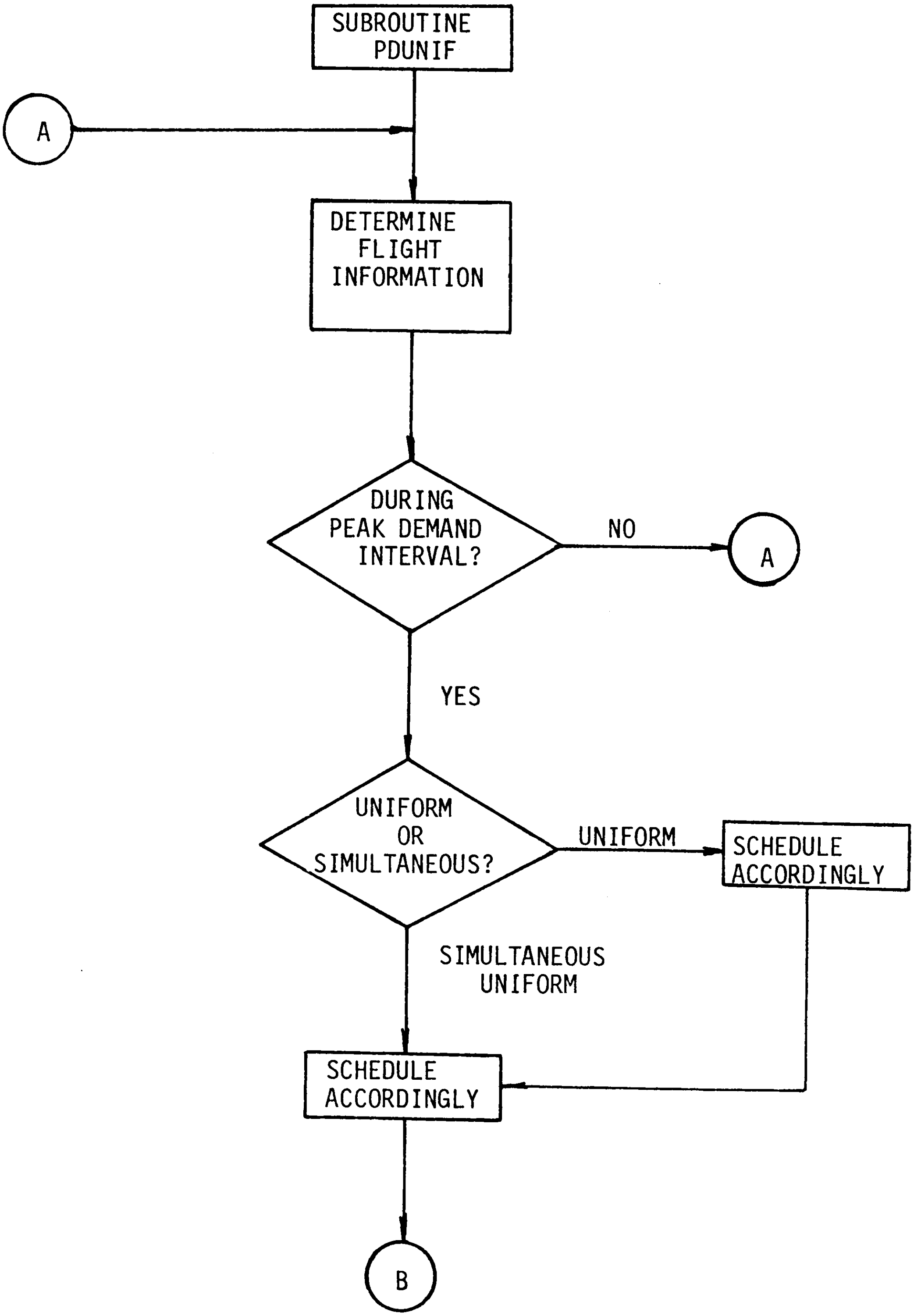
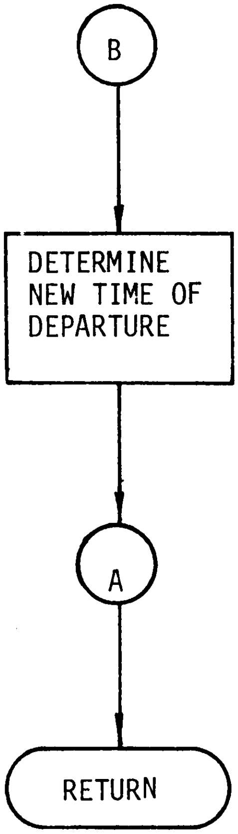


Figure A.5 Macro Flow Chart of Subroutine PDUNIF



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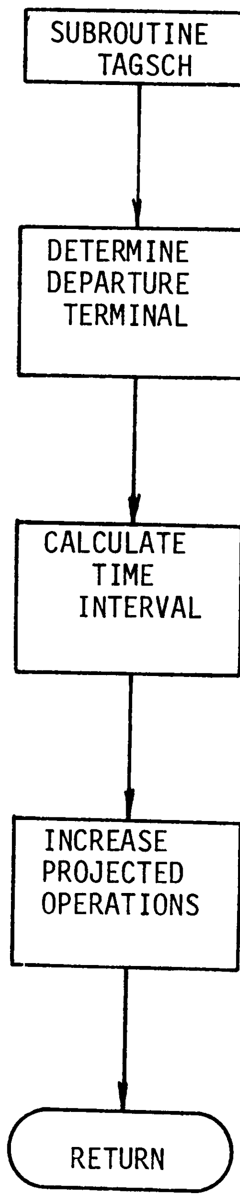


Figure A.6 Macro Flow Chart of Subroutine TAGSCH

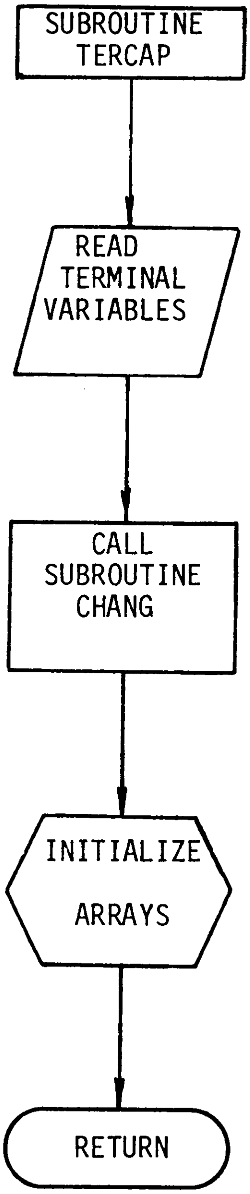


Figure A.7 Macro Flow Chart of Subroutine TERCAP

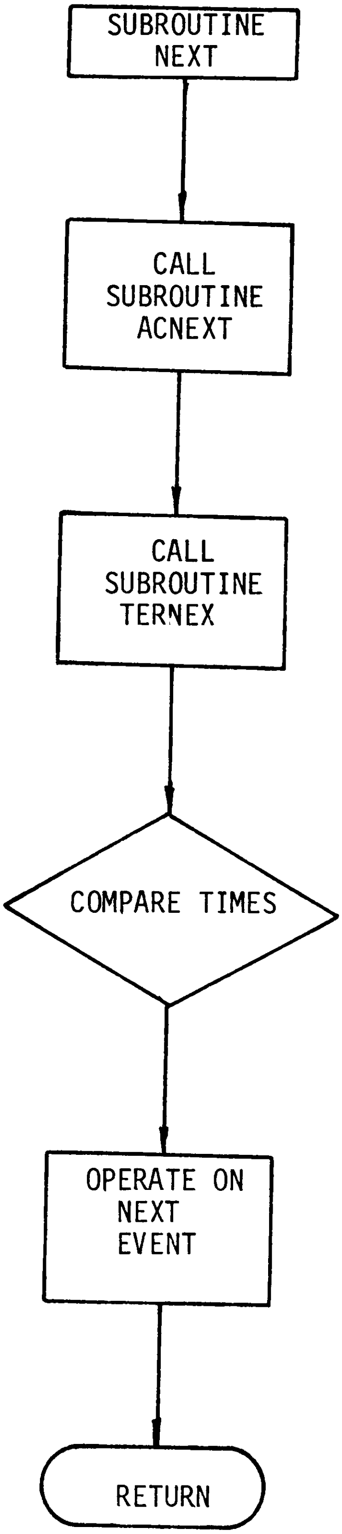


Figure A.8 Macro Flow Chart of Subroutine NEXT

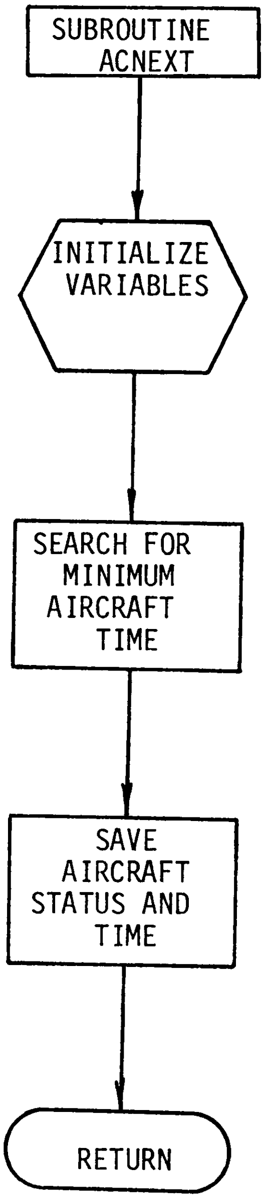


Figure A.9 Macro Flow Chart of Subroutine ACNEXT

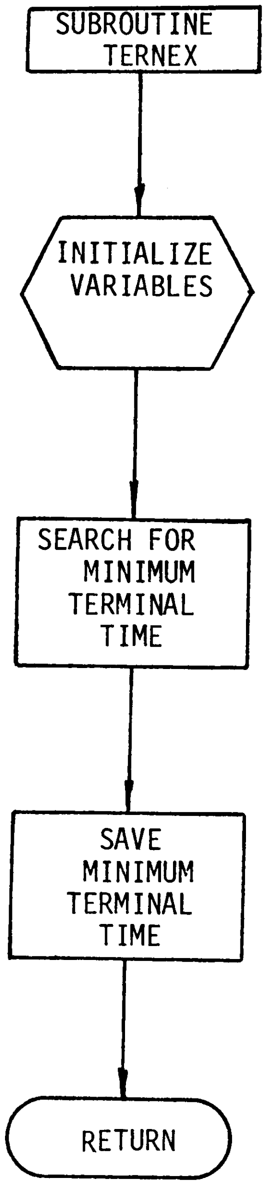


Figure A.10 Macro Flow Chart of Subroutine TERNEX

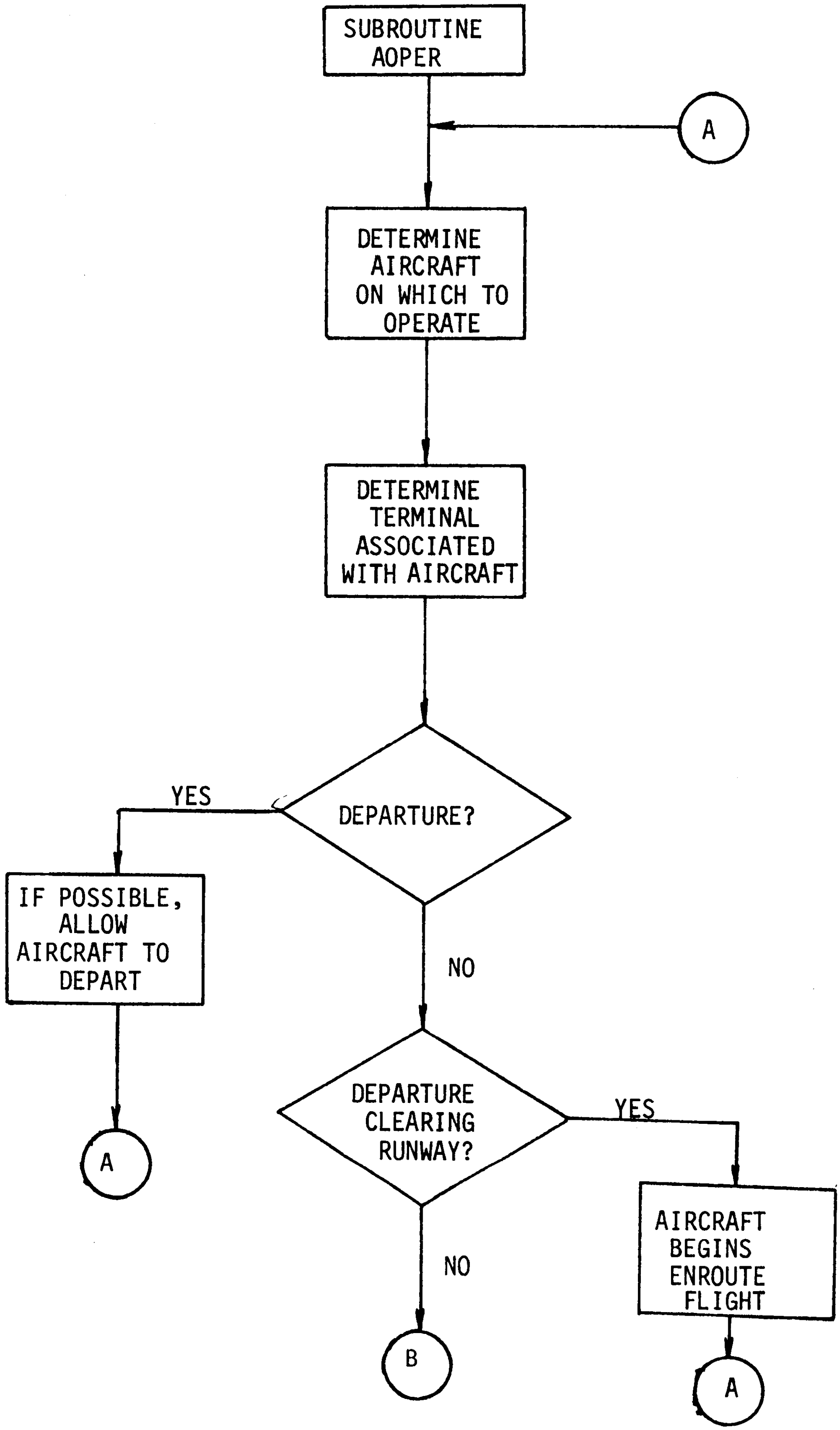
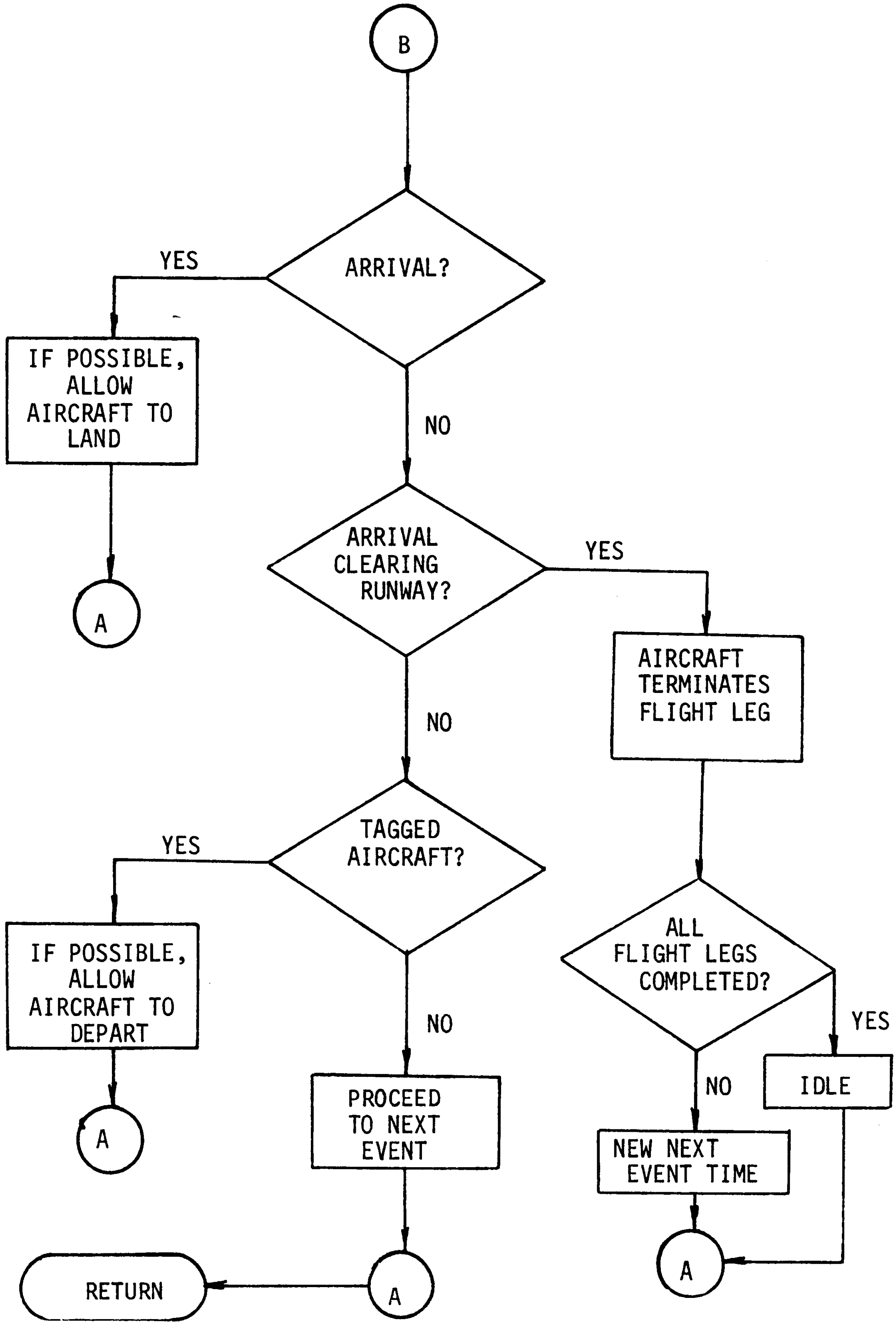


Figure A.11 Macro Flow Chart of Subroutine AOPER



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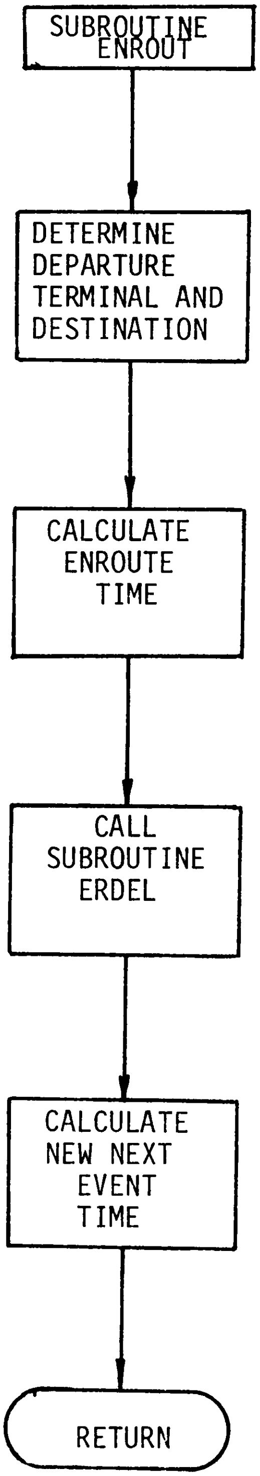


Figure A.12 Macro Flow Chart of Subroutine ENROUT

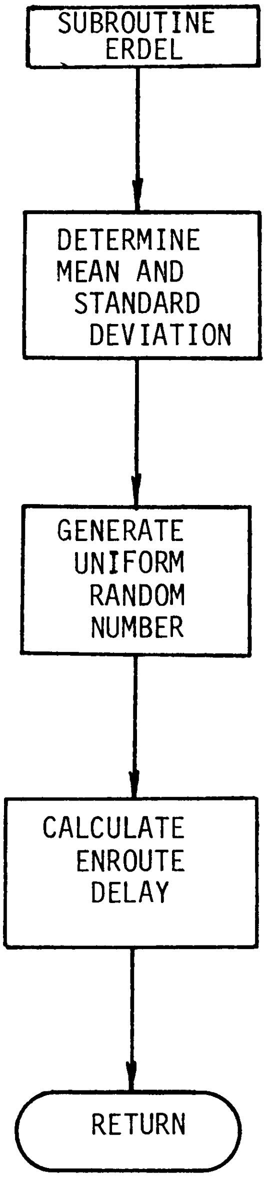


Figure A.13 Macro Flow Chart of Subroutine ERDEL

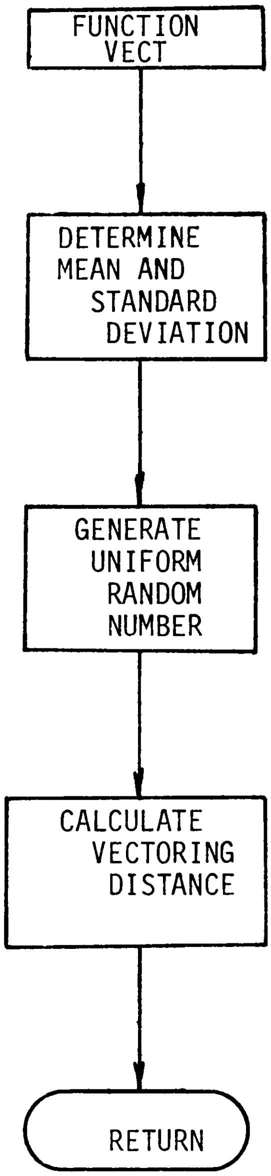


Figure A.14 Macrc Flow Chart of Function VECT

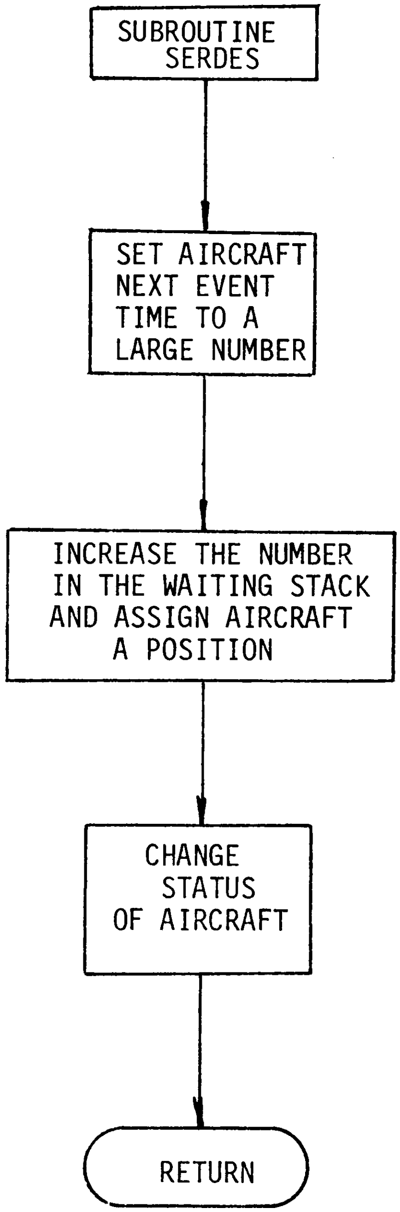


Figure A.15 Macro Flow Chart of Subroutine SERDES

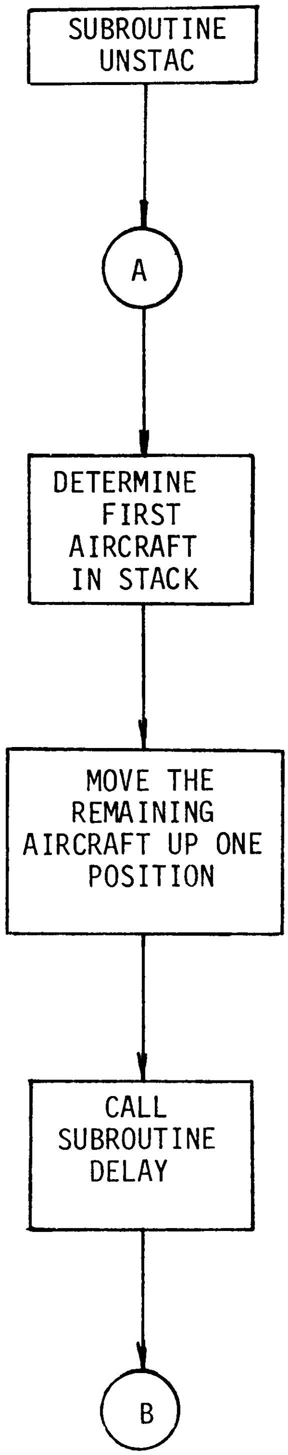
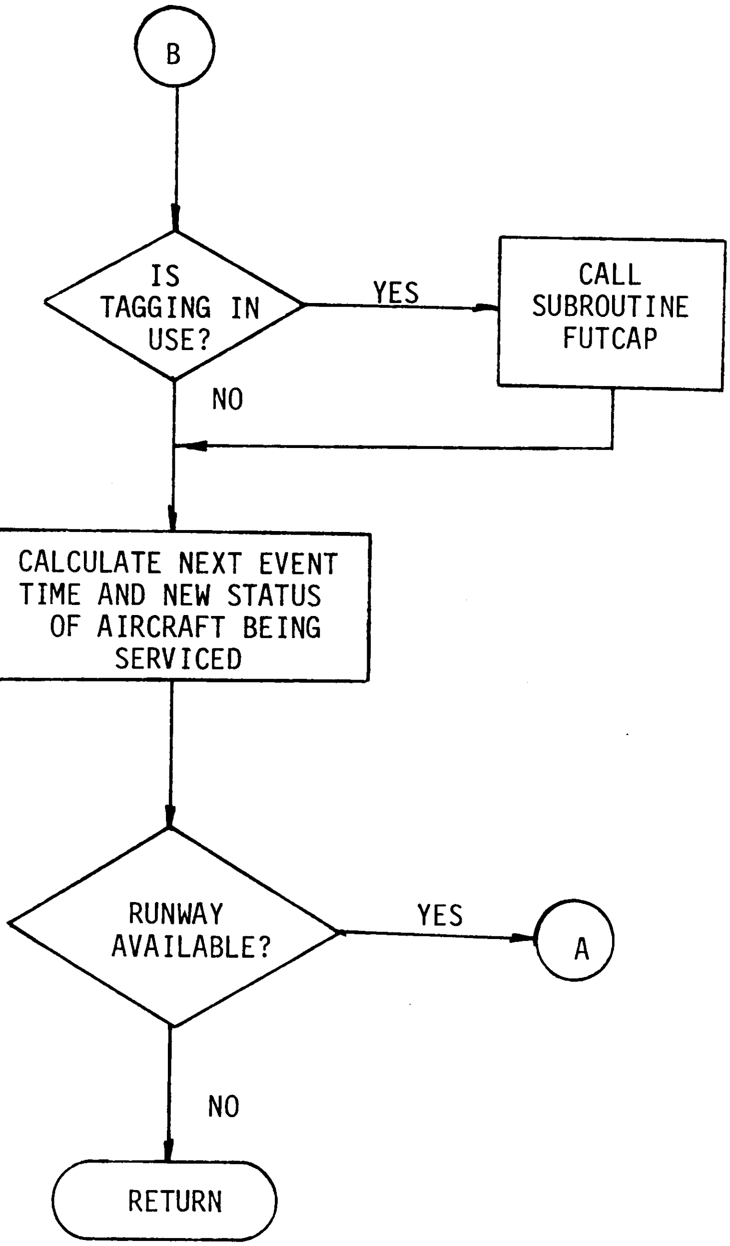


Figure A.16 Macro Flow Chart of Subroutine UNSTAC



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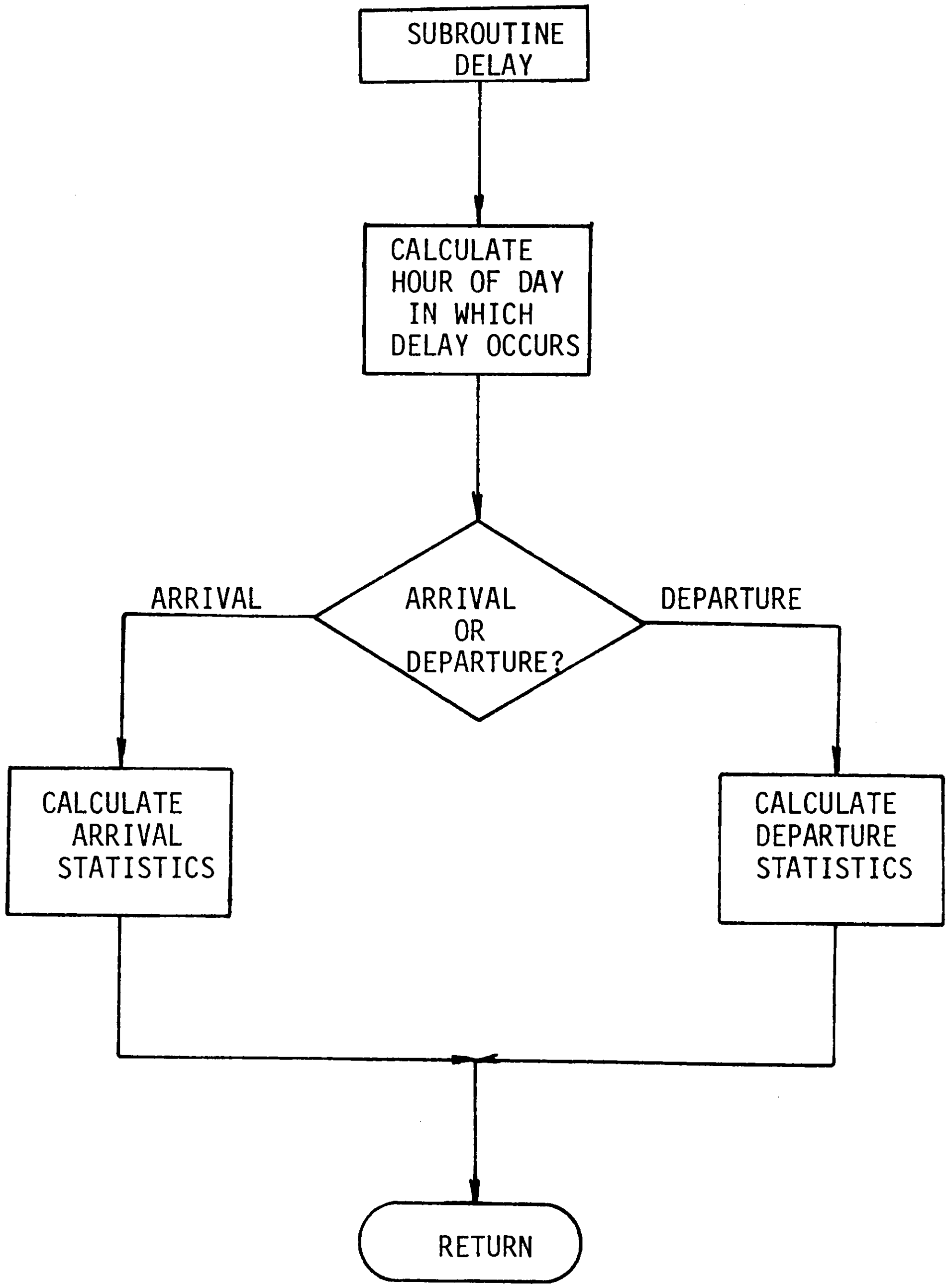


Figure A.17 Macro Flow Chart of Subroutine DELAY

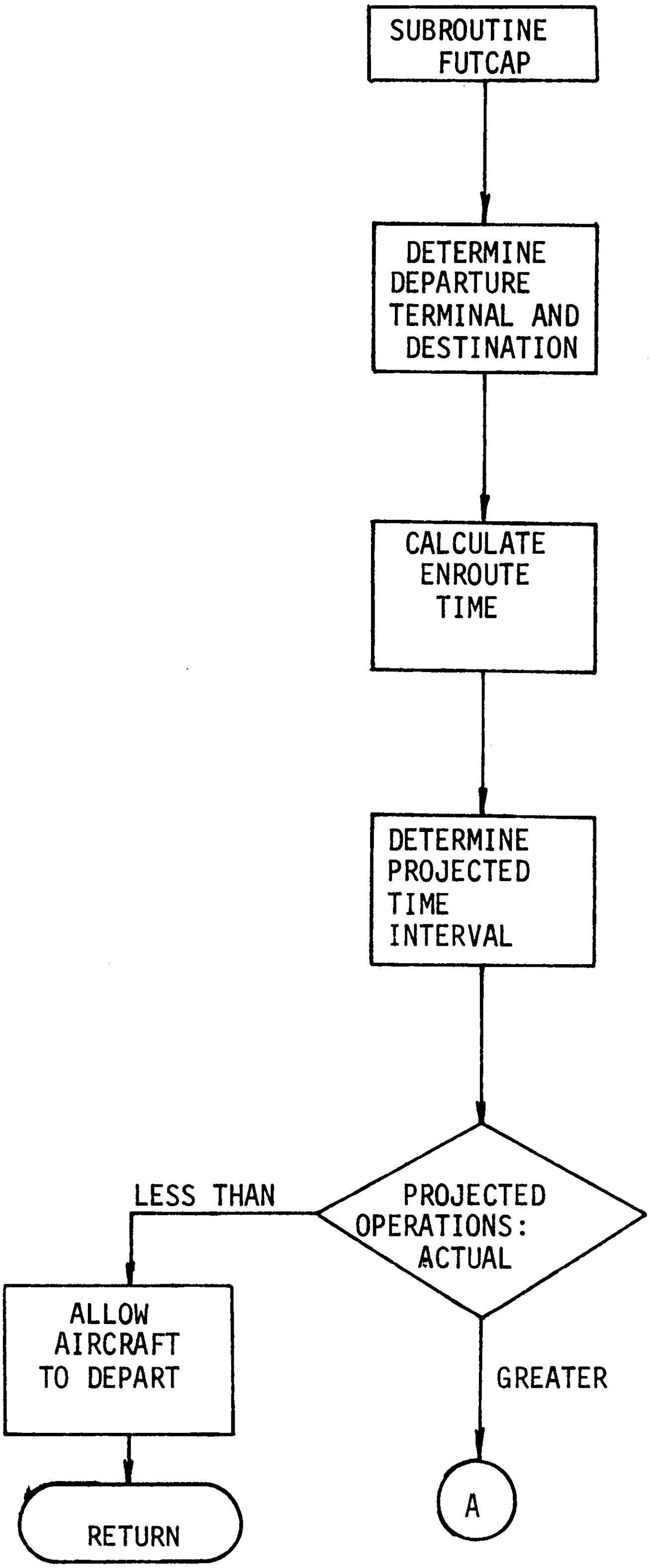
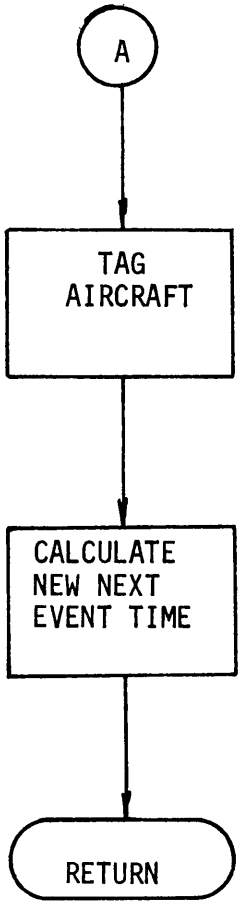


Figure A.18 Macro Flow Chart of Subroutine FUTCAP



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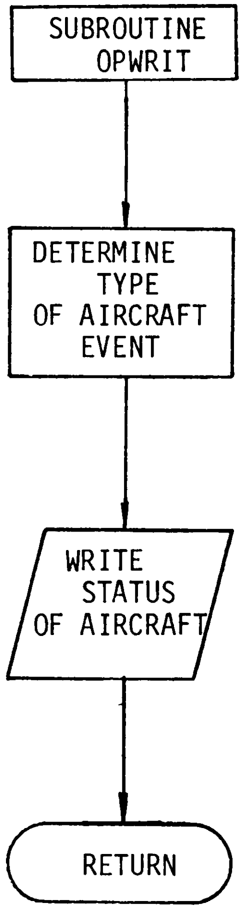

Figure A.19 Macro Flow Chart of Subroutine OPWRIT

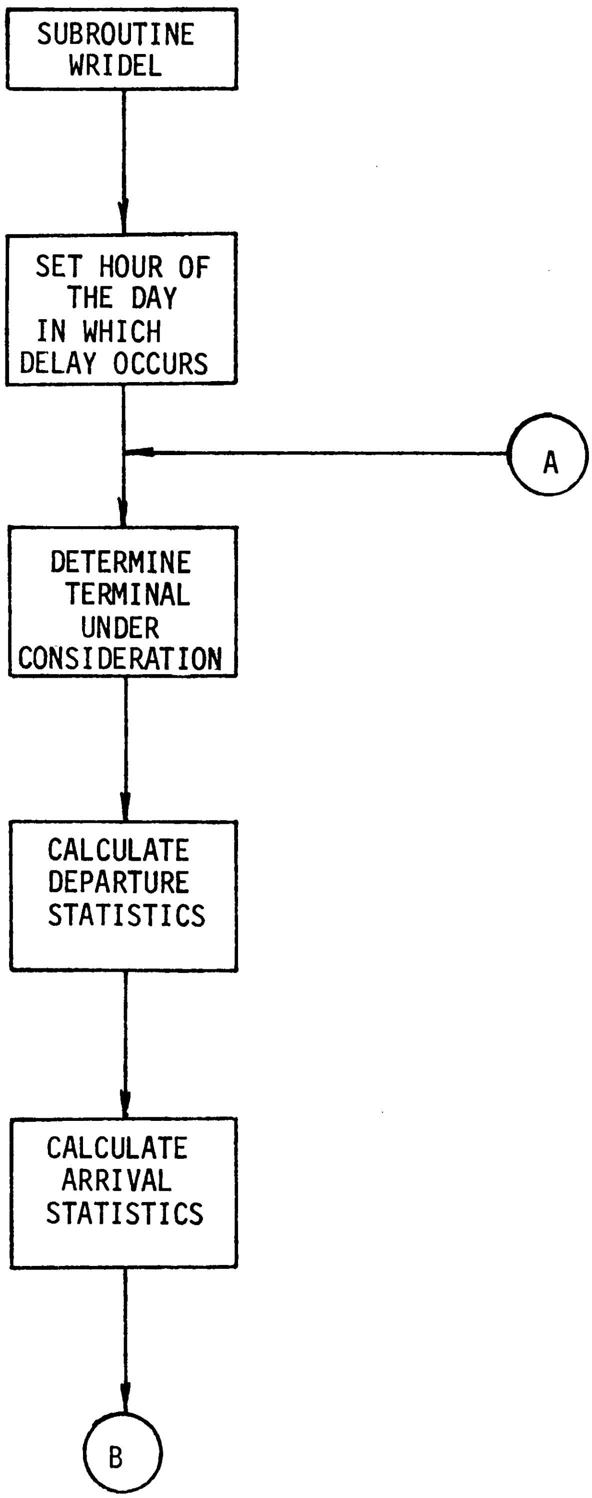

Figure A.20 Macro Flow Chart of Subroutine WRIDEL

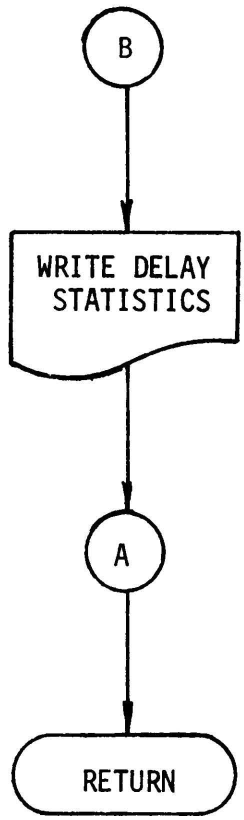

Figure A.20 (continued)

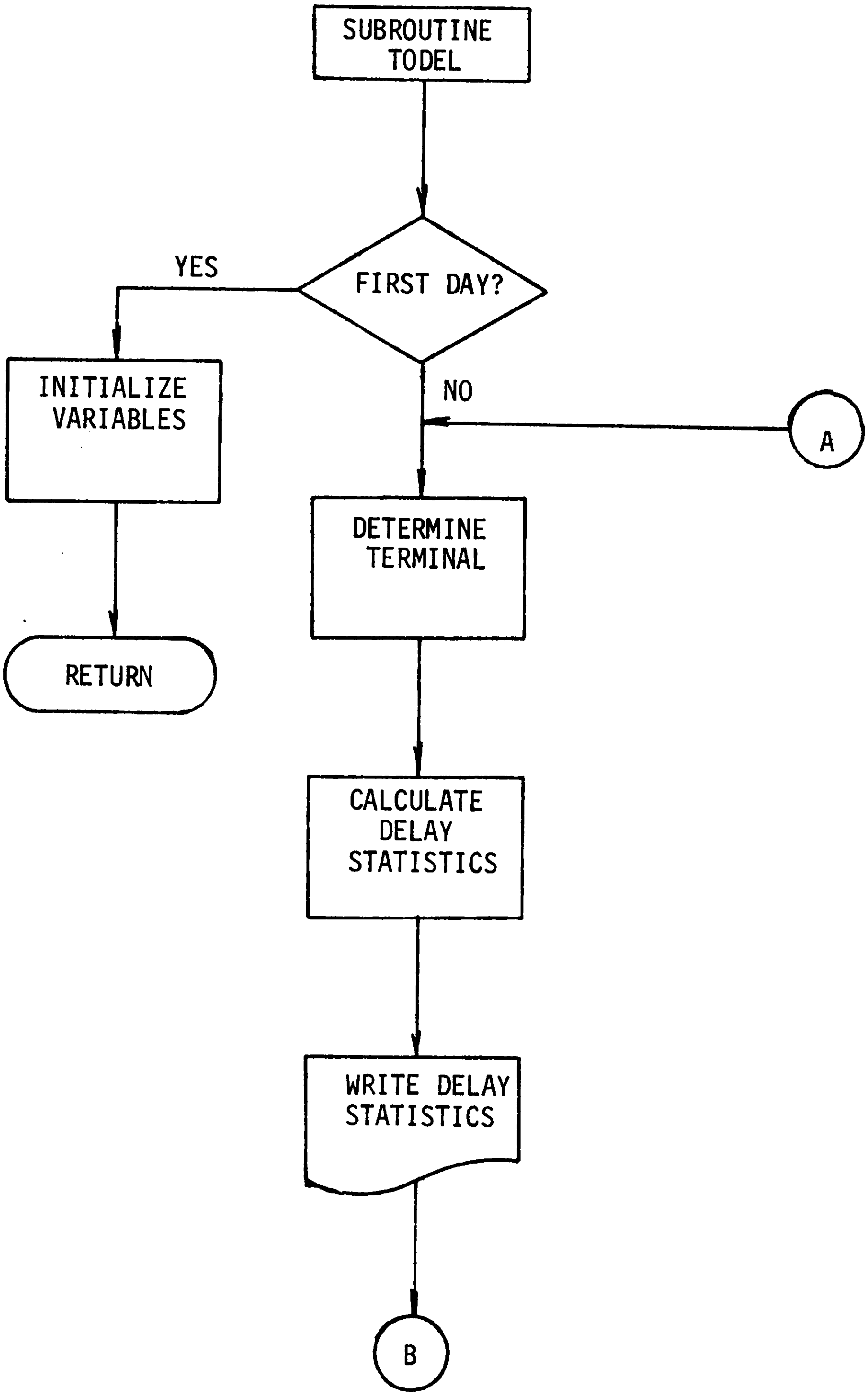

Figure A.21 Macro Flow Chart of Subroutine TODEL

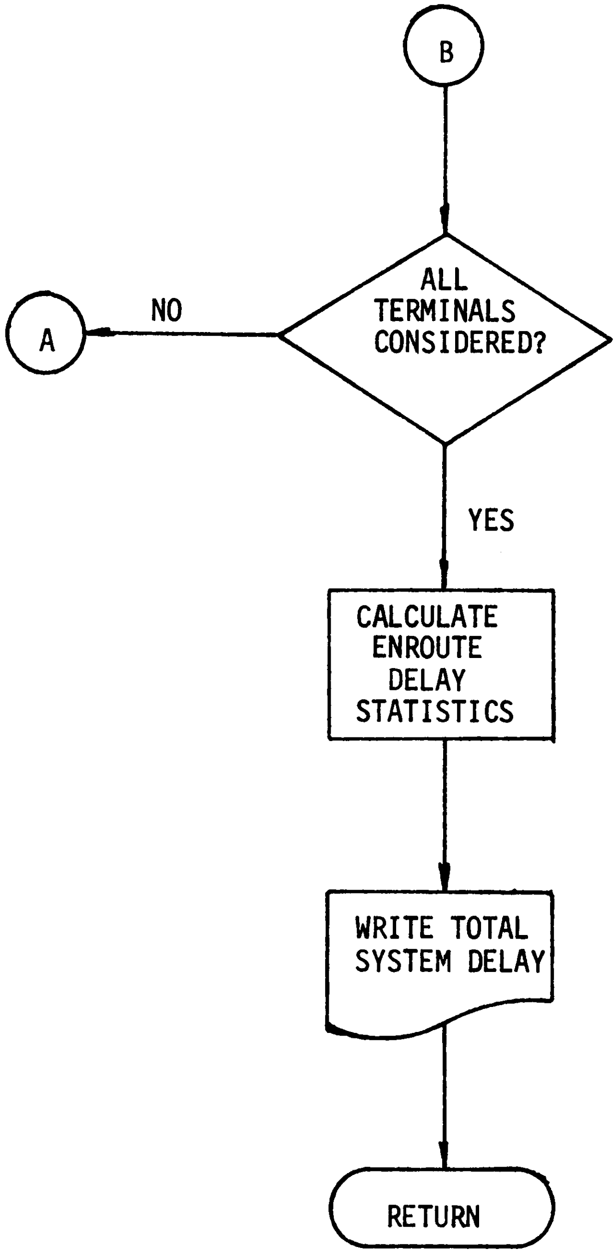

Figure A.21 (continued)

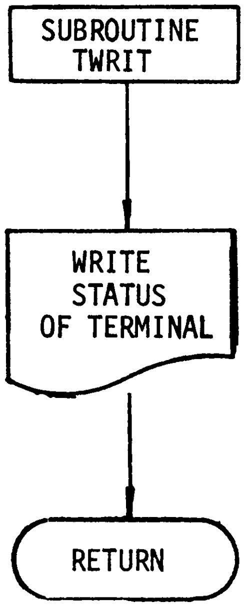

Figure A.22 Macro Flow Chart of Subroutine TWRIT

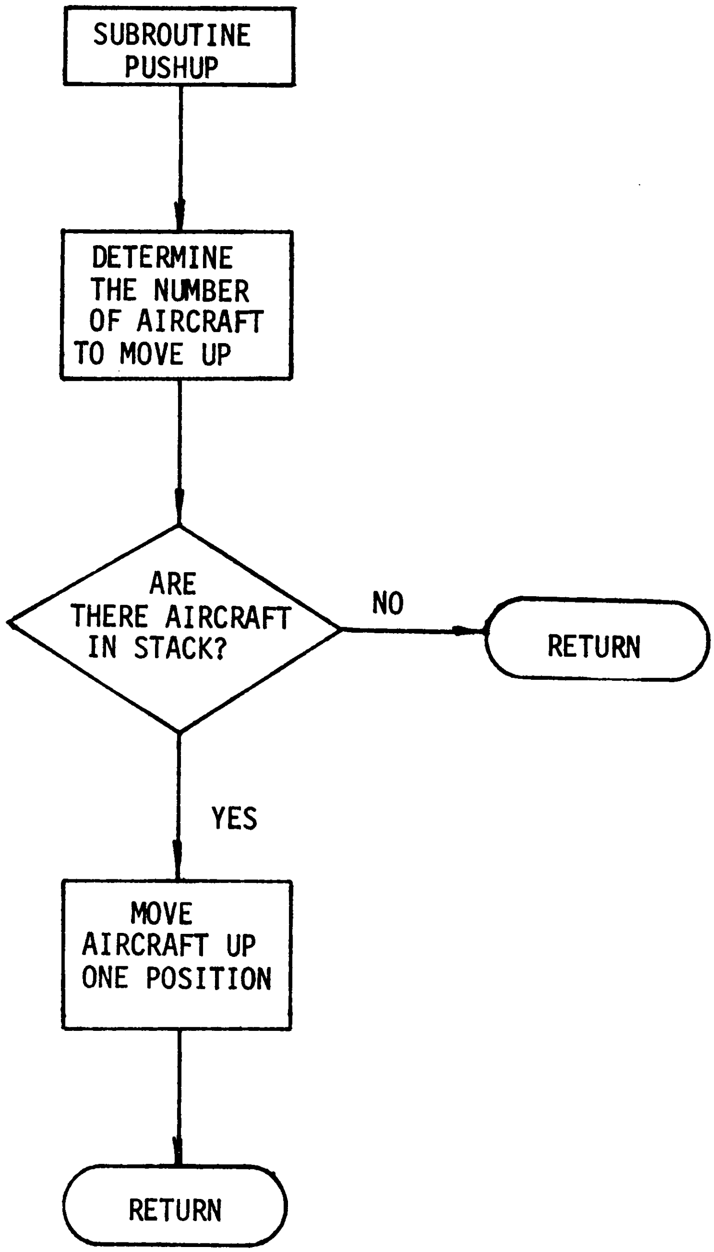

Figure A.23 Macro Flow Chart of Subroutine PUSHUP

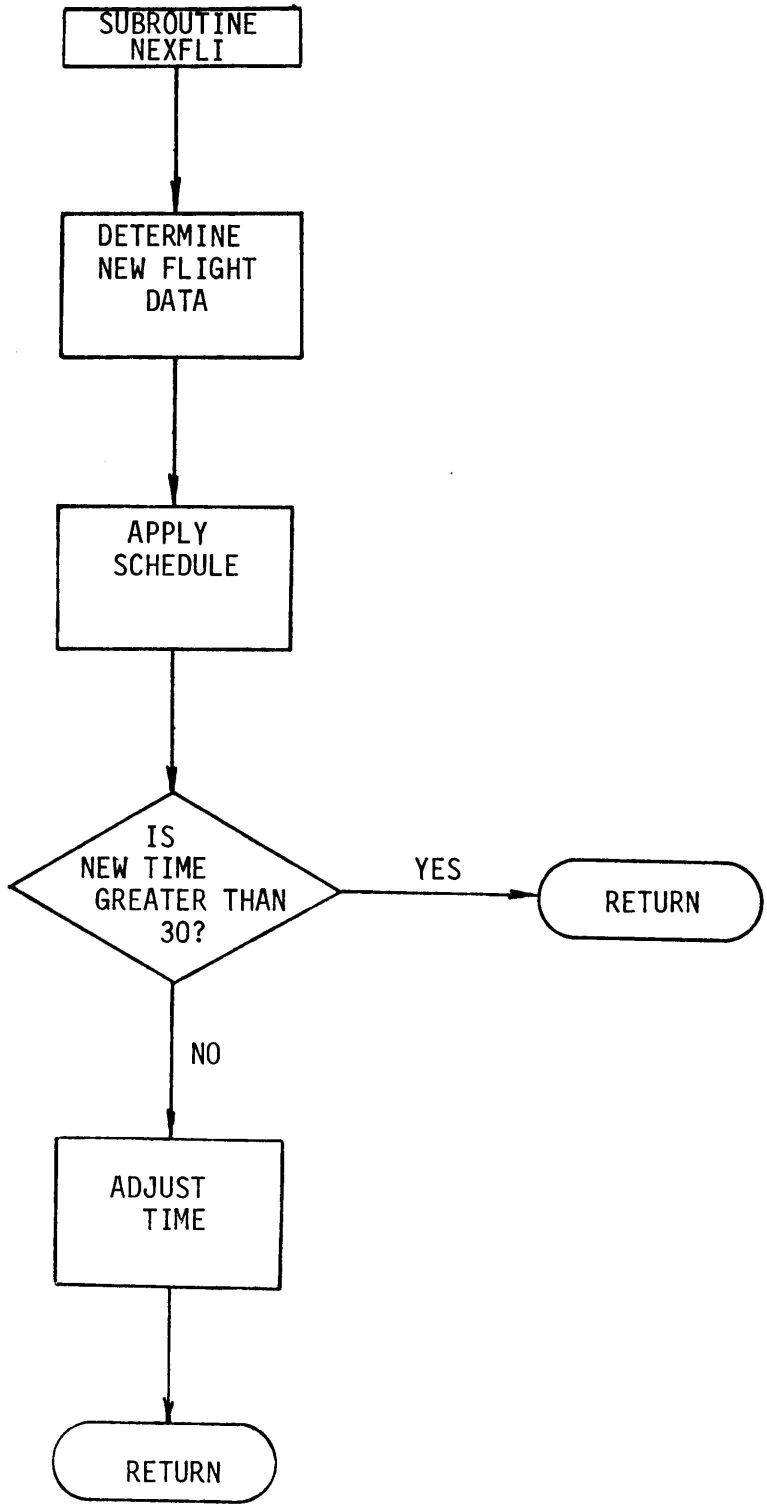

Figure A.24 Macro Flow Chart of Subroutine NEXFLI

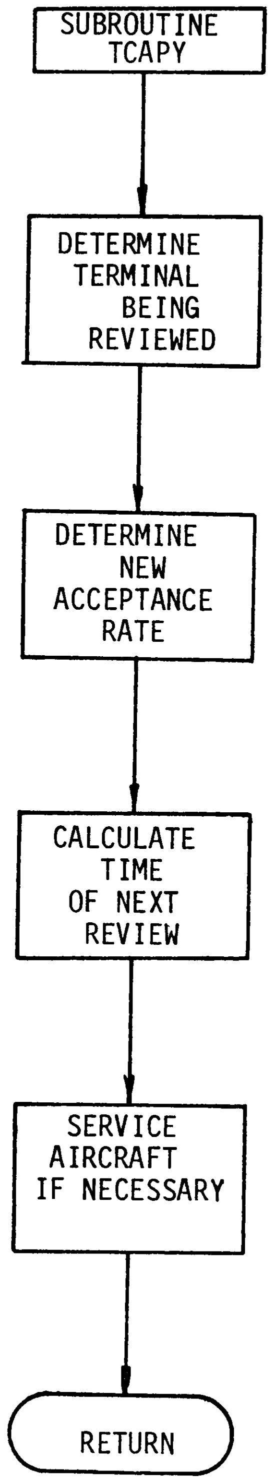

Figure A.25 Macro Flow Chart of Subroutine TCAPY

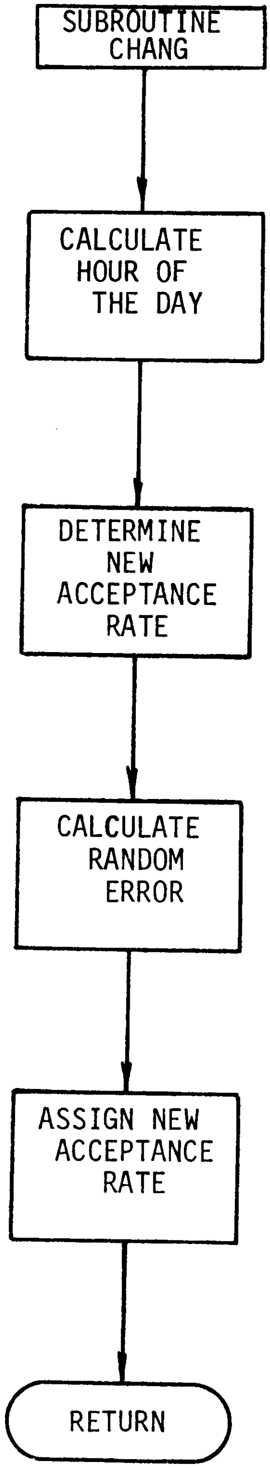

Figure A.26 Macro Flow Chart of Subroutine CHANG

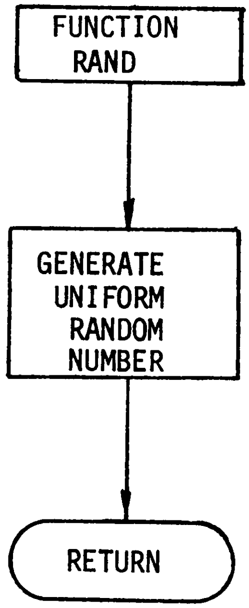

Figure A.27 Macro Flow Chart of Function RAND

APPENDIX B: SAMPLE OF INPUT FLIGHT DATA

```
AIRLINES:       EASTERN
AIRCRAFT TYPE:        737.
AIRCRAFT CRUISE SPEED:       570.
FLIGHT NUMBER:     616
DEPARTURE TERMINAL:         20     3
DESTINATION:                 3    31
DEPARTURE TIME:            570   735

AIRLINES:       EASTERN
AIRCRAFT TYPE:        737.
AIRCRAFT CRUISE SPEED:       570.
FLIGHT NUMBER:     624
DEPARTURE TERMINAL:          3
DESTINATION:                29
DEPARTURE TIME:            565

AIRLINES:       EASTERN
AIRCRAFT TYPE:        72.
AIRCRAFT CRUISE SPEED:       530.
FLIGHT NUMBER:     981
DEPARTURE TERMINAL:          7    24
DESTINATION:                24     3
DEPARTURE TIME:            375   515

AIRLINES:       EASTERN
AIRCRAFT TYPE:        72.
AIRCRAFT CRUISE SPEED:       530.
FLIGHT NUMBER:     982
DEPARTURE TERMINAL:          3    24
DESTINATION:                24     7
DEPARTURE TIME:            625   720

AIRLINES:       EASTERN
AIRCRAFT TYPE:        727.
AIRCRAFT CRUISE SPEED:       520.
FLIGHT NUMBER:     989
DEPARTURE TERMINAL:         37     3
DESTINATION:                 3    25
DEPARTURE TIME:            165   320
```

APPENDIX C: SAMPLE OUTPUT

STATISTICS FOR THE 5TH HOUR OF THE DAY
10 A.M. - 11 A.M.

TERMINAL #	# DEPT.	WAITING TIME	AVE. WAITING TIME	STD. DEV.
1	50 (12)	637	12.74	24.931
2	32 (23)	4780	149.38	134.609
3	87 (71)	13552	155.77	127.430
4	26 (8)	286	11.00	19.361
5	33 (5)	110	3.33	9.317
6	37 (29)	4999	135.11	130.690
7	26 (14)	1291	49.65	60.515

STATISTICS FOR THE 5TH HOUR OF THE DAY
10 A.M. - 11 A.M.

TERMINAL #	# LND.	HOLDING TIME	AVE. HOLDING TIME	STD. DFV.
1	30 (9)	270	9.00	19.594
2	20 (14)	2114	105.70	130.866
3	37 (30)	4266	115.30	109.457
4	5 (0)	0	0.00	0.000
5	25 (5)	143	5.72	13.425
6	21 (16)	3174	151.14	145.363
7	21 (16)	1674	79.71	73.107

APPENDIX D: TABLES OF SAS RESULTS

Table D.I

Results of SAS Three-Way Analysis of Variance for 1750 Aircraft Based on Departure Delay

Source	df	SS	MS	F Value
Schedule	2	200273.98	100136.992	480.39*
Terminal	6	154830.38	25805.063	123.79*
Hour	23	258949.93	11258.69	54.01*
(Schedule)(Terminal)	12	230899.97	19241.66	92.31*
(Schedule)(Hour)	46	341085.40	7414.90	35.57*
(Terminal)(Hour)	138	1001554.70	7257.643	34.81*
(Schedule)(Terminal)(Hour)	276	1763683.65	6390.158	30.65*
Within Cell	1008	210113.35	208.44	
Corrected Total	1511	4161391.36	2754.06	

* Significant at the .995 level.

Table D.II

Results of SAS Three-Way Analysis of Variance
for 2250 Aircraft Based on Departure Delay
(Synthesized flights added in the morning)

Source	df	SS	MS	F Value
Schedule	2	171361797	85680898.4	385.5*
Terminal	6	205586928	34264487.9	154.1*
Hour	23	349230898	15183952.1	68.3*
(Schedule)(Terminal)	12	504251036	42020919.7	189.1*
(Schedule)(Hour)	46	477958870	10390410.2	46.7*
(Terminal)(Hour)	138	455249561	3298909.9	14.8*
(Schedule)(Terminal)(Hour)	276	1056337347	3827309.2	17.2*
Within Cell	1008	223991724	222214.0	
Corrected Total	1511	3443968160	2279264.2	

* Significant at the .995 level.

Table D.III

Results of SAS Three-Way Analysis of Variance
for 2250 Aircraft Based on Departure Delay
(Synthesized flights added in the afternoon)

Source	df	SS	MS	F Value
Schedule	2	130209792	65104896	922.9*
Terminal	6	28064407	4677401.2	66.3*
Hour	23	195523487	8501021.2	120.5*
(Schedule)(Terminal)	12	61553806	5129483.9	72.7*
(Schedule)(Hour)	46	351496156	7641220.8	108.3*
(Terminal)(Hour)	138	82024324	594379.2	8.4*
(Schedule)(Terminal)(Hour)	276	174262673	631386.5	8.9*
Within Cell	1008	71101101	70536.8	
Corrected Total	1511	1094235747	724179.8	

* Significant at the .995 level.

Table D.IV

Results of SAS Three-Way Analysis of Variance for 2750 Aircraft Based on Departure Delay (Synthesized flights added in the morning)

Source	df	SS	MS	F Value
Schedule	2	1195758961	597879480	4003.1*
Terminal	6	526464513	87744086	587.4*
Hour	23	1631597117	70939005	474.9*
(Schedule)(Terminal)	12	1058907981	88242332	590.8*
(Schedule)(Hour)	46	2936055149	63827286	427.3*
(Terminal)(Hour)	138	1424758781	10324339	69.1*
(Schedule)(Terminal)(Hour)	276	3066571781	11110767	74.3*
Within Cell	1008	150547554	149353	
Corrected Total	1511	11990661837	7935580	

*Significant at the .995 level.

Table D.V

Results of SAS Three-Way Analysis of Variance
for 2750 Aircraft Based on Departure Delay
(Synthesized flights added in the afternoon)

Source	df	SS	MS	F Value
Schedule	2	616540498	308270249	3247.5 *
Terminal	6	211246013	35207669	370.9 *
Hour	23	1440754168	62641486	659.9 *
(Schedule)(Terminal)	12	136162464	11364872	119.5 *
(Schedule)(Hour)	46	2012778856	43756062	460.9 *
(Terminal)(Hour)	138	648486497	4699178	49.50*
(Schedule)(Terminal)(Hour)	276	717300086	2598913	27.3 *
Within Cell	1008	95681912	94923	
Corrected Total	1511	5878950494	3890768	

* Significant at the .995 level.

Table D.VI

Results of SAS Three-Way Analysis of Variance for 1750 Aircraft Based on Arrival Delay

Source	df	SS	MS	F Value
Schedule	2	2994.33	1497.16	51.68*
Terminal	6	31511.09	5251.84	181.31*
Hour	23	13596.03	591.13	20.40*
(Schedule)(Terminal)	12	4020.48	335.04	11.56*
(Schedule)(Hour)	46	6023.66	130.94	4.52*
(Terminal)(Hour)	138	48150.57	348.91	12.04*
(Schedule)(Terminal)(Hour)	276	36962.80	133.92	4.62*
Within Cell	1008	29196.95	28.96	
Corrected Total	1511	172455.94	114.13	

* Significant at the .995 level.

Table D.VII

Results of SAS Three-Way Analysis of Variance
for 2250 Aircraft Based on Arrival Delay
(Synthesized flights added in the morning)

Source	df	SS	MS	F Value
Schedule	2	17788517	8894258.2	1941.1*
Terminal	6	23963650	3993941.7	871.6*
Hour	23	36225101	1575004.4	343.7*
(Schedule)(Terminal)	12	29892006	3324333.8	725.5*
(Schedule)(Hour)	46	59590465	1295444.8	282.7*
(Terminal)(Hour)	138	72496647	525338.0	114.6*
(Schedule)(Terminal)(Hour)	276	123902630	448922.5	97.9*
Within Cell	1008	4618617	4581.96	
Corrected Total	1511	378477633	250481.5	

* Significant at the .995 level.

Table D.VIII

Results of SAS Three-Way Analysis of Variance
for 2250 Aircraft Based on Arrival Delay
(Synthesized flights added in the afternoon)

Source	df	SS	MS	F Value
Schedule	2	43418.5	21709.2	6.4*
Terminal	6	637606.3	106267.7	31.5*
Hour	23	1203537.0	52327.6	15.5*
(Schedule)(Terminal)	12	171536.9	14294.7	4.2*
(Schedule)(Hour)	46	510659.9	11101.3	3.2*
(Terminal)(Hour)	138	2800186.2	20291.2	6.0*
(Schedule)(Terminal)(Hour)	276	1421958.0	5152.0	1.5*
Within Cell	1008	3394508.2	3367.5	
Corrected Total	1511	10183411.0	6739.51	

* Significant at the .995 level.

Table D.IX

Results of SAS Three-Way Analysis of Variance
for 2750 Aircraft Based on Arrival Delay
(Synthesized flights added in the morning)

Source	df	SS	MS	Value
Schedule	2	17997017	8998508.6	1170.3*
Terminal	6	36051159	6008526.5	781.4*
Hour	23	47380015	2060000.6	267.9*
(Schedule)(Terminal)	12	43375577	3614631.4	470.1*
(Schedule)(Hour)	46	67196852	1460801.1	189.9*
(Terminal)(Hour)	138	115106977	834108.5	108.4*
(Schedule)(Terminal)(Hour)	276	156230415	566052.2	73.6*
Within Cell	1008	7750046	7688.54	
Corrected Total	1511	491088059	325008.6	

* Significant at the .995 level.

Table D.X

Results of SAS Three-Way Analysis of Variance for 2750 Aircraft Based on Arrival Delay (Synthesized flights added in the afternoon)

Source	df	SS	MS	F Value
Schedule	2	14965320	7482659.8	480.3*
Terminal	6	127636024	21272670.7	1365.6*
Hour	23	218470651	9498723.9	609.7*
(Schedule)(Terminal)	12	26068280	2172356.7	139.4*
(Schedule)(Hour)	46	73891381	1606334.4	103.1*
(Terminal)(Hour)	138	444203629	3218866.9	206.6*
(Schedule)(Terminal)(Hour)	276	132627745	480535.3	30.8*
Within Cell	1008	15701784	15577.2	
Corrected Total	1511	1053564812	697263.3	

* Significant at the .995 level.

Appendix E

TERMINALS INCLUDED IN THE DISTANCE MATRIX

1. New York
2. Chicago
3. Atlanta
4. Los Angeles
5. Washington
6. Dallas
7. Denver
8. Baltimore
9. Boston
10. Buffalo
11. Charlotte
12. Cincinnati
13. Cleveland
14. Columbus, Ohio
15. Dayton
16. Detroit
17. Hartford
18. Houston
19. Indianapolis
20. Jacksonville
21. Kansas City
22. Las Vegas
23. Louisville
24. Memphis
25. Miami
26. Milwaukee
27. Minneapolis
28. Montreal
29. Nashville
30. New Orleans
31. Norfolk
32. Oklahoma City
33. Omaha
34. Ottawa
35. Philadelphia
36. Phoenix
37. Pittsburgh
38. Portland
39. Rochester
40. St. Louis
41. Salt Lake City
42. San Antonio
43. San Diego
44. San Francisco
45. Seattle
46. Syracuse
47. Tampa
48. Toronto
49. Vancouver
50. Winnipeg

APPENDIX F: PROGRAM LISTING

```
C
C ..............................................................
C .     THIS SIMULATOR IS DESIGNED TO SIMULATE THE OPERATIONS      .
C .          OF N AIRCRAFT IN A SYSTEM OF TERMINALS. THE SYSTEM    .
C .          DELAY STATISTICS ARE CALCULATED TO DETERMINE THE      .
C .          EFFECT EACH SCHEDULING ALGORITHM HAS ON DELAY.        .
C ..............................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      INTEGER MBEGPD,MENDPD,NBEGPD,NENDPD
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK11/ NUST(8,24)
      COMMON/BLK12/ NTAG(2750)
      COMMON/BLK13/ MBEGPD,MENDPD,NBEGPD,NENDPD
      COMMON/BLK14/ ENDEL,SENDEL,NEN
      COMMON/BLK15/ WTT(8),NTWT(8),NTDT(8),SDSQ(8),HTT(8),NTHT(8),NTAT(8
     *),SHSQ(8)
C
C ..............................................................
```

```
C .     THE PURPOSE OF THIS PORTION OF THE PROGRAM IS TO INITIALIZE   .
C .          THE NUMBER OF AIRCRAFT IN THE SYSTEM, THE DISTANCE        .
C .          MATRIX, THE SCHEDULING KEY, AND THE VARIABLES RELATED     .
C .          TO TOTAL DELAY. IT CALLS THE VARIOUS SUBROUTINES          .
C .          NECESSARY IN INITIALIZING FLIGHT DATA AND VARIABLES       .
C .          ASSOCIATED WITH THE DELAY STATISTICS AT EACH TERMINAL.    .
C .          IT ALSO CONTROLS THE CALLING OF SUBROUTINE NEXT WHICH     .
C .          WILL DETERMINE THE NEXT EVENT TIME AND TYPE.              .
C ......................................................................
C
C
C ......................................................................
C .     READ DATA TO INITIALIZE THE NUMBER OF AIRCRAFT WHICH WILL     .
C .          BE READ FROM ON-LINE DISK.                                .
C .     READ DATA FOR THE TIME CONVERSION FACTOR, AND THE MAXIMUM     .
C .     ALLOWABLE ENTRY TIME TO THE WAITING STACK.                    .
C ......................................................................
C
      READ(5,60) NA1,NTIM,NSTOP
   60 FORMAT(3I8)
C
C ......................................................................
C .     INITIALIZE THE NUMBER OF DAYS WHICH WILL BE SIMULATED.        .
C .     INITIALIZE THE KEY CONTROLLING THE "WRITE" STATEMENTS.        .
C .     INITIALIZE THE FACTOR CONTROLLING THE SCHEDULING ALGORITHM    .
C .          TO BE USED.                                               .
C ......................................................................
C
      READ(5,61) NREPS
      READ(5,61) IWRIT
      READ(5,61) ISS
C
```

```
C ..................................................................
C .      INITIALIZE TIME INTERVALS TO BE USED DURING THE PEAK DEMAND   .
C .           SCHEDULING ALGORITHM.                                    .
C ..................................................................
C
      READ(5,663) MBEGPD,MENDPD
      READ(5,663) NBEGPD,NENDPD
C
C ..................................................................
C .      INITIALIZE THE NUMBER OF FLIGHTS TO BE SYNTHESIZED AND        .
C .           THE INTERVAL IN WHICH THE FLIGHTS WILL DEPART.           .
C ..................................................................
C
      READ(5,663) IADD,IAD1
  663 FORMAT(2I5)
   61 FORMAT(I5)
C
C ..................................................................
C .      INITIALIZE THE NUMBER OF TERMINALS TO BE USED IN THE          .
C .           SYSTEM.                                                  .
C .      INITIALIZE THE RANDOM NUMBER SEED.                            .
C .      INITIALIZE THE SIMULATION TERMINATION FACTOR TO ZERO.         .
C ..................................................................
C
      NT=8
      IX=65539
      MSTOP=0
      MBEGPD=MBEGPD*NTIM
      MENDPD=MENDPD*NTIM
      NBEGPD=NBEGPD*NTIM
      NENDPD=NENDPD*NTIM
C
```

```
C ......................................................................
C .       INITIALIZE TOTAL SYSTEM DELAY FOR ARRIVING AIRCRAFT AND       .
C .            TOTAL SYSTEM DELAY FOR DEPARTING AIRCRAFT.               .
C ......................................................................
C
      ITHDEL=0
      ITWDEL=0
      ENDEL=0.
      SENDEL=0.
      NEN=0
C
C ......................................................................
C .       READ DATA TO INITIALIZE THE DISTANCE MATRIX.                  .
C .       WRITE THE DISTANCE MATRIX.                                    .
C ......................................................................
C
      NTT=NT-1
      DO 10 NXT=1,NTT
      DO 11 NZT=1,51
      READ(5,20) DIST(NXT,NZT)
   20 FORMAT(F8.1)
   11 CONTINUE
   10 CONTINUE
      WRITE(6,200)
  200 FORMAT(T10,109HNEW YORK         CHICAGO          ATLANTA          LO
     *S ANGELES          WASHINGTON          DALLAS          DENVER)
      DO 12 NYT=1,50
      WRITE(6,100) (DIST(NH,NYT),NH=1,NTT)
  100 FORMAT(T9,F8.1,T25,F8.1,T41,F8.1,T59,F8.1,T79,F8.1,T96,F8.1,T111,F
     *8.1)
   12 CONTINUE
C
```

```
C ..................................................................
C .      ENTER INTO THE ACTUAL SIMULATION CYCLE.                     .
C ..................................................................
C
      DO 50 NYAD=1,NREPS
      MSTOP=0
      NDAY=NYAD
C
C ..................................................................
C .      CALL SUBROUTINE TERCAP TO INITIALIZE ALL VARIABLES RELATED  .
C .          TO THE TERMINALS.                                       .
C .      CALL SUBROUTINE FLIGHT TO INITIALIZE THE FLIGHTS TO BE      .
C .          USED FROM ON-LINE DISK.                                 .
C ..................................................................
C
      CALL TERCAP(NT,NDAY)
      CALL FLIGHT(ISS,NA1,NT)
      IF(IADD.GT.0) CALL ADFLT(IADD,IAD1,NT,ISS,NA1)
      NA=NA1+IADD
C
C ..................................................................
C .      INITIALIZE THE FACTOR CONTROLLING WHICH SCHEDULING          .
C .          ALGORITHM WILL BE USED WITH THE PEAK DEMAND INTERVALS.  .
C .      IF UNIFORM SCHEDULING ALGORITHM IS TO BE USED, SET KFA=1.   .
C .      IF SIMULTANEOUS UNIFORM SCHEDULING ALGORITHM IS TO BE USED  .
C .          SET KFA=2.                                              .
C ..................................................................
C
      KFA=2
      KFA=1
      IF(ISS.EQ.1) KFA=1
      IF(ISS.EQ.2) KFA=2
```

```
C
C ....................................................................
C .      IF THE UNIFORM ALGORITHM OR THE SIMULTANEOUS UNIFORM          .
C .           ALGORITHM IS TO BE USED, CALL SUBROUTINE UNIFM TO        .
C .           SCHEDULE AIRCRAFT ACCORDINGLY.                           .
C .      IF THE PEAK DEMAND ALGORITHM IS TO BE USED, CALL SUBROUTINE   .
C .           PDUNIF TO SCHEDULE AIRCRAFT ACCORDINGLY.                 .
C ....................................................................
C
      IF(ISS.EQ.1.OR.ISS.EQ.2) CALL UNIFM(NA,KFA,NT)
      IF(ISS.FQ.3) CALL PDUNIF(NA,KFA,NT)
C
C ....................................................................
C .      CALL SUBROUTINE NEXT TO DETERMINE NEXT EVENT TIME(S)          .
C .           AND TYPE(S).                                             .
C ....................................................................
C
   30 CALL NEXT(NA,NT,ISS,KFA,NA1)
C
C ....................................................................
C .      IF SIMULATION TERMINATION FACTOR IS EQUAL TO ONE, ACCUMULATE  .
C .           DELAY TIMES FOR AIRCRAFT OCCUPYING POSITIONS             .
C .           IN THE WAITING STACK.                                    .
C ....................................................................
C
      IF(MSTOP.EQ.1) GO TO 52
C
C ....................................................................
C .      IF SIMULATION TERMINATION FACTOR IS EQUAL TO ZERO, DETERMINE  .
C .           IF ALL AIRCRAFT IN THE SYSTEM ARE IDLE.                  .
C .      IF SO, CALCULATE THE DAILY STATISTICS AND PROCEED TO          .
C .           SIMULATE THE OPERATIONS OF THE FOLLOWING DAY.            .
```

```
C .       IF NOT, RETURN TO DETERMINE THE NEXT EVENT.                            .
C ..........................................................................
C
      NAI=0
      DO 40 L=1,NA
   40 IF(NACFT(L,3).EQ.6) NAI=NAI+1
      IF(NAI.EQ.NA) GO TO 500
      GO TO 30
   52 DO 53 NXK=1,NTT
C
C ..........................................................................
C .       DETERMINE IF ANY AIRCRAFT ARE OCCUPYING POSITIONS IN THE              .
C .            WAITING STACK AT TERMINAL "NXK".                                 .
C .       DETERMINE THE NUMBER OF AIRCRAFT WAITING IN THE STACK.                .
C ..........................................................................
C
      IF(NWS(NXK).EQ.0) GO TO 53
      NW=NWS(NXK)
C
C ..........................................................................
C .       CALCULATE THE DELAY WHICH EACH AIRCRAFT IN THE WAITING STACK         .
C .            HAS ENCOUNTERED.                                                 .
C ..........................................................................
C
      DO 54 NWK=1,NW
      MW=1
      NKN=NWSO(NWK,NXK)
      TNEXT=NSTOP
      CALL DELAY(MW,NXK,NKN)
   54 CONTINUE
   53 CONTINUE
C
```

```
C ....................................................................
C .      CALL SUBROUTINE WRIDEL TO CALCULATE HOURLY STATISTICS         .
C .           CONCERNING DELAY AT EACH TERMINAL.                       .
C .      CALL SUBROUTINE TODEL TO CALCULATE THE TOTAL DELAY STATISTICS .
C .           AT EACH TERMINAL.                                        .
C ....................................................................
C
  500 CALL WRIDEL(NTT,ISS)
      IF(NDAY.EQ.NREPS) GO TO 501
      CALL TODEL(NTT,NREPS,NDAY)
   50 CONTINUE
  501 WRITE(6,112)
  112 FORMAT(1H1)
C
C ....................................................................
C .      WRITE INFORMATION CONCERNING THE SYSTEM.                      .
C ....................................................................
C
      WRITE(6,118) NA
  118 FORMAT(/,T10,39HTHE NUMBER OF AIRCRAFT IN THE SYSTEM IS,I5,//)
      IF(ISS.EQ.0) WRITE(6,113)
      IF(ISS.EQ.1) WRITE(6,114) KFA
      IF(ISS.EQ.2) WRITE(6,115) KFA
      IF(ISS.EQ.3) WRITE(6,116) KFA
      IF(ISS.EQ.4) WRITE(6,117)
  113 FORMAT(//,T10,25HAIRCRAFT SCHEDULED BY OAG,//)
  114 FORMAT(//,T10,39HAIRCRAFT SCHEDULED BY UNIFORM ALGORITHM,I5,//)
  115 FORMAT(//,T10,52HAIRCRAFT SCHEDULED BY SIMULTANEOUS UNIFORM ALGORI
     *THM,I5,//)
  116 FORMAT(T10,51HAIRCRAFT SCHEDULED BY PEAK DEMAND UNIFORM ALGORITHM,
     *I5,//)
  117 FORMAT(//,T10,38HAIRCRAFT SCHEDULED BY OAG WITH TAGGING,//)
```

```
CALL TODEL(NTT,NREPS,NDAY)
STOP
END
```

```
      SUBROUTINE FLIGHT(ISS,NA1,NT)
C
C ...................................................................
C .       THIS SUBROUTINE WILL READ IN THE DATA RELATED TO THE        .
C .            VARIOUS FLIGHTS IN THE SYSTEM.                         .
C ...................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      INTEGER MBEGPD,MENDPD,NBEGPD,NENDPD
      INTEGER IO
      DEFINE FILE 9(1750,57,E,IO)
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BLK11/ NUST(8,24)
      COMMON/BLK12/ NTAG(2750)
      COMMON/BLK13/ MBEGPD,MENDPD,NBEGPD,NENDPD
      IF(IWRIT.EQ.0) WRITE(6,29)
   29 FORMAT(1H1)
      IF(IWRIT.EQ.0) WRITE(6,30)
   30 FORMAT(T10,'AIRCRAFT NUMBER',T35,'AIRLINES',T50,'FLIGHT #',T66,'DE
     *P. TER.',T85,'DEST.',T96,'TIME',/)
      DO 10 IF=1,NA1
      IO=IF
C
C ...................................................................
C .       READ DATA CONCERNING THE DAILY FLIGHTS OF THE AIRCRAFT      .
C .            IN THE SYSTEM.                                         .
```

```
C ..................................................................
C
      READ(9'I0,20) (NAM(IF,K),K=1,6),(CHAR(IF,I),I=1,2),NFN(IF),NDF(IF)
     *,NADF1(IF,1),NADF2(IF,1),NADF3(IF,1),NADF1(IF,2),NADF2(IF,2),NADF3
     *(IF,2),NADF1(IF,3),NADF2(IF,3),NADF3(IF,3),NADF1(IF,4),NADF2(IF,4)
     *,NADF3(IF,4)
   20 FORMAT(6A2,2F4.0,I4,I1,4(I2,I2,I4))
C
C ..................................................................
C .       DETERMINE THE RANDOM ERROR FOR AIRCRAFT SPEEDS.          .
C ..................................................................
C
      CSA=0.
C
C ..................................................................
C .       CALCULATE THE NEW AIRCRAFT SPEED BASED ON THE BEST       .
C .            CRUISE SPEED AND THE RANDOM ERROR.                  .
C ..................................................................
C
      CHAR(IF,2)=CHAR(IF,2)+CSA
C
C ..................................................................
C .       ADJUST THE AIRCRAFT SPEED TO THE APPROPRIATE TIME UNITS, .
C .            I.E., MILES/HOUR, MILES/MINUTE, ETC.                .
C ..................................................................
C
      CHAR(IF,2)=CHAR(IF,2)/3600.
C
C ..................................................................
C .       SET VARIABLE WHICH INDICATES THE NUMBER OF FLIGHT LEGS   .
C .            COMPLETED BY AIRCRAFT "I" EQUAL TO ZERO.            .
C ..................................................................
```

```
C
      NDDF(IF)=0
C
C ..................................................................
C .     SET VARIABLE WHICH INDICATES WHETHER OR NOT AN AIRCRAFT      .
C .          HAS BEEN TAGGED EQUAL TO ZERO.                          .
C ..................................................................
C
      NTAG(IF)=0
C
C ..................................................................
C .     DETERMINE THE NUMBER OF DAILY FLIGHT LEGS AIRCRAFT "I"       .
C .          WILL FLY.                                               .
C ..................................................................
C
      NXF=NDF(IF)
      DO 11 INDF=1,NXF
C
C ..................................................................
C .     ADJUST AIRCRAFT DEPARTURE TIMES FOR EACH LEG TO THE          .
C .          APPROPRIATE TIME UNITS, I.E., SECONDS, MINUTES.         .
C ..................................................................
C
      NADF3(IF,INDF)=NADF3(IF,INDF)*NTIM
   11 CONTINUE
C
C ..................................................................
C .     INITIALIZE THE DEPARTURE TERMINAL FOR AIRCRAFT "I" FOR       .
C .          FIRST FLIGHT LEG.                                       .
C ..................................................................
C
      NACFT(IF,1)=NADF1(IF,1)
```

```
C
C ..........................................................................
C .     INITIALIZE THE DESTINATION FOR AIRCRAFT "I" FOR FIRST              .
C .          FLIGHT LEG.                                                   .
C ..........................................................................
C
      NACFT(IF,2)=NADF2(IF,1)
C
C ..........................................................................
C .     INITIALIZE DEPARTURE TIME FOR AIRCRAFT "I" (I.E., NEXT             .
C .          EVENT TIME FOR AIRCRAFT "I").                                 .
C ..........................................................................
C
      NACTM(IF)=NADF3(IF,1)
C
C ..........................................................................
C .     INITIALIZE STATUS FOR THE ITH AIRCRAFT TO THAT                     .
C .          REPRESENTING A DEPARTURE.                                     .
C ..........................................................................
C
      NACFT(IF,3)=0
C
C ..........................................................................
C .     INCREMENT THE COUNTER FOR THE NUMBER OF FLIGHT LEGS                .
C .          COMPLETED BY ONE.                                             .
C ..........................................................................
C
      NDDF(IF)=NDDF(IF)+1
C
C ..........................................................................
C .     IF TAGGING ALGORITHM IS BEING SIMULATED, CALL TAGSCH TO            .
C .          INCREMENT THE PROJECTED NUMBER OF OPERATIONS FOR              .
```

```
C .            DEPARTURE TERMINAL.                                          .
C ......................................................................
C
      IF(ISS.EQ.4) CALL TAGSCH(IF,NT)
      IF(IWRIT.NE.0) GO TO 10
      WRITE(6,31) IF,(NAM(IF,K),K=1,6),NFN(IF)
   31 FORMAT(T14,I5,T33,6A2,T50,I5)
      DO 40 IGF=1,NXF
      WRITE(6,32) NADF1(IF,IGF),NADF2(IF,IGF),NADF3(IF,IGF)
   32 FORMAT(T66,I5,T83,I5,T95,I5,/)
C
C ......................................................................
C .        CONTINUE TO THE NEXT AIRCRAFT.                                    .
C ......................................................................
C
   40 CONTINUE
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ADFLT(IADD,IAD1,NT,ISS,NA1)
C
C ......................................................................
C .       THIS SUBROUTINE WILL SYNTHESIZE N ADDITIONAL FLIGHTS DURING    .
C .            A PRE-DETERMINED INTERVAL OF TIME.                         .
C ......................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      INTEGER MBEGPD,MENDPD,NBEGPD,NENDPD
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK12/ NTAG(2750)
      COMMON/BLK13/ MBEGPD,MENDPD,NBEGPD,NENDPD
C
C ......................................................................
C .       DETERMINE THE NUMBER OF AIRCRAFT TO BE ADDED TO THE SYSTEM.    .
C ......................................................................
C
      NA2=NA1+1
      NA3=NA1+IADD
      DO 10 I=NA2,NA3
C
C ......................................................................
C .       DETERMINE THE DEPARTURE TERMINAL AND DESTINATION FOR           .
C .            AIRCRAFT.                                                  .
C ......................................................................
C
      II=0
   30 II=II+1
```

```
      RN=RAND(DZ)
      IF(RN.GE.0.00.AND.RN.LE.0.1428) LX=1
      IF(RN.GT.0.1428.AND.RN.LE.0.2856) LX=2
      IF(RN.GT.0.2856.AND.RN.LE.0.4284) LX=3
      IF(RN.GT.0.4284.AND.RN.LE.0.5712) LX=4
      IF(RN.GT.0.5712.AND.RN.LE.0.7140) LX=5
      IF(RN.GT.0.7140.AND.RN.LE.0.8568) LX=6
      IF(RN.GT.0.8568) LX=7
      IF(II.EQ.1) LT=LX
      IF(II.EQ.1) GO TO 30
      IF(II.GT.1) LF=LX
      IF(LF.EQ.LT) GO TO 30
C
C ......................................................................
C .      INITIALIZE THE APPROPRIATE VARIABLES RELATED TO THE           .
C .           AIRCRAFT.                                                 .
C ......................................................................
C
      NACFT(I,1)=LT
      NACFT(I,2)=LF
      NACFT(I,3)=0
      NDDF(I)=0
      NDF(I)=1
      NTAG(I)=0
      NDDF(I)=NDDF(I)+1
C
C ......................................................................
C .      CALCULATE THE DEPARTURE TIME BASED ON THE TIME INTERVAL       .
C .           OF THE DAY IN WHICH THE FLIGHTS ARE BEING SYNTHESIZED.   .
C ......................................................................
C
      IF(IAD1.EQ.0) GO TO 20
```

```
      RN=RAND(DZ)
      NACTM(I)=((NENDPD-NBEGPD)*RN)+NBEGPD
      GO TO 40
   20 RN=RAND(DZ)
      NACTM(I)=((MENDPD-MBEGPD)*RN)+MBEGPD
   40 IF(ISS.EQ.4) CALL TAGSCH(I,NT)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE UNIFM(IF,KFA,NT)
C
C ...................................................................
C .      THIS SUBROUTINE WILL SCHEDULE AIRCRAFT DEPARTURE TIMES      .
C .           EITHER ACCORDING TO THE UNIFORM SCHEDULING             .
C .           ALGORITHM OR THE SIMULTANEOUS UNIFORM SCHEDULING       .
C .           ALGORITHM.                                             .
C ...................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BLK11/ NUST(8,24)
   10 DO 20 IFN=1,IF
C
C ...................................................................
C .      DETERMINE DEPARTURE TERMINAL FOR AIRCRAFT "I".              .
C ...................................................................
C
      NTER=NACFT(IFN,1)
      IF(NTER.GE.NT) GO TO 20
C
C ...................................................................
C .      CALCULATE THE HOUR OF THE DAY IN WHICH AIRCRAFT WILL BE     .
C .           SCHEDULED.                                             .
```

```
C ...................................................................
C
      NUS1=NACTM(IFN)/(NTIM**2)
      NUS=NUS1+1
      IF(NUST(NTER,NUS).GE.NHAC(NTER,NUS)) NUS1=NUS1+1
      IF(NUST(NTER,NUS).GE.NHAC(NTER,NUS)) NUS=NUS+1
      NST=120
C
C ...................................................................
C .      IF THE PROJECTED HOURLY ACCEPTANCE RATE IS GREATER THAN     .
C .           ZERO, TIME INTERVAL WILL BE EQUAL TO (60 TIME UNITS    .
C .           DIVIDED BY THE PROJECTED ACCEPTANCE RATE).              .
C ...................................................................
C
      IF(NHAC(NTER,NUS).NE.0) NST=60*NTIM/NHAC(NTER,NUS)
C
C ...................................................................
C .      IF AIRCRAFT ARE BEING SCHEDULED BY THE UNIFORM ALGORITHM    .
C .           THEN KFA=1.                                             .
C .      IF AIRCRAFT ARE BEING SCHEDULED BY THE SIMULTANEOUS         .
C .           UNIFORM ALGORITHM THEN KFA=2.                           .
C ...................................................................
C
      IF(KFA.EQ.1) NACTM(IFN)=(NUS1*60*NTIM)+NUST(NTER,NUS)*NST
      IF(KFA.EQ.2) NACTM(IFN)=(NUS1*60*NTIM)+(NUST(NTER,NUS)/NSOP(NTER))
     1*NST
C
C ...................................................................
C .      INCREMENT THE NUMBER OF AIRCRAFT ALREADY SCHEDULED AT       .
C .           TERMINAL "NTER" DURING NTH HOUR.                        .
C ...................................................................
C
```

```
      NUST(NTER,NUS)=NUST(NTER,NUS)+1
   20 CONTINUE
   15 RETURN
      END
```

```
      SUBROUTINE PDUNIF(IFG,KFA,NT)
C
C .....................................................................
C .       THIS SUBROUTINE WILL SCHEDULE AIRCRAFT EITHER ACCORDING     .
C .            TO THE UNIFORM ALGORITHM OR THE SIMULTANEOUS UNIFORM   .
C .            ALGORITHM DURING THE PEAK DEMAND PERIODS OF THE DAY.   .
C .....................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      INTEGER MBEGPD,MENDPD,NBEGPD,NENDPD
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BLK11/ NUST(8,24)
      COMMON/BLK13/ MBEGPD,MENDPD,NBEGPD,NENDPD
      DO 10 IFN=1,IFG
C
C .....................................................................
C .       DETERMINE IF AIRCRAFT DEPARTURE TIME FALLS WITHIN ONE OF    .
C .            THE PRE-SPECIFIED PEAK DEMAND TIME INTERVALS. IF       .
C .            SO, SCHEDULE AIRCRAFT ACCORDINGLY. IF NOT, PROCEED     .
C .            TO NEXT AIRCRAFT.                                      .
C .....................................................................
C
      IF(NACTM(IFN).GE.MBEGPD.AND.NACTM(IFN).LE.MENDPD) GO TO 20
      IF(NACTM(IFN).GE.NBEGPD.AND.NACTM(IFN).LE.NENDPD) GO TO 20
```

```
      GO TO 10
C
C ..............................................................
C .     DETERMINE DEPARTURE TERMINAL FOR AIRCRAFT "I".          .
C ..............................................................
C
   20 NTER=NACFT(IFN,1)
      IF(NTER.GE.NT) GO TO 10
C
C ..............................................................
C .     CALCULATE THE HOUR OF THE DAY IN WHICH AIRCRAFT WILL BE .
C .          SCHEDULED.                                          .
C ..............................................................
C
      NPD1=NACTM(IFN)/(NTIM**2)
      NPD=NPD1+1
      NST=120
      IF(NUST(NTER,NPD).GE.NHAC(NTER,NPD)) NPD1=NPD1+1
      IF(NUST(NTER,NPD).GE.NHAC(NTER,NPD)) NPD=NPD+1
C
C ..............................................................
C .     IF THE PROJECTED HOURLY ACCEPTANCE RATE IS GREATER THAN  .
C .          ZERO, TIME INTERVAL WILL BE EQUAL TO (60 TIME UNITS .
C .          DIVIDED BY THE PROJECTED ACCEPTANCE RATE).          .
C ..............................................................
C
      IF(NHAC(NTER,NPD).NE.0) NST=60*NTIM/NHAC(NTER,NPD)
C
C ..............................................................
C .     IF AIRCRAFT ARE BEING SCHEDULED BY THE UNIFORM ALGORITHM .
C .          THEN KFA=1.                                         .
C .     IF AIRCRAFT ARE BEING SCHEDULED BY THE SIMULTANEOUS      .
```

```
C .           UNIFORM ALGORITHM THEN KFA=2.                            .
C .....................................................................
C
      IF(KFA.EQ.1) NACTM(IFN)=(NPD1*60*NTIM)+NUST(NTER,NPD)*NST
      IF(KFA.EQ.2) NACTM(IFN)=(NPD1*60*NTIM)+(NUST(NTER,NPD)/NSOP(NTER))
     1*NST
C
C .....................................................................
C .       INCREMENT THE NUMBER OF AIRCRAFT ALREADY SCHEDULED AT        .
C .           TERMINAL "NTER" DURING NTH HOUR.                         .
C .....................................................................
C
      NUST(NTER,NPD)=NUST(NTER,NPD)+1
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TAGSCH(IFZ,NT)
C
C ....................................................................
C .      THIS SUBROUTINE IS USED IN CONJUNCTION WITH THE TAGGING      .
C .          ALGORITHM AND IS USED TO CALCULATE THE PROJECTED         .
C .          NUMBER OF FLIGHTS DEPARTING EACH TERMINAL DURING ANY     .
C .          GIVEN TIME INTERVAL.                                     .
C ....................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
C
C ....................................................................
C .      DETERMINE THE DEPARTURE TERMINAL FOR AIRCRAFT UNDER           .
C .          CONSIDERATION.                                            .
C ....................................................................
C
      NTER=NACFT(IFZ,1)
      IF(NTER.GE.NT) NTER=NT
C
C ....................................................................
C .      DETERMINE THE TIME INTERVAL IN WHICH THE AIRCRAFT WILL DEMAND .
C .          DEPARTURE SERVICE.                                        .
C ....................................................................
C
      NHR=NACTM(IFZ)/900+1
C
C ....................................................................
C .      INCREMENT THE NUMBER OF PROJECTED OPERATIONS AT THAT          .
```

```
C .              TERMINAL DURING THE CALCULATED TIME INTERVAL.           .
C ......................................................................
C
      NFCAP(NTER,NHR)=NFCAP(NTER,NHR)+1
      RETURN
      END
```

```
      SUBROUTINE TERCAP(NT,NDAY)
C
C ..................................................................
C .       THIS SUBROUTINE WILL READ IN THE TIME INTERVAL BETWEEN      .
C .            PERIODIC REVIEWS AT EACH TERMINAL, THE NUMBER OF       .
C .            SIMULTANEOUS OPERATIONS EACH TERMINAL CAN SERVICE,     .
C .            AND THE AVERAGE HOURLY ACCEPTANCE RATE FOR EACH        .
C .            HOUR OF THE DAY. IT ALSO CONTROLS THE INITIALIZATION   .
C .            OF THE VARIABLES ASSOCIATED WITH THE TERMINALS.        .
C ..................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK11/ NUST(8,24)
C
C ..................................................................
C .       SET THE PRESENT TIME EQUAL TO ZERO.                         .
C ..................................................................
C
      TNEXT=0
C
```

```
C ..................................................................
C .      IF THE FIRST DAY OF OPERATIONS HAS BEEN SIMULATED,           .
C .           PROCEED TO STATEMENT #9 AND DO NOT READ THE VARIABLE    .
C .           RELATING TO THE TIME BETWEEN REVIEWS OF THE ACCEPTANCE  .
C .           RATE FOR EACH TERMINAL.                                 .
C ..................................................................
C
      IF(NDAY.GE.2) GO TO 9
C
C ..................................................................
C .      READ VARIABLE INITIALIZING THE TIME BETWEEN ACCEPTANCE       .
C .           RATE REVIEWS.                                           .
C ..................................................................
C
      READ(5,30) NCCAP
   30 FORMAT(I8)
C
C ..................................................................
C .      SET COUNTER FOR TERMINALS EQUAL TO ZERO.                     .
C ..................................................................
C
    9 NTN=0
C
C ..................................................................
C .      INCREASE COUNTER FOR TERMINALS BY ONE.                       .
C ..................................................................
C
   10 NTN=NTN+1
C
C ..................................................................
C .      DETERMINE IF THE COUNTER IS GREATER THAN "NT", THE           .
C .           NUMBER OF TERMINALS IN THE SYSTEM. IF SO, RETURN TO     .
```

```
C .            THE MAIN PROGRAM. IF NOT, CONTINUE TO THE NEXT           .
C .            STATEMENT.                                               .
C ......................................................................
C
      IF(NTN.GT.NT) GO TO 70
C
C ......................................................................
C .       IF THE FIRST DAY OF OPERATIONS HAS BEEN SIMULATED,            .
C .            PROCEED TO STATEMENT #60 AND DO NOT READ THE             .
C .            VARIABLES RELATING TO THE NUMBER OF SIMULTANEOUS         .
C .            OPERATIONS EACH TERMINAL MAY SERVICE AND THE HOURLY      .
C .            ACCEPTANCE RATES FOR EACH TERMINAL.                      .
C ......................................................................
C
      IF(NDAY.GE.2) GO TO 60
C
C ......................................................................
C .       READ THE VARIABLE RELATED TO THE NUMBER OF SIMULTANEOUS       .
C .            OPERATIONS.                                              .
C .       READ THE VARIABLE RELATED TO THE HOURLY ACCEPTANCE RATE.      .
C ......................................................................
C
      READ(5,30) NSOP(NTN)
      READ(5,40) (NHAC(NTN,J),J=1,24)
C
C ......................................................................
C .       CALL SUBROUTINE CHANG WHICH WILL CALCULATE THE ACCEPTANCE     .
C .            RATE FOR THE FIRST HOUR OF THE DAY.                      .
C ......................................................................
C
   60 CALL CHANG(NTN)
   40 FORMAT(24I3)
```

```
      DO 20 NTX=1,24
C
C ..................................................................
C .       INITIALIZE THE NUMBER OF DEPARTURES FOR EACH TERMINAL       .
C .            DURING EACH HOUR EQUAL TO ZERO.                        .
C ..................................................................
C
      NDT(NTN,NTX)=0
C
C ..................................................................
C .       INITIALIZE THE NUMBER OF ARRIVALS FOR EACH TERMINAL DURING  .
C .            EACH HOUR EQUAL TO ZERO.                               .
C ..................................................................
C
      NAT(NTN,NTX)=0
C
C ..................................................................
C .       INITIALIZE THE NUMBER OF AIRCRAFT THAT HOLD AT TERMINAL     .
C .            "NTN" TO ZERO.                                         .
C ..................................................................
C
      NHT(NTN,NTX)=0
C
C ..................................................................
C .       INITIALIZE THE NUMBER OF AIRCRAFT THAT MUST WAIT            .
C .            AT TERMINAL "NTN" TO ZERO.                             .
C ..................................................................
C
      NWT(NTN,NTX)=0
C
C ..................................................................
C .       INITIALIZE THE ARRIVAL DELAY TIME TO ZERO.                  .
```

```
C ....................................................................
C
      IHDEL(NTN,NTX)=0
C
C ....................................................................
C .      INITIALIZE THE DEPARTURE DELAY TIME TO ZERO.                 .
C ....................................................................
C
      IWDEL(NTN,NTX)=0
C
C ....................................................................
C .      INITIALIZE THE SUM OF SQUARES FOR DEPARTURE DELAY EQUAL      .
C .           TO ZERO.                                                .
C ....................................................................
C
      SSQUD(NTN,NTX)=0
C
C ....................................................................
C .      INITIALIZE THE SUM OF SQUARES FOR ARRIVAL DELAY EQUAL        .
C .           TO ZERO.                                                .
C ....................................................................
C
      SSQUA(NTN,NTX)=0
C
C ....................................................................
C .      INITIALIZE THE NUMBER OF OPERATIONS SCHEDULED PER HOUR       .
C .           EQUAL TO ZERO.                                          .
C
C ....................................................................
C .      INITIALIZE THE NUMBER OF AIRCRAFT ALREADY SCHEDULED AT       .
C .           TERMINAL "NTN" DURING A GIVEN HOUR EQUAL TO ZERO.       .
C ....................................................................
```

```
C
   80 NUST(NTN,NTX)=0
   20 CONTINUE
C
C ..........................................................................
C .      INITIALIZE THE PROJECTED OPERATIONS FOR TERMINAL "NTN"           .
C .           TO ZERO.                                                      .
C ..........................................................................
C
      DO 50 NTM=1,96
   50 NFCAP(NTN,NTM)=0
C
C ..........................................................................
C .      INITIALIZE THE ACTUAL NUMBER OF OPERATIONS FOR TERMINAL          .
C .           "NTN" EQUAL TO ZERO.                                          .
C ..........................................................................
C
      NACAP(NTN)=0
C
C ..........................................................................
C .      INITIALIZE THE NUMBER IN THE WAITING STACK EQUAL TO ZERO.        .
C ..........................................................................
C
      NWS(NTN)=0
C
C ..........................................................................
C .      CALCULATE THE TIME OF THE FIRST REVIEW.                           .
C ..........................................................................
C
      NCHCAP(NTN)=0
      NCHCAP(NTN)=NCHCAP(NTN)+NCCAP
      IF(NTN.EQ.NT) NCHCAP(NTN)=999999
```

```
      GO TO 10
   70 RETURN
      END
```

```
      SUBROUTINE NEXT(NA,NT,ISS,KFA,NA1)
C
C ......................................................................
C .       THIS SUBROUTINE CONTROLS THE STEPS FOR DETERMINING THE        .
C .            NEXT EVENT TIME AND NEXT EVENT TYPE.                     .
C ......................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      INTEGER MBEGPD,MENDPD,NBEGPD,NENDPD
      DIMENSION NUEV(3)
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK11/ NUST(8,24)
      COMMON/BLK12/ NTAG(2750)
      COMMON/BLK13/ MBEGPD,MENDPD,NBEGPD,NENDPD
      COMMON/BLK14/ ENDEL,SENDEL,NEN
C
C ......................................................................
C .       CALL ACNEXT TO DETERMINE MINIMUM NEXT EVENT TIME AMONG        .
C .            AIRCRAFT.                                                .
```

```
C ......................................................................
C
      CALL ACNEXT(NA,NV)
C
C ......................................................................
C .      CALL TERNEX TO DETERMINE MINIMUM NEXT EVENT TIME AMONG          .
C .          TERMINALS.                                                  .
C ......................................................................
C
      CALL TERNEX(NT,NIAT)
C
C ......................................................................
C .      SET END OF SIMULATION TIME.                                     .
C ......................................................................
C
      INEXT(3)=86400
C
C ......................................................................
C .      SET NEXT EVENT COUNTER FOR TIME TIES EQUAL TO ZERO.             .
C ......................................................................
C
      NQW=0
C
C ......................................................................
C .      SET TNEXT TO A LARGE NUMBER.                                    .
C ......................................................................
C
      TNEXT=888888
C
C ......................................................................
C .      COMPARE MINIMUM AIRCRAFT NEXT EVENT TIME, MINIMUM TERMINAL      .
C .          NEXT EVENT TIME, AND END OF SIMULATION TO THE VALUE         .
```

```
C .           OF TNEXT TO DETERMINE THE NEXT EVENT.                    .
C ......................................................................
C
      DO 10 NTU=1,3
      IF(INEXT(NTU).GT.TNEXT) GO TO 10
C
C ......................................................................
C .       IF "INEXT(I)" IS LESS THAN "TNEXT", THEN PROCEED TO          .
C .           STATEMENT  # 20 SINCE "INEXT(I)" IS A UNIQUE TIME.       .
C ......................................................................
C
      IF(INEXT(NTU).LT.TNEXT) GO TO 20
C
C ......................................................................
C .       IF "INEXT(I)" IS EQUAL TO "TNEXT" THEN PROCEED TO NEXT       .
C .           STATEMENT SINCE "INEXT(I)" IS NOT A UNIQUE TIME.         .
C ......................................................................
C
C
C ......................................................................
C .       INCREMENT THE NUMBER OF TIME TIES BY ONE.                    .
C ......................................................................
C
      NQW=NQW+1
C
C ......................................................................
C .       SAVE THE TYPE OF NEXT EVENT.                                 .
C ......................................................................
C
      NUEV(NQW)=NTU
      GO TO 10
C
```

```
C ..................................................................
C .      SINCE NEXT EVENT TIME IS UNIQUE, SET "NQW" EQUAL TO          .
C .           ONE.                                                    .
C ..................................................................
C
  20 NQW=1
C
C ..................................................................
C .      SET "TNEXT" EQUAL TO "INEXT(NTU)".                           .
C ..................................................................
C
     TNEXT=INEXT(NTU)
C
C ..................................................................
C .      SAVE THE TYPE OF NEXT EVENT, EITHER AIRCRAFT, TERMINAL       .
C .           OR END OF SIMULATION, FOR THE "NQW" EVENT.              .
C ..................................................................
C
     NUEV(NQW)=NTU
C
C ..................................................................
C .      CONTINUE TO THE FOLLOWING NEXT EVENT TIME.                   .
C ..................................................................
C
  10 CONTINUE
     IF(IWRIT.EQ.0) WRITE(6,40) TNEXT
  40 FORMAT(T5,'NEXT EVENT TIME =',I6,/)
C
C ..................................................................
C .      OPERATE ON THE NEXT EVENT TYPE. IF IT IS AN AIRCRAFT         .
C .           EVENT,CALL SUBROUTINE AOPER. IF IT IS A TERMINAL        .
C .           EVENT,CALL SUBROUTINE TCAPY.                            .
```

```
C .............................................................................
C
      DO 30 NTY=1,NQW
      IF(NUEV(NTY).EQ.1) CALL AOPER(NV,NA,NT,ISS,KFA,NA1)
      IF(MSTOP.EQ.1) GO TO 50
      IF(NUEV(NTY).EQ.2) CALL TCAPY(NIAT,NT,NA,ISS,NA1)
      IF(NUEV(NTY).EQ.3) MSTOP=1
      IF(NUEV(NTY).EQ.3) RETURN
   30 CONTINUE
   50 RETURN
      END
```

```
      SUBROUTINE ACNEXT(NA,NV)
C
C ....................................................................
C .       THIS SUBROUTINE DETERMINES THE MINIMUM NEXT EVENT TIME      .
C .            AMONG ALL THE AIRCRAFT IN THE SYSTEM.                  .
C ....................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
C
C ....................................................................
C .       SET "TNEXT" EQUAL TO A LARGE NUMBER.                        .
C ....................................................................
C
      TNEXT=888888
C
C ....................................................................
C .       SET "INEXT(1)", VALUE CORRESPONDING TO MINIMUM AIRCRAFT     .
C .            EVENT TIME, EQUAL TO "TNEXT".                          .
C ....................................................................
C
      INEXT(1)=TNEXT
C
C ....................................................................
C .       SET AIRCRAFT COUNTER EQUAL TO 1.                            .
C ....................................................................
```

```
C
      IN=1
C
C ..............................................................
C .       COMPARE THE AIRCRAFT COUNTER TO THE NUMBER OF AIRCRAFT      .
C .            IN THE SYSTEM.  IF IT IS GREATER THAN THE NUMBER       .
C .            OF AIRCRAFT IN THE SYSTEM, RETURN TO  SUBROUTINE       .
C .            NEXT.                                                  .
C .       IF IT IS LESS THAN THE NUMBER OF AIRCRAFT IN THE            .
C .            SYSTEM, PROCEED TO NEXT STATEMENT.                     .
C ..............................................................
C
   10 IF(IN.EQ.(NA+1)) GO TO20
C
C ..............................................................
C .       COMPARE THE NEXT EVENT TIME FOR AIRCRAFT "IN" TO THE        .
C .            VALUE OF "TNEXT".                                      .
C .       IF IT IS LESS THAN OR EQUAL TO"TNEXT" GO TO STATEMENT 30.   .
C .       IF IT IS GREATER THAN "TNEXT" GO TO STATEMENT 40 AND        .
C .            INCREMENT THE AIRCRAFT COUNTER BY 1.                   .
C ..............................................................
C
      IF(NACTM(IN).LE.TNEXT) GO TO 30
   40 IN=IN+1
      GO TO 10
C
C ..............................................................
C .       IF THE AIRCRAFT EVENT TIME IS STRICTLY LESS THAN            .
C .            "TNEXT" GO TO STATEMENT 50.  IF IT IS EQUAL TO         .
C .            "TNEXT" PROCEED TO THE NEXT STATEMENT AND              .
C .            INCREMENT THE NUMBER OF AIRCRAFT TIME TIES.            .
C ..............................................................
```

```
C
   30 IF(NACTM(IN).LT.TNEXT) GO TO 50
      NV=NV+1
C
C ......................................................................
C .      SAVE THE AIRCRAFT NUMBER ASSOCIATED WITH THAT TIME AND         .
C .            PROCEED TO THE NEXT AIRCRAFT TIME.                       .
C ......................................................................
C
      NFFP(NV)=IN
      GO TO 40
C
C ......................................................................
C .      SET NUMBER OF AIRCRAFT EVENTS EQUAL  TO 1.                     .
C ......................................................................
C
   50 NV=1
C
C ......................................................................
C .      SAVE AIRCRAFT NUMBER AND NEXT EVENT TIME.                      .
C ......................................................................
C
      NFFP(NV)=IN
      INEXT(1)=NACTM(IN)
      TNEXT=NACTM(IN)
C
C ......................................................................
C .      PROCEED TO NEXT AIRCRAFT TIME.                                 .
C ......................................................................
C
      GO TO 40
   20 RETURN
```

END

```
      SUBROUTINE TERNEX(NT,NIAT)
C
C ..................................................................
C .      THIE SUBROUTINE DETERMINES THE MINIMUM NEXT EVENT TIME      .
C .           AMONG THE TERMINALS IN THE SYSTEM, WHERE THE EVENT     .
C .           WOULD BE A PERIODIC REVIEW OF THE ACCEPTANCE RATE.     .
C ..................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
C
C ..................................................................
C .      INITIALIZE TNEXT TO A LARGE NUMBER.                         .
C ..................................................................
C
      TNEXT=888888
C
C ..................................................................
C .      INITIALIZE THE VARIABLE RELATED TO THE MINIMUM TERMINAL     .
C .           NEXT EVENT TIME EQUAL TO TNEXT.                        .
C ..................................................................
C
      INEXT(2)=TNEXT
C
C ..................................................................
C .      SET THE COUNTER WHICH ACCUMULATES THE NUMBER OF TERMINAL    .
C .           TIME TIES EQUAL TO  ZERO.                              .
C ..................................................................
```

```
C
      NIAT=0
C
C ..........................................................................
C .       SET THE TERMINAL COUNTER EQUAL TO  1.                            .
C ..........................................................................
C
   10 MNT=1
C
C ..........................................................................
C .       COMPARE THE ABOVE COUNTER TO THE NUMBER OF TERMINALS,            .
C .            NT, IN THE SYSTEM.                                          .
C .       IF IT IS GREATER THAN NT, RETURN TO  SUBROUTINE NEXT.            .
C ..........................................................................
C
   20 IF(MNT.EQ.(NT+1)) GO TO 30
C
C ..........................................................................
C .       COMPARE TERMINAL NEXT EVENT TIME TO TNEXT. IF TERMINAL           .
C .            TIME IS GREATER THAN TNEXT GO TO 40 AND INCREMENT           .
C .            THE NUMBER OF TERMINALS WHICH HAVE BEEN SEARCHED            .
C .            FOR NEXT EVENT. IF TIME IS LESS THAN TNEXT THEN             .
C .            PROCEED TO NEXT STATEMENT.                                  .
C ..........................................................................
C
      IF(NCHCAP(MNT).GT.TNEXT) GO TO 40
      IF(NCHCAP(MNT).LT.TNEXT) GO TO 50
      NIAT=NIAT+1
      IDMT(NIAT)=MNT
      GO TO 40
C
C ..........................................................................
```

```
C .      SAVE TIME AND TERMINAL AT WHICH THE MINIMUM NEXT EVENT TIME   .
C .           OCCURRED.                                                 .
C .....................................................................
C
   50 TNEXT=NCHCAP(MNT)
      INEXT(2)=NCHCAP(MNT)
      NIAT=1
      IDMT(NIAT)=MNT
   40 MNT=MNT+1
      GO TO 20
   30 RETURN
      END
```

```
      SUBROUTINE AOPER(NV,NA,NT,ISS,KFA,NA1)
C
C ......................................................................
C .       THIS SUBROUTINE WILL SERVICE THE AIRCRAFT NEXT EVENTS         .
C .           WHICH OCCUR.                                               .
C ......................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      INTEGER MBEGPD,MENDPD,NBEGPD,NENDPD
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK11/ NUST(8,24)
      COMMON/BLK12/ NTAG(2750)
      COMMON/BLK13/ MBEGPD,MENDPD,NBEGPD,NENDPD
      COMMON/BLK14/ ENDEL,SENDEL,NEN
      NHZ=TNEXT/(NTIM**2)+1
      IADT=0
      IF(NHZ.GE.25) IADT=1
      DO 5 NAV=1,NV
      ISZ=1
```

```
      ISU=0
C
C ..................................................................
C .       DETERMINE WHICH AIRCRAFT WILL BE SERVICED AT THE PRESENT    .
C .       TIME.                                                       .
C .       DETERMINE THE TERMINAL AT WHICH THE SERVICE WILL TAKE PLACE. .
C .       DETERMINE THE TYPE OF SERVICE THAT WILL TAKE PLACE.         .
C ..................................................................
C
      NKN=NFFP(NAV)
      IF(NACFT(NKN,3).EQ.0) NTER=NACFT(NKN,1)
      IF(NACFT(NKN,3).EQ.1) NTER=NACFT(NKN,1)
      IF(NACFT(NKN,3).EQ.3) NTER=NACFT(NKN,2)
      IF(NACFT(NKN,3).EQ.4) NTER=NACFT(NKN,2)
      IF(NACFT(NKN,3).EQ.7) NTER=NACFT(NKN,1)
      IF(NTER.GE.NT) NTER=NT
      IF(NACFT(NKN,3).EQ.0) GO TO 20
      IF(NACFT(NKN,3).EQ.1) GO TO 30
      IF(NACFT(NKN,3).EQ.3) GO TO 50
      IF(NACFT(NKN,3).EQ.4) GO TO 60
      IF(NACFT(NKN,3).EQ.7) GO TO 70
C
C ..................................................................
C .       DETERMINE WHETHER OR NOT THE NUMBER OF DEPARTURES           .
C .            FROM TERMINAL UNDER CONSIDERATION SHOULD BE INCREMENTED. .
C ..................................................................
C
   20 IF(IADT.EQ.0) NDT(NTER,NHZ)=NDT(NTER,NHZ)+1
C
C ..................................................................
C .       STORE TIME AT WHICH AIRCRAFT DEMANDS SERVICE.               .
C ..................................................................
```

```
C
      NDEL(NKN)=TNEXT
C
C ......................................................................
C .      IF THE ACCEPTANCE RATE AT TERMINAL IS ZERO, HAVE AIRCRAFT      .
C .          ENTER THE WAITING STACK.                                   .
C ......................................................................
C
      IF(NCAPTR(NTER).EQ.0) GO TO 21
C
C ......................................................................
C .      IF A WAITING STACK ALREADY EXISTS AT THE TERMINAL PUT          .
C .          AIRCRAFT IN THE WAITING STACK BEHIND THE LAST              .
C .          AIRCRAFT.                                                  .
C ......................................................................
C
      IF(NWS(NTER).NE.0) GO TO 21
C
C ......................................................................
C .      IF A RUNWAY IS NOT AVAILABLE THEN PUT AIRCRAFT IN THE          .
C .          WAITING STACK.                                             .
C ......................................................................
C
      IF((NACAP(NTER)+1).GT.NSOP(NTER)) GO TO 21
C
C ......................................................................
C .      IF THE TAGGING ALGORITHM IS BEING USED, CALL SUBROUTINE        .
C .          FUTCAP TO DETERMINE WHETHER OR NOT THE AIRCRAFT            .
C .          UNDER CONSIDERATION SHOULD BE ALLOWED TO DEPART.           .
C .      IF THE AIRCRAFT IS NOT ALLOWED TO DEPART THEN PROCEED TO       .
C .          NEXT EVENT.                                                .
C ......................................................................
```

```
C
      IF(ISS.EQ.4) CALL FUTCAP(NKN,NTER,ISZ,NT,ISU,NA1,NA)
      IF(ISS.EQ.4.AND.ISZ.EQ.0) GO TO 5
C
C ......................................................................
C .       CALCULATE RUNWAY OCCUPANCY TIME BASED ON THE
C .            ACCEPTANCE RATE OF THE TERMINAL.                        .
C ......................................................................
C
      IF(IWRIT.EQ.0) CALL OPWRIT(NKN)
      IF(NTER.EQ.NT) NST=2*NTIM
      IF(NTER.NE.NT) NST=NCCAP/NCAPTR(NTER)
C
C ......................................................................
C .       DETERMINE THE NEW NEXT EVENT TIME FOR AIRCRAFT.              .
C ......................................................................
C
      NACTM(NKN)=NACTM(NKN)+NST
C
C ......................................................................
C .       INCREASE THE NUMBER OF OPERATIONS PRESENTLY BEING SERVICED   .
C .            AT TERMINAL UNDER CONSIDERATION.                        .
C ......................................................................
C
      NACAP(NTER)=NACAP(NTER)+1
C
C ......................................................................
C .       CHANGE THE STATUS OF THE AIRCRAFT.                           .
C ......................................................................
C
      NACFT(NKN,3)=1
C
```

```
C ......................................................................
C .      CALL SUBROUTINE DELAY TO DETERMINE THE AMOUNT OF DELAY           .
C .           THAT THE AIRCRAFT MAY HAVE ENCOUNTERED.                     .
C ......................................................................
C
      MW=1
      CALL DELAY(MW,NTER,NKN)
      GO TO 5
C
C ......................................................................
C .      CALL SUBROUTINE SERDES TO PUT THE AIRCRAFT IN THE WAITING        .
C .           STACK.                                                      .
C ......................................................................
C
   21 IKEY=0
      CALL SERDES(NKN,NTER,IKEY)
      GO TO 5
C
C ......................................................................
C .      CHANGE THE STATUS OF THE AIRCRAFT TO THAT REPRESENTING           .
C .           THE ENROUTE PORTION OF THE FLIGHT LEG.                      .
C ......................................................................
C
   30 IF(IWRIT.EQ.0) CALL OPWRIT(NKN)
      NACFT(NKN,3)=3
      NTAG(NKN)=0
C
C ......................................................................
C .      CALL SUBROUTINE ENROUT TO DETERMINE THE LENGTH OF TIME           .
C .           THE AIRCRAFT WILL BE ENROUTE TO ITS DESTINATION.            .
C ......................................................................
C
```

```
      CALL ENROUT(NKN,NT,NA1,NA)
C
C ......................................................................
C .       DECREASE THE NUMBER OF OPERATIONS PRESENTLY BEING SERVICED     .
C .            AT TERMINAL UNDER CONSIDERATION.                          .
C ......................................................................
C
      NACAP(NTER)=NACAP(NTER)-1
C
C ......................................................................
C .       CALL SUBROUTINE UNSTAC TO REMOVE AN AIRCRAFT FROM THE WAITING .
C .            STACK IF ONE IS WAITING.                                  .
C ......................................................................
C
      IF(NWS(NTER).NE.0) CALL UNSTAC(NTER,NT,ISS,NA1,NA)
      IF(MSTOP.EQ.1) GO TO 90
      GO TO 5
C
C ......................................................................
C .       DETERMINE WHETHER OR NOT THE NUMBER OF ARRIVALS TO             .
C .            TERMINAL UNDER CONSIDERATION SHOULD BE INCREMENTED.       .
C ......................................................................
C
   50 IF(IADT.EQ.0) NAT(NTER,NHZ)=NAT(NTER,NHZ)+1
C
C ......................................................................
C .       STORE TIME AT WHICH AIRCRAFT DEMANDS SERVICE.                  .
C ......................................................................
C
      NDEL(NKN)=TNEXT
C
C ......................................................................
```

```
C .      IF ACCEPTANCE RATE AT TERMINAL IS ZERO, HAVE AIRCRAFT              .
C .           ENTER THE WAITING STACK.                                      .
C .........................................................................
C
      IF(NCAPTR(NTER).EQ.0) GO TO 51
C
C .........................................................................
C .      IF A WAITING STACK ALREADY EXISTS AT THE TERMINAL PUT              .
C .           AIRCRAFT IN THE WAITING STACK.                                .
C .........................................................................
C
      IF(NWS(NTER).NE.0) GO TO 51
C
C .........................................................................
C .      IF A RUNWAY IS NOT AVAILABLE THEN PUT AIRCRAFT IN THE              .
C .           WAITING STACK.                                                .
C .........................................................................
C
      IF((NACAP(NTER)+1).GT.NSOP(NTER)) GO TO 51
C
C .........................................................................
C .      CALCULATE RUNWAY OCCUPANCY TIME BASED ON THE                       .
C .           ACCEPTANCE RATE OF THE TERMINAL.                              .
C .........................................................................
C
      IF(IWRIT.EQ.0) CALL OPWRIT(NKN)
      IF(NTER.EQ.NT) NST=2*NTIM
      IF(NTER.NE.NT) NST=NCCAP/NCAPTR(NTER)
C
C .........................................................................
C .      DETERMINE THE NEW NEXT EVENT TIME FOR AIRCRAFT.                    .
C .........................................................................
```

```
C
      NACTM(NKN)=NACTM(NKN)+NST
C
C ......................................................................
C .       INCREASE THE NUMBER OF OPERATIONS PRESENTLY BEING SERVICED   .
C .            AT TERMINAL UNDER CONSIDERATION.                          .
C ......................................................................
C
      NACAP(NTER)=NACAP(NTER)+1
C
C ......................................................................
C .       CALL SUBROUTINE DELAY TO DETERMINE ANY DELAY THAT THE        .
C .            AIRCRAFT MAY HAVE ENCOUNTERED.                            .
C ......................................................................
C
      MW=1
      CALL DELAY(MW,NTER,NKN)
C
C ......................................................................
C .       CHANGE THE STATUS OF THE AIRCRAFT.                             .
C ......................................................................
C
      NACFT(NKN,3)=4
      GO TO 5
C
C ......................................................................
C .       CALL SUBROUTINE SERDES TO PUT AIRCRAFT IN THE WAITING        .
C .            STACK.                                                    .
C ......................................................................
C
   51 IKEY=0
      CALL SERDES(NKN,NTER,IKEY)
```

```
      GO TO 5
   60 IF(IWRIT.EQ.0) CALL OPWRIT(NKN)
C
C ......................................................................
C .      DECREASE THE NUMBER OF OPERATIONS PRESENTLY BEING SERVICED    .
C .           AT TERMINAL.                                              .
C ......................................................................
C
      NACAP(NTER)=NACAP(NTER)-1
C
C ......................................................................
C .      DETERMINE WHETHER OR NOT AIRCRAFT UNDER CONSIDERATION HAS     .
C .           ANOTHER FLIGHT LEG. IF SO, CALL SUBROUTINE NEXFLI         .
C .           TO INITIALIZE THE NEW FLIGHT DATA.                        .
C .      IF THE AIRCRAFT HAS COMPLETED ALL ITS DAILY FLIGHT LEGS       .
C .           REMOVE THAT AIRCRAFT FROM THE SYSTEM.                     .
C ......................................................................
C
      IF(NDDF(NKN).GE.NDF(NKN)) GO TO 61
      NDDF(NKN)=NDDF(NKN)+1
      NDFX=NDDF(NKN)
      NTAG(NKN)=0
      CALL NEXFLI(NDFX,NKN,ISS,KFA,NT)
      GO TO 67
   61 NACFT(NKN,3)=6
      NACTM(NKN)=999999
C
C ......................................................................
C .      CHECK WAITING STACK TO DETERMINE WHETHER OR NOT ANY           .
C .           AIRCRAFT ARE WAITING FOR SERVICE.                         .
C ......................................................................
C
```

```
   67 IF(NWS(NTER).NE.0) CALL UNSTAC(NTER,NT,ISS,NA1,NA)
      IF(MSTOP.EQ.1) GO TO 90
      GO TO 5
   70 NACFT(NKN,3)=0
C
C ...................................................................
C .      THIS PORTION OF SUBROUTINE AOPER IS USED ONLY IN CONJUNCTION .
C .          WITH THE TAGGING ALGORITHM.                              .
C .      IT WILL ATTEMPT TO SERVICE AN AIRCRAFT ONCE IT HAS BEEN      .
C .          TAGGED.                                                  .
C ...................................................................
C
C ...................................................................
C .      IF THE ACCEPTANCE RATE AT TERMINAL IS ZERO, HAVE THE         .
C .          AIRCRAFT ENTER THE WAITING STACK.                        .
C ...................................................................
C
      IF(NCAPTR(NTER).EQ.0) GO TO 72
C
C ...................................................................
C .      IF A WAITING STACK ALREADY EXISTS AT THE TERMINAL PUT        .
C .          AIRCRAFT IN THE WAITING STACK.                           .
C ...................................................................
C
      IF(NWS(NTER).NE.0) GO TO 72
C
C ...................................................................
C .      IF A RUNWAY IS NOT AVAILABLE THEN PUT AIRCRAFT IN THE        .
C .          WAITING STACK.                                           .
C ...................................................................
C
      IF((NACAP(NTER)+1).GT.NSOP(NTER)) GO TO 72
```

```
      ISZ=1
      ISU=1
C
C ......................................................................
C .     CALL SUBROUTINE FUTCAP TO DETERMINE WHETHER OR NOT THE          .
C .          AIRCRAFT CAN STILL BE SERVICED AT ITS DESTINATION ONCE    .
C .          IT ARRIVES.                                               .
C ......................................................................
C
      CALL FUTCAP(NKN,NTER,ISZ,NT,ISU,NA1,NA)
      IF(ISZ.EQ.0) GO TO 5
      NHD=NDEL(NKN)/(NTIM**2)+1
      IF(NHD.GE.25) GO TO 73
      MW=1
C
C ......................................................................
C .     CALL SUBROUTINE DELAY TO CALCULATE THE DELAY ENCOUNTERED       .
C .          BY AIRCRAFT.                                              .
C ......................................................................
C
      CALL DELAY(MW,NTER,NKN)
   73 IF(IWRIT.EQ.0) CALL OPWRIT(NKN)
C
C ......................................................................
C .     CALCULATE RUNWAY OCCUPANCY TIME FOR AIRCRAFT.                  .
C ......................................................................
C
      IF(NTER.EQ.NT) NST=2*NTIM
      IF(NTER.NE.NT) NST=NCCAP/NCAPTR(NTER)
C
C ......................................................................
C .     CALCULATE THE NEW NEXT EVENT TIME FOR AIRCRAFT.                .
```

```
C ..................................................................
C
      NACTM(NKN)=NACTM(NKN)+NST
C
C ..................................................................
C .     INCREASE THE NUMBER OF OPERATIONS PRESENTLY BEING          .
C .          SERVICED AT TERMINAL BY ONE.                          .
C ..................................................................
C
      NACAP(NTER)=NACAP(NTER)+1
C
C ..................................................................
C .     CHANGE STATUS OF THE AIRCRAFT.                             .
C ..................................................................
C
      NACFT(NKN,3)=1
      NTAG(NKN)=0
      GO TO 5
C
C ..................................................................
C .     CALL SUBROUTINE SERDES TO PUT AIRCRAFT IN THE WAITING      .
C .          STACK.                                                .
C ..................................................................
C
   72 IKEY=1
      CALL SERDES(NKN,NTER,IKEY)
    5 CONTINUE
   90 RETURN
      END
```

```
      SUBROUTINE ENROUT(NKN,NT,NA1,NA)
C
C .....................................................................
C .      THIS SUBROUTINE CALCULATES THE ENROUTE TIME FOR ANY GIVEN     .
C .          FLIGHT.                                                   .
C .....................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BLK14/ ENDEL,SENDEL,NEN
C
C .....................................................................
C .      DETERMINE DEPARTURE TERMINAL OF AIRCRAFT UNDER                .
C .          CONSIDERATION.                                            .
C .....................................................................
C
      LF=NACFT(NKN,1)
C
C .....................................................................
C .      DETERMINE DESTINATION OF AIRCRAFT UNDER CONSIDERATION.        .
C .....................................................................
C
      LT=NACFT(NKN,2)
C
C .....................................................................
```

```
C .      CALCULATE RANDOM VECTORING DISTANCE ASSOCIATED WITH          .
C .           FLIGHT.                                                 .
C ....................................................................
C
      EDIS=VECT(DZ)
C
C ....................................................................
C .      CALCULATE THE DISTANCE TO BE TRAVELLED BASED ON              .
C .           DEPARTURE TERMINAL, DESTINATION, AND RANDOM             .
C .           VECTORING DISTANCE.                                     .
C ....................................................................
C
      IF(LF.LT.NT) DISTAN=DIST(LF,LT)+EDIS
      IF(LF.GE.NT) DISTAN=DIST(LT,LF)+EDIS
C
C ....................................................................
C .      CALCULATE ENROUTE TIME BASED ON DISTANCE AND AIRCRAFT        .
C .           CRUISE SPEED.                                           .
C ....................................................................
C
      IF(NKN.GT.NA1) ENRT=(DISTAN/540.)*3600.
      IF(NKN.LE.NA1) ENRT=DISTAN/CHAR(NKN,2)
C
C ....................................................................
C .      CALL SUBROUTINE ERDEL TO CALCULATE THE ENROUTE               .
C .           DELAY TIME.                                             .
C ....................................................................
C
      CALL ERDEL(EX)
C
C ....................................................................
C .      INCREASE THE NUMBER OF AIRCRAFT WHICH ACTUALLY ARE           .
```

```
C .             ALLOWED TO DEPART.                                        .
C ........................................................................
C
      NEN=NEN+1
C
C ........................................................................
C .         ADD ENROUTE DELAY TO TOTAL ENROUTE DELAY FOR THE SYSTEM.      .
C ........................................................................
C
      ENDEL=ENDEL+EX
C
C ........................................................................
C .         ADD SQUARE OF ENROUTE DELAY TO SUM OF SQUARES FOR             .
C .             ENROUTE DELAY.                                            .
C ........................................................................
C
      SENDEL=(EX**2)+SENDEL
C
C ........................................................................
C .         ADD ENROUTE DELAY TO ENROUTE TIME CALCULATED ABOVE TO         .
C .             OBTAIN ACTUAL ENROUTE TIME.                               .
C ........................................................................
C
      ENRT=ENRT+EX
C
C ........................................................................
C .         CALCULATE NEXT EVENT TIME FOR AIRCRAFT "NKN" BY ADDING        .
C .             ENROUTE TIME TO PRESENT TIME.                             .
C ........................................................................
C
      NACTM(NKN)=NACTM(NKN)+ENRT
      RETURN
```

END

```
      SUBROUTINE ERDEL(EY)
C
C ...................................................................
C .      THIS SUBROUTINE GENERATES NORMALLY DISTRIBUTED RANDOM       .
C .          DELAY FOR THE ENROUTE PORTION OF FLIGHT LEG.             .
C ...................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      XLAM=9.2
      SIG=2.5
      RN=RAND(DZ)
      V1=ABS(1.-2.*RN)
      V2=0.5*(1-V1)
      V3=-2.*ALOG(V2)
      V=SQRT(V3)
      RN=RAND(DZ)
      X1=((RN-0.5)/ABS(RN-0.5))*SIG
      X2=2.515517+(0.802853*V)+(0.010328*(V**2))
      X3=1.+(1.432788*V)+(0.189269*(V**2))+(0.001308*(V**3))
      X4=V-(X2/X3)
      EY=(XLAM+(X1*X4))*(NTIM)
      RETURN
      END
```

```
      FUNCTION VECT(DZZ)
C
C ...................................................................
C .     THIS FUNCTION WILL GENERATE A VECTORING DISTANCE FOR A      .
C .          FLIGHT.                                                .
C ...................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      COMMON/BLK8/ IX,IWRIT
      SIG=5.0
      XLAM=50.
      RN=RAND(DZ)
      V1=ABS(1.-2.*RN)
      V2=0.5*(1-V1)
      V3=-2.*ALOG(V2)
      V=SQRT(V3)
      RN=RAND(DZ)
      X1=((RN-0.5)/ABS(RN-0.5))*SIG
      X2=2.515517+(0.802853*V)+(0.010328*(V**2))
      X3=1.+(1.432788*V)+(0.189269*(V**2))+(0.001308*(V**3))
      X4=V-(X2/X3)
      VECT=XLAM+(X1*X4)
      RETURN
      END
```

```
      SUBROUTINE SERDES(NKN,NTER,IKEY)
C
C ......................................................................
C .      THIS SUBROUTINE WILL ASSIGN A POSITION IN THE WAITING           .
C .           STACK AT A GIVEN TERMINAL TO AN AIRCRAFT THAT MUST         .
C .           WAIT.                                                      .
C ......................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK12/ NTAG(2750)
C
C ......................................................................
C .      SET AIRCRAFT "I"'S NEXT EVENT TIME EQUAL TO A LARGE NUMBER.     .
C ......................................................................
C
      NACTM(NKN)=999999
C
C ......................................................................
C .      INCREMENT THE NUMBER IN THE STACK AT TERMINAL NTER BY ONE.      .
C ......................................................................
```

```
C
      NWS(NTER)=NWS(NTER)+1
C
C ......................................................................
C .      ASSIGN THE NW POSITION IN THE STACK TO AIRCRAFT "NKN"          .
C ......................................................................
C
      NW=NWS(NTER)
      IF(NW.GT.999) WRITE(6,10) NTER
   10 FORMAT(T10,'THE NUMBER IN THE WAITING STACK AT TERMINAL',5X,I3,5X,
     *'IS GREATER THAN 999',/)
      NWSO(NW,NTER)=NKN
C
C ......................................................................
C .      DETERMINE THE HOUR OF THE DAY, NHZ.                            .
C ......................................................................
C
   40 NHZ=TNEXT/(NTIM**2)+1
      IF(NHZ.GE.25) GO TO 30
C
C ......................................................................
C .      IF THE AIRCRAFT WAS DEPARTING, INCREASE THE NUMBER OF          .
C .           AIRCRAFT THAT MUST WAIT AT TERMINAL NTER DURING           .
C .           THE NTH HOUR OF THE DAY BY ONE.                           .
C ......................................................................
C
      IF(NACFT(NKN,3).EQ.0.AND.IKEY.EQ.0) NWT(NTER,NHZ)=NWT(NTER,NHZ)+1
C
C ......................................................................
C .      IF THE AIRCRAFT WAS ARRIVING, INCREASE THE NUMBER OF           .
C .           AIRCRAFT THAT MUST HOLD AT TERMINAL NTER.                 .
C ......................................................................
```

```
C
      IF(NACFT(NKN,3).EQ.3.AND.IKEY.EQ.0) NHT(NTER,NHZ)=NHT(NTER,NHZ)+1
C
C ...........................................................................
C .      DETERMINE THE NEW STATUS OF THE AIRCRAFT BASED ON                   .
C .           PREVIOUS STATUS.                                               .
C ...........................................................................
C
   30 IF(NACFT(NKN,3).EQ.0) NACFT(NKN,3)=2
      IF(NACFT(NKN,3).EQ.3) NACFT(NKN,3)=5
      IF(IWRIT.EQ.0) CALL OPWRIT(NKN)
   20 RETURN
      END
```

```
      SUBROUTINE UNSTAC(MXD,NT,ISS,NA1,NA)
C
C .............................................................
C .      THIS SUBROUTINE WILL SERVICE AN AIRCRAFT WHICH LEAVES      .
C .           THE WAITING STACK AFTER A RUNWAY HAS BEEN CLEARED.    .
C .............................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK12/ NTAG(2750)
C
C .............................................................
C .      DETERMINE THE NUMBER OF AIRCRAFT IN THE WAITING STACK.     .
C .............................................................
C
      NW=NWS(MXD)
C
C .............................................................
C .      IF THE NUMBER IN THE WAITING STACK IS EQUAL TO ZERO,       .
C .           RETURN TO CALLING SUBROUTINE.                         .
```

```
C ...................................................................
C
      IF(NW.EQ.0) RETURN
C
C ...................................................................
C .       IF THE HOURLY ACCEPTANCE RATE IS ZERO, RETURN TO CALLING   .
C .            SUBROUTINE.                                           .
C ...................................................................
C
      IF(NCAPTR(MXD).EQ.0) GO TO 15
C
C ...................................................................
C .       CALCULATE THE RUNWAY OCCUPANCY TIME FOR AIRCRAFT.          .
C ...................................................................
C
   10 NST=NCCAP/NCAPTR(MXD)
C
C ...................................................................
C .       DETERMINE THE NUMBER CORRESPONDING TO THE FIRST AIRCRAFT   .
C .            IN THE WAITING STACK.                                 .
C ...................................................................
C
      NKN=NWSO(1,MXD)
      MW=1
      ISZ=1
      ISU=1
C
C ...................................................................
C .       IF THE TIME THE FIRST AIRCRAFT ENTERED THE WAITING         .
C .            STACK IS GREATER THAN OR EQUAL TO A PRESCRIBED        .
C .            TIME, SET MSTOP EQUAL TO 1.                           .
C ...................................................................
```

```
C
      IF(NDEL(NKN).GE.NSTOP) MSTOP=1
C
C ..................................................................
C .       IF THE TIME THE FIRST AIRCRAFT ENTERED THE WAITING        .
C .            STACK IS GREATER THAN OR EQUAL TO A PRESCRIBED       .
C .            TIME, RETURN TO CALLING SUBROUTINE.                  .
C ..................................................................
C
      IF(NDEL(NKN).GE.NSTOP) RETURN
C
C ..................................................................
C .       IF PRESENT TIME MINUS THE TIME THE AIRCRAFT WENT INTO     .
C .            THE WAITING STACK IS ZERO, SET MW EQUAL TO ZERO.     .
C ..................................................................
C
      IF((TNEXT-NDEL(NKN)).EQ.0) MW=0
C
C ..................................................................
C .       CALL SUBROUTINE  PUSHUP WHICH WILL MOVE ALL THE
C .            AIRCRAFT REMAINING IN THE STACK UP ONE POSITION.     .
C ..................................................................
C
      CALL PUSHUP(NW,MXD,NWSO)
C
C ..................................................................
C .       DECREASE THE NUMBER IN THE WAITING SATACK BY ONE.         .
C ..................................................................
C
      NWS(MXD)=NWS(MXD)-1
      NW=NWS(MXD)
C
```

```
C ......................................................................
C .      IF TAGGING ALGORITHM IS BEING USED CALL SUBROUTINE              .
C .          FUTCAP.                                                     .
C ......................................................................
C
      IF(ISS.EQ.4) NACTM(NKN)=TNEXT
      IF(ISS.EQ.4.AND.NACFT(NKN,3).EQ.2) CALL FUTCAP(NKN,MXD,ISZ,NT,ISU,
     *NA1,NA)
      IF(ISS.EQ.4.AND.ISZ.EQ.0) GO TO 13
C
C ......................................................................
C .      CALCULATE THE DELAY WHICH AIRCRAFT ENCOUNTERED.                  .
C ......................................................................
C
      CALL DELAY(MW,MXD,NKN)
      NTAG(NKN)=0
C
C ......................................................................
C .      CALCULATE AIRCRAFT'S NEXT EVENT TIME.                            .
C ......................................................................
C
      NACTM(NKN)=TNEXT+NST
      NACAP(MXD)=NACAP(MXD)+1
C
C ......................................................................
C .      DETERMINE THE NEW STATUS FOR AIRCRAFT.                           .
C ......................................................................
C
      IF(NACFT(NKN,3).EQ.2) NACFT(NKN,3)=0
      IF(NACFT(NKN,3).EQ.5) NACFT(NKN,3)=3
      IF(IWRIT.EQ.0) CALL OPWRIT(NKN)
      IF(NACFT(NKN,3).EQ.0) NACFT(NKN,3)=1
```

```
      IF(NACFT(NKN,3).EQ.3) NACFT(NKN,3)=4
C
C ..............................................................................
C .       IF NO AIRCRAFT REMAIN IN THE STACK RETURN TO CALLING                   .
C .            SUBROUTINE.                                                       .
C ..............................................................................
C
   13 IF(NWS(MXD).EQ.0) GO TO 15
C
C ..............................................................................
C .       IF A RUNWAY IS AVAILABLE THEN REMOVE THE FIRST ARICRAFT                .
C .            IN THE WAITING STACK AND SERVICE IT.                              .
C ..............................................................................
C
      IF((NACAP(MXD)+1).LE.NSOP(MXD)) GO TO 10
   15 RETURN
      END
```

```
      SUBROUTINE DELAY(MW,NTER,NKN)
C
C .................................................................
C .      THIS SUBROUTINE CALCULATES THE AMOUNT OF DELAY WHICH AN    .
C .           AIRCRAFT MAY ENCOUNTER WHILE WAITING FOR SERVICE,     .
C .           EITHER DEPARTURE OR ARRIVAL.                          .
C .................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK12/ NTAG(2750)
C
C .................................................................
C .      CALCULATE THE HOUR OF THE DAY, NHD, IN WHICH THE DELAY     .
C .           WILL BE ATTRIBUTED.                                   .
C .................................................................
C
      NHD=NDEL(NKN)/(NTIM**2)+1
C
C .................................................................
C .      IF THE CALCULATED HOUR IS GREATER THAN OR EQUAL            .
C .           TO 25, RETURN TO CALLING SUBROUTINE.                  .
C .................................................................
C
```

```
      IF(NHD.GE.25) GO TO 20
C
C ..................................................................
C .      DETERMINE WHETHER THE DELAY SHOULD BE ATTRIBUTED TO A         .
C .           DEPARTING AIRCRAFT OR AN ARRIVING AIRCRAFT.  IF IT       .
C .           IS RELATED TO AN ARRIVING AIRCRAFT, GO TO                .
C .           STATEMENT 10.                                            .
C ..................................................................
C
      IF(NACFT(NKN,3).EQ.5.OR.NACFT(NKN,3).EQ.3) GO TO 10
C
C ..................................................................
C .      ADD TO THE TOTAL DEPARTURE DELAY AT TERMINAL "NTER"           .
C .           DURING NHD HOUR BY SUBTRACTING TIME AIRCRAFT             .
C .           ENTERED  THE WAITING STACK FROM THE PRESENT TIME.        .
C ..................................................................
C
      IWDEL(NTER,NHD)=TNEXT-NDEL(NKN)+IWDEL(NTER,NHD)
C
C ..................................................................
C .      IF THE TIME IN WHICH THE AIRCRAFT ENTERED THE WAITING         .
C .           STACK MINUS THE PRESENT TIME IS EQUAL TO ZERO AND        .
C .           MW IS EQUAL TO ZERO, DECREASE THE NUMBER OF AIRCRAFT     .
C .           THAT WAITED AT TERMINAL "NTER" DURING THE NHD HOUR.      .
C ..................................................................
C
      IF((TNEXT-NDEL(NKN)).EQ.0.AND.MW.EQ.0) NWT(NTER,NHD)=NWT(NTER,NHD)
     *-1
C
C ..................................................................
C .      CALCULATE THE SUM OF THE SQUARES FOR DEPARTURE DELAY.         .
C ..................................................................
```

```
C
      SQUD=TNEXT-NDEL(NKN)
      SSQUD(NTER,NHD)=(SQUD**2)+SSQUD(NTER,NHD)
C
C ..................................................................
C .       INCREASE THE TOTAL SYSTEM DEPARTURE DELAY.                 .
C ..................................................................
C
      ITWDEL=TNEXT-NDEL(NKN)+ITWDEL
      RETURN
C
C ..................................................................
C .       ADD TO THE ARRIVAL DELAY AT TERMINAL "NTER"                .
C .            DURING NHD HOUR BY SUBTRACTING TIME AIRCRAFT ENTERED  .
C .            THE WAITING STACK FROM THE PRESENT TIME.              .
C ..................................................................
C
   10 IHDEL(NTER,NHD)=TNEXT-NDEL(NKN)+IHDEL(NTER,NHD)
C
C ..................................................................
C .       IF THE TIME IN WHICH THE AIRCRAFT ENTERED THE WAITING      .
C .            STACK MINUS THE PRESENT TIME IS EQUAL TO ZERO AND     .
C .            MW IS EQUAL TO ZERO, DECREASE THE NUMBER OF AIRCRAFT  .
C .            THAT HELD AT TERMINAL "NTER" DURING THE NHD HOUR.     .
C ..................................................................
C
      IF((TNEXT-NDEL(NKN)).EQ.0.AND.MW.EQ.0) NHT(NTER,NHD)=NHT(NTER,NHD)
     *-1
C
C ..................................................................
C .       CALCULATE THE SUM OF SQUARES FOR ARRIVAL DELAY.            .
C ..................................................................
```

```
C
      SQUA=TNEXT-NDEL(NKN)
      SSQUA(NTER,NHD)=(SQUA**2)+SSQUA(NTER,NHD)
C
C ...................................................................
C .      INCREASE THE TOTAL SYSTEM ARRIVAL DELAY.                     .
C ...................................................................
C
      ITHDEL=TNEXT-NDEL(NKN)+ITHDEL
   20 RETURN
      END
```

```
      SUBROUTINE FUTCAP(NKN,NTER,ISZ,NT,ISU,NA1,NA)
C
C ..........................................................................
C .     THIS SUBROUTINE DETERMINES WHETHER OR NOT AN AIRCRAFT              .
C .          SHOULD BE ALLOWED TO DEPART UNDER THE TAGGING                 .
C .          ALGORITHM.                                                    .
C ..........................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      INTEGER NEARTM,NDTM
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK11/ NUST(8,24)
      COMMON/BLK12/ NTAG(2750)
      IF(NACFT(NKN,2).GE.NT) GO TO 11
C
C ..........................................................................
C .     DETERMINE RUNWAY OCCUPANCY TIME.                                   .
C ..........................................................................
C
      IF(NTER.EQ.NT) NST=2*NTIM
```

```
      IF(NTER.NE.NT) NST=NCCAP/NCAPTR(NTER)
C
C .....................................................................
C .       DETERMINE DEPARTURE TERMINAL AND DESTINATION OF AIRCRAFT      .
C .            BEING SERVICED.                                          .
C .....................................................................
C
      LF=NACFT(NKN,1)
      LT=NACFT(NKN,2)
      EDIS=VECT(DZ)
C
C .....................................................................
C .       DETERMINE  THE DISTANCE THAT WILL BE TRAVELLED.               .
C .....................................................................
C
      IF(LF.LT.NT) DISTAN=DIST(LF,LT)+EDIS
      IF(LF.GE.NT) DISTAN=DIST(LT,LF)+EDIS
      IF(NA.LE.NA1) ENRT=DISTAN/CHAR(NKN,2)
      IF(NA.GT.NA1) ENRT=(DISTAN/540.)*3600.
C
C .....................................................................
C .       CALCULATE THE EXPECTED TIME OF ARRIVAL OF AIRCRAFT.           .
C .....................................................................
C
      NEARTM=NACTM(NKN)+ENRT+NST
      NHR=NEARTM/(15*NTIM)+1
      NAR=NEARTM/(60*NTIM)+1
      IF(NHR.GT.96) GO TO 11
C
C .....................................................................
C .       CALCULATE THE ACCEPTANCE RATE FOR THE TIME INTERVAL IN        .
C .            WHICH THE AIRCRAFT IS EXPECTED TO ARRIVE.                .
```

```
C ..............................................................
C
      NFMAC=NHAC(LT,NAR)/4
C
C ..............................................................
C .       COMPARE THE PROJECTED NUBER OF OPERATIONS TO THE      .
C .            CALCULATED ACCEPTANCE RATE.                      .
C ..............................................................
C
      IF((NFCAP(LT,NHR)+1).GT.NFMAC) GO TO 20
C
C ..............................................................
C .       ALLOW THE AIRCRAFT TO DEPART AT THE PRESENT TIME.     .
C ..............................................................
C
      NFCAP(LT,NHR)=NFCAP(LT,NHR)+1
   11 ISZ=1
      GO TO 10
C
C ..............................................................
C .       TAG THE AIRCRAFT.                                     .
C ..............................................................
C
   20 ISZ=0
C
C ..............................................................
C .       DETERMINE THE TIME INTERVAL IN WHICH THE AIRCRAFT WILL .
C .            BE ALLOWED TO DEPART.                            .
C ..............................................................
C
      NCOUNT=0
   21 NCOUNT=NCOUNT+1
```

```
      NDTM=NEARTM+(NCOUNT*15*NTIM)
      NHR=NDTM/(15*NTIM)+1
      NAR=NDTM/(60*NTIM)+1
      NFMAC=NHAC(LT,NAR)/4
      IF((NFCAP(LT,NHR)+1).GT.NFMAC) GO TO 21
C
C ......................................................................
C .      ASSIGN A NEW DEPARTURE TIME TO THE AIRCRAFT.                 .
C ......................................................................
C
      NACTM(NKN)=NACTM(NKN)+(NCOUNT*15*NTIM)
      NACFT(NKN,3)=7
      IF(NTAG(NKN).EQ.1) GO TO 24
      NTAG(NKN)=1
      NHD=NDEL(NKN)/(NTIM**2)+1
      IF(NHD.GE.25) GO TO 22
   24 IF(ISU.EQ.0) NWT(NTER,NHD)=NWT(NTER,NHD)+1
   22 IF(IWRIT.EQ.0) WRITE(6,300) NKN
  300 FORMAT(T10,8HAIRCRAFT,I5,18H   HAS BEEN TAGGED)
   10 RETURN
      END
```

```
      SUBROUTINE OPWRIT(NKN)
C
C ....................................................................
C .      THIS SUBROUTINE WRITES INFORMATION CONCERNING AIRCRAFT       .
C .           OPERATIONS.                                             .
C ....................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      IF(NACFT(NKN,3).EQ.0) WRITE(6,10) NKN,NACFT(NKN,1)
      IF(NACFT(NKN,3).EQ.1) WRITE(6,60) NKN,NACFT(NKN,1),NACFT(NKN,2)
      IF(NACFT(NKN,3).EQ.2) WRITE(6,30) NKN,NACFT(NKN,1)
      IF(NACFT(NKN,3).EQ.3) WRITE(6,40) NKN,NACFT(NKN,2)
      IF(NACFT(NKN,3).EQ.4) WRITE(6,20) NKN,NACFT(NKN,2)
      IF(NACFT(NKN,3).EQ.5) WRITE(6,50) NKN,NACFT(NKN,2)
   10 FORMAT(T10,'AIRCRAFT NUMBER',T30,I5,T40,'IS BEGINNING TO DEPART TE
     *RMINAL',T80,I5,//)
   20 FORMAT(T10,'AIRCRAFT NUMBER',T30,I5,T40,'IS CLEARING RUNWAY AT TER
     *MINAL',T80,I5,//)
   30 FORMAT(T10,'AIRCRAFT NUMBER',T30,I5,T40,'IS WAITING TO DEPART AT T
     *ERMINAL',T80,I5,//)
   40 FORMAT(T10,'AIRCRAFT NUMBER',T30,I5,T40,'IS BEGINNING TO LAND AT T
     *ERMINAL',T80,I5,//)
   50 FORMAT(T10,'AIRCRAFT NUMBER',T30,I5,T40,'IS HOLDING AT TERMINAL',T
     *80,I5,//)
   60 FORMAT(T10,'AIRCRAFT NUMBER',T30,I5,T40,'IS CLEARING RUNWAY AT TER
     *MINAL',T80,I5,T90,'AND IS ENROUTE TO TERMINAL',T120,I5,//)
      RETURN
      END
```

```
      SUBROUTINE WRIDEL(NT,ISS)
C
C ..................................................................
C .      THIS SUBROUTINE CALCULATES HOURLY DELAY STATISTICS AT      .
C .      THE END OF A DAY'S SIMULATION.                             .
C ..................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
C
C ..................................................................
C .      CALCULATE THE HOUR OF THE DAY FOR WHICH THE DELAY          .
C .           WILL BE SUMMARIZED.                                   .
C ..................................................................
C
      NHOUR=6
      NCOUN=0
      DO 51 NHZ=1,24
      NCOUN=NCOUN+1
      NHOU1=NHOUR+1
      IF(NHOU1.GE.13) NHOU1=NHOU1-12
      WRITE(6,12)
   12 FORMAT(T2,'#######################################################
     *##############################################################')
      IF(NHZ.EQ.1.OR.NHZ.EQ.21) WRITE(6,1) NHZ
      IF(NHZ.EQ.2.OR.NHZ.EQ.22) WRITE(6,2) NHZ
      IF(NHZ.EQ.3.OR.NHZ.EQ.23) WRITE(6,3) NHZ
```

```
      IF(NHZ.GE.4.AND.NHZ.LE.20) WRITE(6,4) NHZ
      IF(NHZ.EQ.24) WRITE(6,4) NHZ
    1 FORMAT(T5,'STATISTICS FOR THE',T25,I3,T28,'ST   HOUR OF THE DAY')
    2 FORMAT(T5,'STATISTICS FOR THE',T25,I3,T28,'ND   HOUR OF THE DAY')
    3 FORMAT(T5,'STATISTICS FOR THE',T25,I3,T28,'RD   HOUR OF THE DAY')
    4 FORMAT(T5,'STATISTICS FOR THE',T25,I3,T28,'TH   HOUR OF THE DAY')
      IF(NCOUN.LE.5) WRITE(6,5) NHOUR,NHOU1
      IF(NCOUN.EQ.6) WRITE(6,6) NHOUR,NHOU1
      IF(NCOUN.GT.6.AND.NCOUN.LE.17) WRITE(6,7) NHOUR,NHOU1
      IF(NCOUN.EQ.18) WRITE(6,8) NHOUR,NHOU1
      IF(NCOUN.GT.18) WRITE(6,5) NHOUR,NHOU1
    5 FORMAT(T10,I2,T13,7HA.M. - ,I2,5H A.M.,///)
    6 FORMAT(T10,I2,T13,7HA.M. - ,I2,5H P.M.,///)
    7 FORMAT(T10,I2,T13,7HP.M. - ,I2,5H P.M.,///)
    8 FORMAT(T10,I2,T13,7HP.M. - ,I2,5H A.M.,///)
      WRITE(6,115)
  115 FORMAT(T2,'TERMINAL #',T16,'# DEPT.',T26,'WAITING TIME',T42,'AVE.
     *WAITING TIME',T63,'STD. DEV.',T75,'# LND.',T88,'HOLDING TIME',T104
     *,'AVE. HOLDING TIME',T124,'STD. DEV.',/)
C
C ....................................................................
C .      DETERMINE THE TERMINAL FOR WHICH DELAY WILL BE SUMMARIZED.    .
C ....................................................................
C
      DO 111 NTO=1,NT
      IF(NDT(NTO,NHZ).EQ.0) GO TO 10
C
C ....................................................................
C .      CALCULATE AVERAGE DEPARTURE DELAY.                           .
C ....................................................................
C
      AWT=FLOAT(IWDEL(NTO,NHZ))/NDT(NTO,NHZ)
```

```
      IF(NDT(NTO,NHZ).EQ.1) GO TO 11
C
C .....................................................................
C .       CALCULATE THE STANDARD DEVIATION OF DEPARTURE DELAY.         .
C .....................................................................
C
      SDWT=SQRT((SSQUD(NTO,NHZ)-((IWDEL(NTO,NHZ)**2)/NDT(NTO,NHZ)))/(NDT
     *(NTO,NHZ)-1))
      GO TO 30
   10 AWT=0.
   11 SDWT=0.0
   30 IF(NAT(NTO,NHZ).EQ.0) GO TO 20
C
C .....................................................................
C .       CALCULATE THE AVERAGE ARRIVAL DELAY .                        .
C .....................................................................
C
      AHT=FLOAT(IHDEL(NTO,NHZ))/NAT(NTO,NHZ)
      IF(NAT(NTO,NHZ).EQ.1) GO TO 21
C
C .....................................................................
C .       CALCULATE THE STANDARD DEVIATION OF ARRIVAL DELAY.           .
C .....................................................................
C
      SDAT=SQRT((SSQUA(NTO,NHZ)-((IHDEL(NTO,NHZ)**2)/NAT(NTO,NHZ)))/(NAT
     *(NTO,NHZ)-1))
      GO TO 50
   20 AHT=0.
   21 SDAT=0.0
   50 CONTINUE
C
C .....................................................................
```

```
C .      WRITE THE DELAY STATISTICS FOR HOUR AND TERMINAL CALCULATED   .
C .           ABOVE.
C ....................................................................
C
      WRITE(6,112) NTO,NDT(NTO,NHZ),NWT(NTO,NHZ),IWDEL(NTO,NHZ),AWT,SDWT
     *,NAT(NTO,NHZ),NHT(NTO,NHZ),IHDEL(NTO,NHZ),AHT,SDAT
  112 FORMAT(T4,I3,T13,I4,T18,'(',T19,I4,T23,')',T25,I9,T45,F9.2,T61,F11
     *.4,T73,I4,T77,'(',T78,I4,T82,')',T89,I9,T107,F9.2,T123,F11.4,//)
  111 CONTINUE
      NHOUR=NHOU1
   51 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TODEL(NTT,NREPS,NDAY)
C
C ......................................................................
C .     THIS SUBROUTINE ACCUMULATES THE TOTAL DELAY STATISTICS FOR     .
C .          EACH TERMINAL AT THE END OF A DAY'S SIMULATION.           .
C ......................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      COMMON/BLK14/ ENDEL,SENDEL,NEN
      COMMON/BLK15/ WTT(8),NTWT(8),NTDT(8),SDSQ(8),HTT(8),NTHT(8),NTAT(8
     *),SHSQ(8)
      NT1=NTT+1
      IF(NDAY.EQ.1) GO TO 610
      IF(NDAY.EQ.2) GO TO 630
      WRITE(6,13)
   13 FORMAT(T2,'######################################################
     *################################################################')
      WRITE(6,5) NREPS
    5 FORMAT(T5,10HSUMMARY OF,I5,5X,20HDAY(S) OF SIMULATION,/)
      WRITE(6,115)
  115 FORMAT(T2,'TERMINAL #',T16,'# DEPT.',T26,'WAITING TIME',T42,'AVE.
     *WAITING TIME',T63,'STD. DEV.',T75,'# LND.',T88,'HOLDING TIME',T104
     *,'AVE. HOLDING TIME',T124,'STD. DEV.',/)
      IF(NDAY.EQ.NREPS) GO TO 630
  610 NXTD=0
      NXTA=0
```

```
      XHTT=0.
      XWTT=0.
  630 DO 10 ITO=1,NT1
      IF(NDAY.GT.1) GO TO 640
      WTT(ITO)=0.
      NTDT(ITO)=0
      NTWT(ITO)=0
      SDSQ(ITO)=0.
      NTAT(ITO)=0
      NTHT(ITO)=0
      HTT(ITO)=0.
      SHSQ(ITO)=0.
  640 DO 40 ITP=1,24
C
C ..........................................................................
C .      INCREASE THE NUMBER OF AIRCRAFT THAT DEPART DURING THE DAY.       .
C ..........................................................................
C
      NXTD=NDT(ITO,ITP)+NXTD
C
C ..........................................................................
C .      INCREASE THE NUMBER OF DEPARTURES AT TERMINAL "J".                .
C ..........................................................................
C
      NTDT(ITO)=NDT(ITO,ITP)+NTDT(ITO)
C
C ..........................................................................
C .      INCREASE THE NUMBER OF AIRCRAFT THAT MUST WAIT DURING THE DAY..
C ..........................................................................
C
      NTWT(ITO)=NWT(ITO,ITP)+NTWT(ITO)
C
```

```
C ..................................................................
C .      INCREASE THE TOTAL DEPARTURE  DELAY TIME AT TERMINAL "J".     .
C ..................................................................
C
      WTT(ITO)=IWDEL(ITO,ITP)+WTT(ITO)
C
C ..................................................................
C .      INCREASE THE TOTAL DEPARTURE DELAY TIME.                      .
C ..................................................................
C
      XWTT=IWDEL(ITO,ITP)+XWTT
      SDSQ(ITO)=SSQUD(ITO,ITP)+SDSQ(ITO)
C
C ..................................................................
C .      INCREASE THE NUMBER OF ARRIVALS AT TERMINAL "J".              .
C ..................................................................
C
      NTAT(ITO)=NAT(ITO,ITP)+NTAT(ITO)
      NXTA=NAT(ITO,ITP)+NXTA
C
C ..................................................................
C .      INCREASE THE NUMBER OF AIRCRAFT THAT MUST HOLD DURING THE     .
C .          DAY.                                                      .
C ..................................................................
C
      NTHT(ITO)=NHT(ITO,ITP)+NTHT(ITO)
C
C ..................................................................
C .      INCREASE THE TOTAL ARRIVAL DELAY TIME AT TERMINAL "J".        .
C ..................................................................
C
      HTT(ITO)=IHDEL(ITO,ITP)+HTT(ITO)
```

```
C
C ....................................................................
C .      INCREASE THE TOTAL ARRIVAL DELAY TIME.                        .
C ....................................................................
C
      XHTT=IHDEL(ITO,ITP)+XHTT
      SHSQ(ITO)=SSQUA(ITO,ITP)+SHSQ(ITO)
   40 CONTINUE
      IF(NDAY.NE.NREPS) GO TO 10
      IF(NTDT(ITO).EQ.0) GO TO 11
C
C ....................................................................
C .      CALCULATE AVERAGE DEPARTURE DELAY.                            .
C ....................................................................
C
      AWT=WTT(ITO)/NTDT(ITO)
      IF(NTDT(ITO).EQ.1) GO TO 12
C
C ....................................................................
C .      CALCULATE STANDARD DEVIATION OF DEPARTURE DELAY.              .
C ....................................................................
C
      SDWT=SQRT((SDSQ(ITO)-((WTT(ITO)**2)/NTDT(ITO)))/(NTDT(ITO)-1))
      GO TO 30
   11 AWT=0.
   12 SDWT=0.
   30 IF(NTAT(ITO).EQ.0) GO TO 20
C
C ....................................................................
C .      CALCULATE AVERAGE ARRIVAL DELAY.                              .
C ....................................................................
C
```

```
      AHT=HTT(ITO)/NTAT(ITO)
      IF(NTAT(ITO).EQ.1) GO TO 21
C
C ...................................................................
C .       CALCULATE STANDARD DEVIATION OF ARRIVAL DELAY.             .
C ...................................................................
C
      SDAT=SQRT((SHSQ(ITO)-((HTT(ITO)**2)/NTAT(ITO)))/(NTAT(ITO)-1))
      GO TO 50
   20 AHT=0.
   21 SDAT=0.
C
C ...................................................................
C .       WRITE DELAY STATISTICS FOR TERMINAL UNDER CONSIDERATION.   .
C ...................................................................
C
   50 WRITE(6,112) ITO,NTDT(ITO),NTWT(ITO),WTT(ITO),AWT,SDWT,NTAT(ITO),N
     *THT(ITO),HTT(ITO),AHT,SDAT
  112 FORMAT(T4,I3,T13,I4,T18,'(',T19,I4,T23,')',T25,F9.0,T45,F9.2,T61,F
     *9.4,T73,I4,T77,'(',T78,I4,T82,')',T89,F9.0,T107,F9.2,T123,F9.4,//)
   10 CONTINUE
      IF(NDAY.NE.NREPS) GO TO 620
      AXWTT=XWTT/NXTD
      AXHTT=XHTT/NXTA
C
C ...................................................................
C .       CALCULATE AVERAGE ENROUTE DELAY AND CORRESPONDING          .
C .              STANDARD DEVIATION.                                 .
C ...................................................................
C
      AEND=ENDEL/NEN
      SEND=SQRT((SENDEL-((ENDEL**2)/NEN))/(NEN-1))
```

```
      WRITE(6,110) ITHDEL,ITWDEL
  110 FORMAT(T15,'THE TOTAL SYSTEM DELAY FOR ARRIVING AIRCRAFT IS EQUAL
     *TO',T85,I9,T95,'TIME UNITS',//,T15,'THE TOTAL SYSTEM DELAY FOR DEP
     *ARTING AIRCRAFT IS EQUAL TO',T85,I9,T95,'TIME UNITS',//)
      WRITE(6,113) AXWTT,AEND,SEND,AXHTT
  113 FORMAT(T15,'THE AVERAGE WAITING TIME PER AIRCRAFT IN THE SYSTEM IS
     *',5X,F12.4,5X,'TIME UNITS',//,T15,'THE AVERAGE ENROUTE DELAY PER A
     *IRCRAFT IN THE SYSTEM IS',5X,F12.4,5X,'TIME UNITS',//,T15,'THE STA
     *NDARD DEVIATION OF ENROUTE DELAY IS',5X,F12.4,//,T15,'THE AVERAGE
     *HOLDING TIME PER AIRCRAFT IN THE SYSTEM IS',5X,F12.4,5X,'TIME UNIT
     *S',//)
  620 RETURN
      END
```

```
      SUBROUTINE TWRIT(MXD)
C
C ......................................................................
C .      THIS SUBROUTINE WILL WRITE INFORMATION CONCERNING PERIODIC    .
C .              REVIEWS OF TERMINAL'S ACCEPTANCE RATE.                 .
C ......................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      WRITE(6,10) MXD,NCAPTR(MXD)
   10 FORMAT(T5,'PERIODIC REVIEW OF ACCEPTANCE RATE AT TERMINAL',T55,I5,
     *T65,'INDICATES THAT ACCEPTANCE RATE FOR NEXT PERIOD WILL BE',T120,
     *I5,/)
      RETURN
      END
```

```
      SUBROUTINE PUSHUP(NW,NTER,NDUM)
C
C ......................................................................
C .      THIS SUBROUTINE WILL ADVANCE ALL AIRCRAFT OCCUPYING            .
C .           POSITIONS IN THE WAITING STACK AT A GIVEN TERMINAL        .
C .           ONE POSITION.                                             .
C ......................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      DIMENSION NDUM(999,8)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
C
C ......................................................................
C .      DECREASE THE NUMBER OF AIRCRAFT IN THE WAITING STACK           .
C .           BY ONE.                                                   .
C ......................................................................
C
      N=NW-1
C
C ......................................................................
C .      CALCULATE THE NUMBER OF AIRCRAFT REMAINING IN THE              .
C .           WAITING STACK.                                            .
C .      IF THERE ARE NO AIRCRAFT REMAINING IN THE WAITING              .
C .           STACK, RETURN TO CALLING SUBROUTINE.                      .
C ......................................................................
C
      IF(N.EQ.0) RETURN
C
C ......................................................................
C .      PROCEED IN MOVING THE AIRCRAFT UP IN THE WAITING STACK.        .
C ......................................................................
```

```
C
      DO 10 KL=1,N
      KLL=KL+1
C
C ..................................................................
C .       SET POSITION ONE EQUAL TO POSITION TWO, AND SO FORTH.      .
C ..................................................................
C
   10 NDUM(KL,NTER)=NDUM(KLL,NTER)
      RETURN
      END
```

```
      SUBROUTINE NEXFLI(NDFX,NKN,ISS,KFA,NT)
C
C ..................................................................
C .      THIS SUBROUTINE WILL DETERMINE THE INFORMATION RELATIVE    .
C .           TO AN AIRCRAFT'S SUBSEQUENT FLIGHT LEG.                .
C ..................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      INTEGER MBEGPD,MENDPD,NBEGPD,NENDPD
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BLK11/ NUST(8,24)
      COMMON/BLK13/ MBEGPD,MENDPD,NBEGPD,NENDPD
C
C ..................................................................
C .      INITIALIZE THE MINIMUM TIME BETWEEN FLIGHT LEGS.           .
C ..................................................................
C
      NWN=30
C
C ..................................................................
C .      DETERMINE THE NEW DEPARTURE TIME FOR AIRCRAFT "I".         .
C ..................................................................
C
      NACFT(NKN,1)=NADF1(NKN,NDFX)
```

```
C
C ..................................................................
C .      DETERMINE THE DESTINATION FOR THE NEXT FLIGHT LEG OF         .
C .           AIRCRAFT "I".                                           ,
C ..................................................................
C
      NACFT(NKN,2)=NADF2(NKN,NDFX)
      NACTM(NKN)=NADF3(NKN,NDFX)
      NACFT(NKN,3)=0
      NTERX=NACFT(NKN,1)
      IF(NTERX.GE.NT) NTERX=NT
C
C ..................................................................
C .      APPLY THE SCHEDULING ALGORITHM BEING USED TO THE NEW         .
C .           DEPARTURE TIME FOR AIRCRAFT "I".                        .
C ..................................................................
C
      IF(ISS.EQ.1.OR.ISS.EQ.2) GO TO 10
      IF(ISS.EQ.3.AND.TNEXT.GE.MBEGPD.AND.TNEXT.LE.MENDPD) GO TO 10
      IF(ISS.EQ.3.AND.TNEXT.GE.NBEGPD.AND.TNEXT.LE.NENDPD) GO TO 10
      IF(NACTM(NKN).LT.(TNEXT+(NWN*NTIM))) GO TO 20
      NHR=NACTM(NKN)/900+1
C
C ..................................................................
C .      CALCULATE THE NEW PROJECTED NUMBER OF OPERATIONS FOR         .
C .           TERMINAL "J" DURING APPROPRIATE TIME INTERVAL.          .
C ..................................................................
C
      IF(NHR.LE.96) NFCAP(NTERX,NHR)=NFCAP(NTERX,NHR)+1
      GO TO 30
   20 NTWA=NWN*NTIM
C
```

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C ..........................................................
C .      ASSIGN NEW DEPARTURE TIME TO AIRCRAFT "I".          .
C ..........................................................
C
      NACTM(NKN)=TNEXT+NTWA
      NHR=NACTM(NKN)/900+1
      IF(NHR.LE.96) NFCAP(NTERX,NHR)=NFCAP(NTERX,NHR)+1
      GO TO 30
C
C ..........................................................
C .      DETERMINE WHETHER OR NOT AIRCRAFT HAS AT LEAST 30 MINUTES   .
C .             BETWEEN FLIGHT LEGS.                                 .
C ..........................................................
C
   10 IF(NACTM(NKN).LT.(TNEXT+(NWN*NTIM))) GO TO 20
      NHD=NACTM(NKN)/(NTIM**2)+1
      NHD1=NHD-1
      IF(NHAC(NTERX,NHD).NE.0) NST=60*NTIM/NHAC(NTERX,NHD)
C
C ..........................................................
C .      ASSIGN NEW DEPARTURE TIME TO AIRCRAFT "I".          .
C ..........................................................
C
      IF(KFA.EQ.1) NACTM(NKN)=(NHD1*NTIM*60)+NUST(NTERX,NHD)*NST
      IF(KFA.EQ.2) NACTM(NKN)=(NHD1*60*NTIM)+(NUST(NTERX,NHD)/NSOP(NTERX
     1))*NST
      IF(NTERX.EQ.NT) NST=120
      IF(NACTM(NKN).LT.(TNEXT+(NWN*NTIM))) GO TO 20
      NUST(NTERX,NHD)=NUST(NTERX,NHD)+1
   30 RETURN
      END
```

```
      SUBROUTINE TCAPY(NIAT,NT,NA,ISS,NA1)
C
C ....................................................................
C .       THIS SUBROUTINE CONTROLS THE STEPS IN REVIEWING THE          .
C .            ACCEPTANCE RATE OF A TERMINAL.                          .
C ....................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      DIMENSION NCSAV(8)
      COMMON/BLK1/ NACFT(2750,3),NACTM(2750),NADF1(1750,4),NADF2(1750,4)
      COMMON/BLKC1/ NADF3(1750,4),NDDF(2750),NDF(2750)
      COMMON/BLK2/ NFN(1750),CHAR(1750,2),NAM(1750,6),NCCAP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK4/ INEXT(3),DIST(7,51),NACAP(8),NWS(8),NSOP(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
      COMMON/BK9/ NDEL(2750),IHDEL(8,24),IWDEL(8,24),NDT(8,24),NAT(8,24)
      COMMON/BLK10/ ITHDEL,ITWDEL,SSQUD(8,24),SSQUA(8,24),NHT(8,24)
      COMMON/BLKC10/ NWT(8,24)
      DO 10 NB=1,NIAT
C
C ....................................................................
C .       DETERMINE THE TERMINAL AT WHICH A PERIODIC REVIEW WILL       .
C .            BE TAKEN.                                               .
C ....................................................................
C
      MXD=IDMT(NB)
   31 NCSAV(MXD)=0
```

```
   21 IF(NCAPTR(MXD).EQ.0) NCSAV(MXD)=1
C
C ...................................................................
C .      CALL SUBROUTINE CHANG TO DETERMINE THE NEW ACCEPTANCE        .
C .           RATE.                                                   .
C ...................................................................
C
      CALL CHANG(MXD)
C
C ...................................................................
C .      DETERMINE THE NEW NEXT EVENT TIME FOR TERMINAL UNDER         .
C .           CONSIDERATION.                                          .
C ...................................................................
C
   11 NCHCAP(MXD)=NCHCAP(MXD)+NCCAP
   10 CONTINUE
C
C ...................................................................
C .      IF ACCEPTANCE RATE INCREASED FROM ZERO, CALL SUBROUTINE      .
C .           UNSTAC TO SERVICE ANY WAITING AIRCRAFT.                 .
C ...................................................................
C
      DO 30 NCB=1,NIAT
      MXD=IDMT(NCB)
      IF(NCSAV(MXD).EQ.0) GO TO 30
      CALL UNSTAC(MXD,NT,ISS,NA1,NA)
   30 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CHANG(MXD)
C
C ......................................................................
C .       THIS SUBROUTINE DETERMINES THE NEW HOURLY ACCEPTANCE RATE    .
C .            FOR A GIVEN TERMINAL AT EACH PERIODIC REVIEW.            .
C ......................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL,NSTOP
      COMMON/BLK3/ NFFP(500),NCHCAP(8),NCAPTR(8),IDMT(8)
      COMMON/BLK5/ NWSO(999,8),NFCAP(8,96),NHAC(8,24)
      COMMON/BLK6/ TNEXT,NSTOP,MSTOP
      COMMON/BLK7/ NTIM
      COMMON/BLK8/ IX,IWRIT
C
C ......................................................................
C .       CALCULATE THE HOUR OF THE DAY, NHD, UNDER CONSIDERATION.     .
C .       IF NHD IS GREATER THAN 24, THEN SUBTRACT 24 FROM NHD.         .
C ......................................................................
C
      NHD=TNEXT/(NTIM**2)+1
      IF(NHD.GT.24) NHD=NHD-24
C
C ......................................................................
C .       BASED ON THE HOUR OF THE DAY, DETERMINE THE ACCEPTANCE       .
C .            RATE FOR TERMINAL MXD.                                   .
C ......................................................................
C
      NC=NHAC(MXD,NHD)
C
C ......................................................................
```

```
C .      CALCULATE RANDOM ERROR.                                          .
C ..........................................................................
C
   20 NCE=0
C
C ..........................................................................
C .      ADD RANDOM ERROR TO HOURLY ACCEPTANCE RATE.                      .
C ..........................................................................
C
      NCAPTR(MXD)=NC+NCE
C
C ..........................................................................
C .      IF IWRIT IS EQUAL TO ZERO, CALL TWRIT TO WRITE THE NEW           .
C .          ACCEPTANCE RATE.                                             .
C ..........................................................................
C
      IF(IWRIT.EQ.0) CALL TWRIT(MXD)
      RETURN
      END
```

```
      FUNCTION RAND(DZ)
C
C .....................................................................
C .      THIS FUNCTION GENERATES A UNIFORMLY DISTRIBUTED RANDOM       .
C .           NUMBER BEWTEEN ZERO AND ONE.                            .
C .....................................................................
C
      IMPLICIT INTEGER*2 (I-N)
      INTEGER NACTM,NADF3,TNEXT,TPRST,TLAST,NCHCAP,INEXT,IX
      INTEGER NDEL,IHDEL,IWDEL,ITHDEL,ITWDEL
      INTEGER IZ
      COMMON/BLK8/ IX,IWRIT
      IZ=IX*65539
      IF(IZ) 5,5,6
    5 IZ=IZ+2147483647+1
    6 YFL=IZ
      YFL=YFL*.4656613E-9
      RAND=YFL
      IX=IZ
      RETURN
      END
```

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THE EFFECT OF SCHEDULING

ON AIR TRAFFIC DELAY

by

Randal R. Crockett

(ABSTRACT)

At the present time, millions of dollars are being lost by major airlines each year because of the inability of high density air terminals to efficiently service all of the demands placed upon them during peak periods of demand. Up to the present time, studies involving congestion have been aimed primarily at the implementation of computerized techniques to aid the air traffic controller during peak demand periods. By scheduling aircraft in a given system in a different manner, delay, caused by congestion, could possibly be reduced at high density terminals even more than it has been reduced by the results obtained from previous studies.

The approach taken in this study involves testing different heuristic scheduling algorithms, based on what has been done previously, to determine what extent total system delay can be reduced. The method of approach which was followed was based on a simulator which models aircraft movement between N major terminals. For each scheduling algorithm developed, hourly statistics related to the number of aircraft demanding service, average departure delay, and average arrival delay were calculated along with total system delay times for arriving and departing aircraft. The results obtained from these algorithms were

analyzed and compared with the scheduling algorithm which resulted in a reduction in delay being examined in greater detail to determine whether or not such a schedule would actually be feasible and worthwhile.