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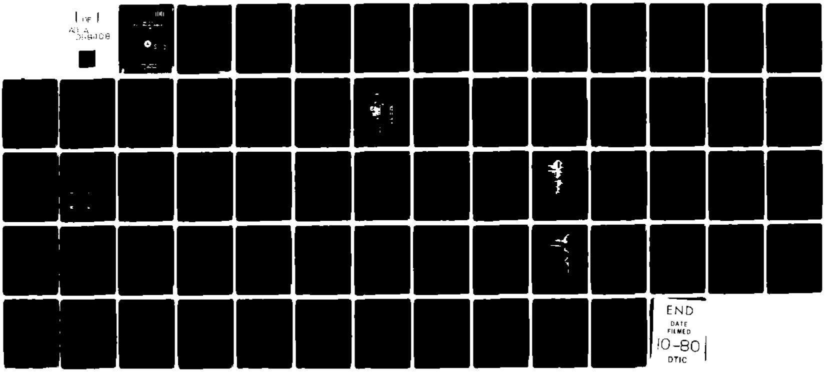

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# ANALYSIS OF POTENTIALLY CORRECTABLE LANDING DELAYS AT ATLANTA



NOVEMBER 1979



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**16. Abstract**

The Local Flow Traffic Management order (DOT/FAA 7110.72), dated 15 November 1976, provided for the establishment of local procedures, at designated airports (16 initially), that would assist aircraft operators in minimizing fuel usage. These local procedures would be predicted on the aircraft performing a profile descent in conjunction with en route metering. This report presents the results of a field data collection and analysis of arrival traffic flows into the Atlanta-Hartsfield International Airport. The purpose of the analysis was to quantify the effect of traffic flow on runway utilization and to identify avoidable delays. Recommendations to improve the flow of traffic are also discussed.





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## ABSTRACT

The Local Flow Traffic Management order (DOT/FAA 7110.72), dated 15 November 1976, provided for the establishment of local procedures, at designated airports (16 initially), that would assist aircraft operators in minimizing fuel usage. These local procedures would be predicated on the aircraft performing a profile descent in conjunction with en route metering. This report presents the results of a field data collection and analysis of arrival traffic flows into the Atlanta-Hartsfield International Airport. The purpose of the analysis was to quantify the effect of traffic flow on runway utilization and to identify avoidable delays. Recommendations to improve the flow of traffic are also discussed.

## EXECUTIVE SUMMARY

At the request of the Office of Systems Engineering Management (OSEM), an analysis of data collected at the Atlanta-Hartsfield Airport was conducted to measure the performance of the existing en route metering and profile descent procedures and determine the problem areas and their relative importance. The data were collected in January 1978. The analysis indicated that the procedures in use resulted in considerable delays that can be potentially avoided by automation aids. These delays resulted due to difficulties in advanced planning and coordination in a manual mode. If an automated planning tool is available to assign arrival aircraft to runways before they are merged into a common path and to assist in early coordination with the Metering Center, procedures can be designed to avoid much of the potentially correctable delay. Since the field personnel have been briefed on these results, the current manual procedures may be considerably improved over those in use during early 1978.

### Observed Performance

Data on arrival traffic were collected during a two and a half hour period of moderate to heavy demand. Based on observed intervals of very heavy demand, a capacity ("observed capacity"), that can be practically achieved, was computed. Comparing this capacity with the actual landing (throughput) indicated that two factors prevented the expedient flow of traffic.

1. Excessive Metering. A 10 mile in-trail spacing constraint was in effect at all of the en route metering fixes long before the demand was near observed capacity. During the first one and one-half hour period, arriving traffic was delayed en route even though the runway demand was such that all, or nearly all, could have landed with little or no delay. The in-trail restrictions that were in effect at the start of the last hour had the effect of backing the early arrivals into the later arrivals during the peak, producing bigger than necessary delays for all. The in-trial restriction at the busiest fix was belatedly reduced to 5 miles, but the action came too late to be fully effective.

2. Unbalanced Runway Demand. It was observed that in the presence of an unbalanced demand (arrival direction versus available runway capacity), one runway was under-utilized relative to the other, even though these runways are

sufficiently separated to permit independent approaches. Since the utilization of the two runways was not balanced, additional delays were imposed by the terminal area.

Improved Traffic Flow

Additional analysis was conducted to assess the potential for more expedient flow with more efficient metering and with better untilization of both runways. Landing delays were computed based on the assumption that the aircraft which were delayed by ATC could have arrived at the runway with an undelayed flying time equal to the average for aircraft which were not delayed by ATC. Then, necessary landing delays were computed using an improved sequencing and spacing algorithm which was based on two assumptions:

1. The south runway could be utilized as heavily as the north runway without interference in ground traffic. The minimum spacing between aircraft on final approach for either runway was set equal to the average observed spacing during heavy demand.

2. Arrival times at the runways could be predicted far enough in advance so that individual aircraft could be assigned to either runway regardless of the direction from which it is coming, and before they are merged into a common flow. Further, the two streams of traffic could be sequenced and spaced independent of each other, using route, altitude, or longitudinal (time) separation.

Based upon this analysis, it was determined that the overly aggressive metering (i.e., 10 mile spacing) accounted for about 42% of the total observed landing delay, and under-utilization of the south runway accounted for about 31%. Together, these potentially correctable delays accounted for about 73% of the total landing delay. The residual 27%, is the necessary landing delay due to demand exceeding capacity.

Recommendation

Under the present manual procedures, it is not possible to achieve a more expedient flow due to the level of interfacility coordination and advanced planning that will be required. However, if an automated planning aid is available that can

(1) assess the anticipated demand against the available capacity and

(2) efficiently and equitably assign arrival aircraft to the available runways before merging them into a common flow,

then procedural changes could be implemented to avoid most of the potentially correctable delays.

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS

## LIST OF ILLUSTRATIONS
(CONT'D)

## 1. INTRODUCTION

DOT/FAA Order 7110.72, Local-Flow Traffic Management, dated 15 November 1976, provided for the establishment of "profile descent" and "en route metering" procedures in order to promote aircraft fuel conservation. The en route metering procedures are intended to shift delay absorption from the low altitude airspace to the high altitude en route area.

A previously published theoretical analysis (Reference 1) addressed the possibility that, due to landing time prediction errors which increase with lookahead time, imposing too much delay in the en route airspace could reduce runway utilization to the extent that fuel benefits from profile descents could be negated. Figure 1-1 (from Reference 1) is an example of the increase in expected delay per aircraft as a function of demand due to a loss in runway throughput. This figure calls attention to the effect that a fairly small loss in runway utilization can result in a substantial increase in delay per aircraft. A loss of 4.5 aircraft per hour or 13%, can cause the average delay per aircraft to increase by 4.3 minutes at a demand of 35 aircraft per hour, in this example. Figure 1-2 (from Reference 1) depicts the estimated net fuel savings of a profile descent procedure per aircraft under profile descents as a function of achieved or actual landing rate. It is observed that a loss in runway utilization of 4.5 aircraft per hour negates the fuel savings achieved by profile descent procedures. The analysis concluded that landing delays estimated and taken en route should be discounted to assure that no aircraft arrives late for final sequencing to the runway. Of course, the terminal area should have enough control capability to absorb the necessary delays if the aircraft arrive early.

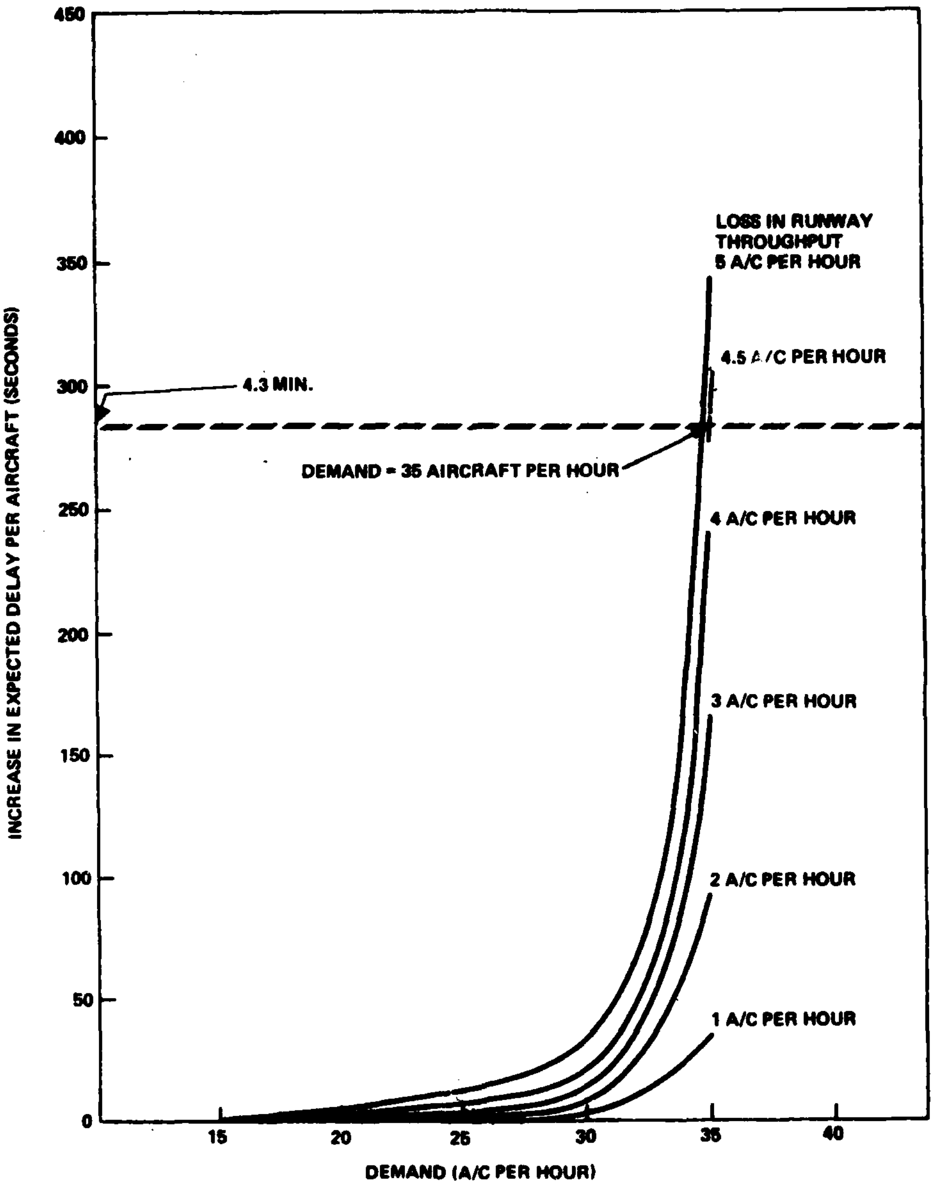



**FIGURE 1-1**
**INCREASE IN TIME DELAY (ABOVE AVERAGE DELAYS)**
**DUE TO A LOSS IN RUNWAY THROUGHPUT**
**AS A FUNCTION OF DEMAND**
**(FOR ARRIVALS ONLY)**

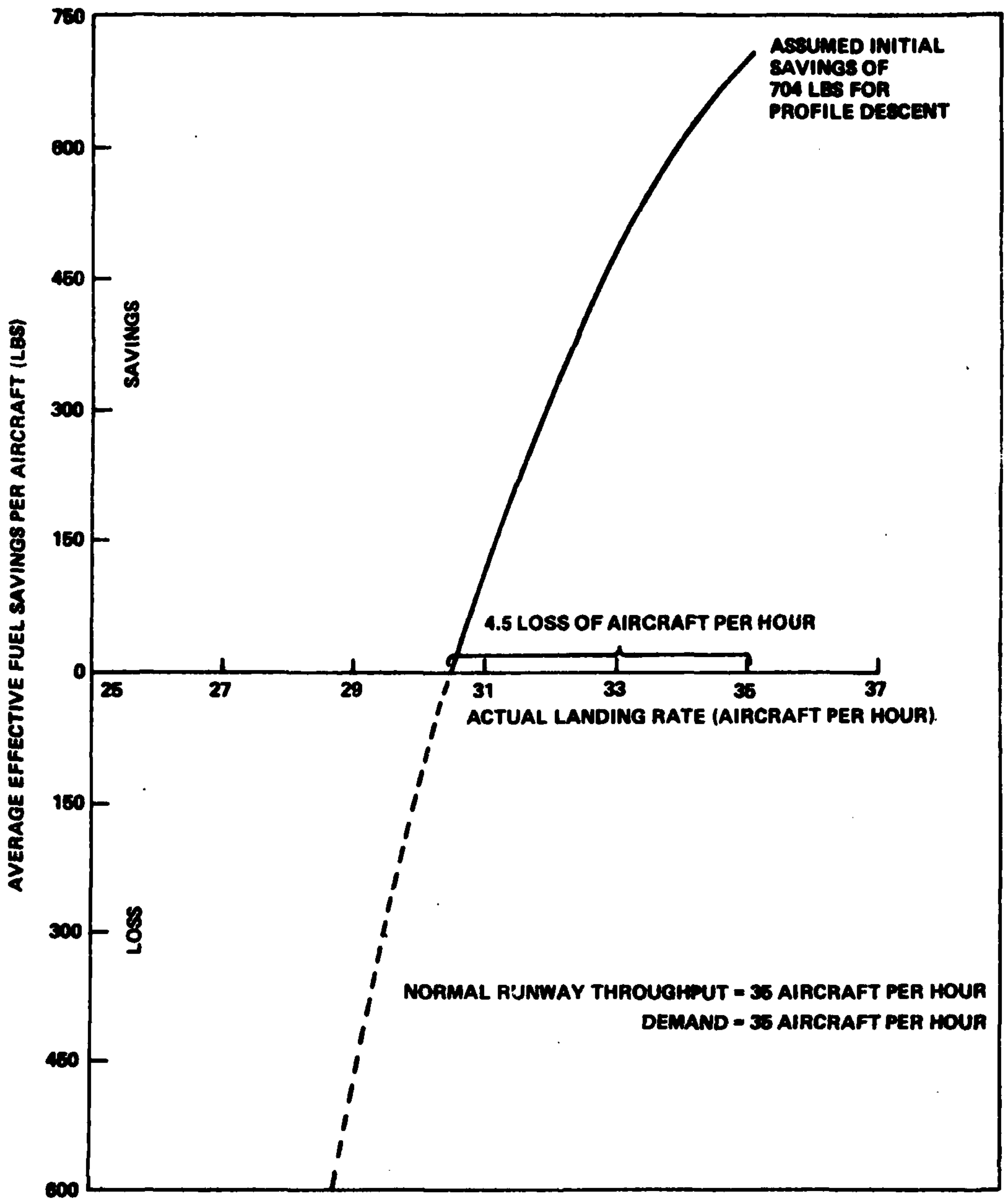



**FIGURE 1-2**
**EFFECTIVE FUEL SAVINGS AS A FUNCTION OF ACTUAL RUNWAY THROUGHPUT (FOR ARRIVALS ONLY)**

A data collection and analysis of operations at a specific site were considered desirable in order to ascertain how often aircraft, in fact, receive en route delays while the runway is not fully utilized. Such an effort could be useful in refining the metering and profile descent procedures so as to result in improved overall fuel conservative procedures.

Atlanta was chosen as the study site for three reasons. First, because of high traffic volumes, it represented a challenging profile descent operating environment. Secondly, profile descent procedures had been in effect for some time, and thus operating methods should have stabilized. Finally, aircraft arriving in Atlanta airport seemed to be experiencing more delays than were anticipated.

As a result, the study effort was designed to investigate and analyze the total arrival flows from the Center boundary to the runway thresholds. The study was designed to answer such questions as:

1. Did under-utilization of either or both runways occur, and how was it related to demand?

2. What effect did under-utilization have on delays?

3. If the delays observed were excessive or unnecessary, what were the factors and their relative importance?

4. Were the actual delays more than that required to efficiently meter the aircraft so as to achieve the proper sequencing and spacing?

This document presents the data collection effort (Section 2), the observed performance (Section 3) and what could have been achieved under improved procedures (Section 4).

# 2. ATLANTA DATA COLLECTION, REDUCTION AND ANALYSIS

This section presents the operating conditions at Atlanta during the time the data was collected and describes the data collection, reduction and analysis techniques.

## 2.1 Data Period Conditions

Since the Atlanta airport is used by the airlines as a connecting airport, a heavy arrival traffic period is typically followed by a heavy departure traffic period. Since this study is concerned with only arrival traffic flows, a data collection period during the first morning arrival peak was chosen.

This particular arrival peak normally occurrs about 10:00 a.m., with the traffic build up starting about 8:30 a.m. Prior to this time, the traffic is very light, thereby insuring that the collected data would not be affected by any residual landing delay problems from a preceding peak period.

Table 2-1 summarizes the data period conditions and observed traffic. Data was collected on 107 aircraft, with 96 of them landing on either 8 or 9R. Aircraft which did not land on these runways were not part of the en route metering process and are not included in the analysis.

### 2.1.1 Weather and Airport Demand Conditions

The weather conditions during the data collection period permitted visual approaches from the vicinity of the base leg. Data at the command center central flow control facility was reviewed in order to establish that this particular day was

TABLE 2-1

DATA PERIOD CONDITIONS

DATA COLLECTED AT ATLANTA ARTCC/TRACON FACILITIES

| | |
|---|---|
| DATE | THURSDAY, JANUARY 12, 1978 |
| TIME PERIOD | 8:30-11:00 AM (1230-1500 ZEBRA) |
| WEATHER | VISUAL (VFR) |

| ARRIVAL MIX | TOTAL ARRIVALS ON 8, 9L OR 9R | | ARRIVALS LANDING ON 8 OR 9R |
|---|---|---|---|
| STANDARD TURBOJET | 87 | (80%) | 87 |
| HEAVY TURBOJET | 7 | ( 7%) | 7 |
| TURBOPROP | 5 | ( 5%) | 2 |
| PISTON PROP | 8 | ( 8%) | 0 |
| TOTAL | 107 | | 96 (DATA SAMPLE) |

typical in terms of demand and traffic arrival rate as determined by weather and operating conditions and other major hubs.

### 2.1.2 Runway Usage

The Atlanta Hartsfield International Airport has four major runways as depicted in Figure 2-1. During the data collection time period, Runways 8 and 9R were utilized for all arriving jet traffic, while runway 9L was used for all departures and arriving IFR and VFR propeller aircraft. Runways 9R and 8 are spaced and equipped to accommodate simultaneous IFR approaches. The actual arrivals are tabulated in Table 2-2. The terminal complex is located to the north of all runways. Therefore, the north runway (8) is the normally preferred landing runway since it involves the minimum taxi distance to the terminal complex. Also, runway 15/33 was decommissioned due to construction.

Traffic arriving on the south runway (9R) must cross the other two runways during taxi. However, based upon observations and discussions with the tower supervisor, arriving traffic was not impacted by the number of crossing taxiways. The interarrival spacing is normally adequate to permit aircraft to cross the active runway without impacting arriving traffic. This observation is limited to the study data period traffic.

## 2.2 Traffic Conditions

Figure 2-2 depicts the arrival routes that are utilized at Atlanta. In general, the traffic follows the STAR arrivals

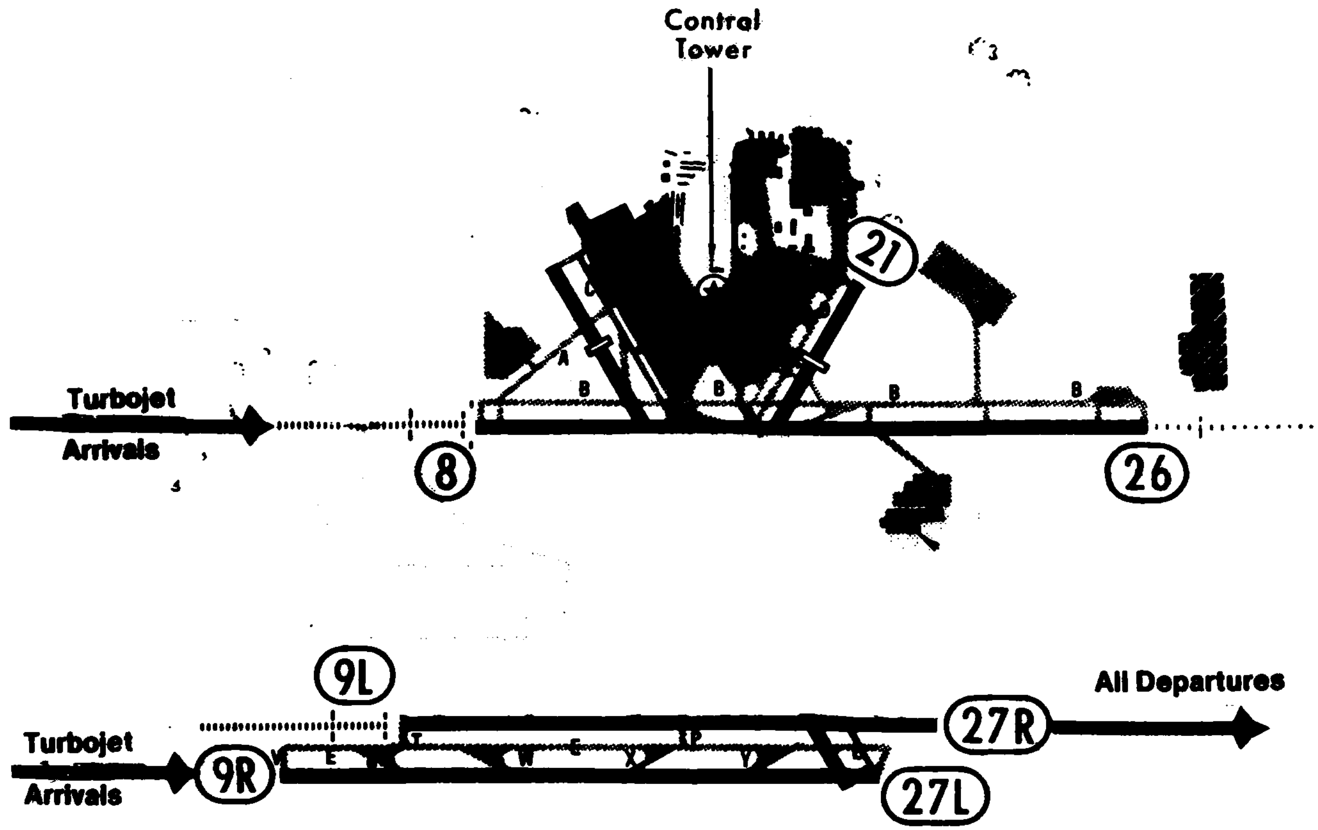



FIGURE 2-1
ATLANTA AIRPORT LAYOUT

TABLE 2-2
OBSERVED AIRCRAFT ARRIVALS

| AIRCRAFT IDENTIFICATION | AIRCRAFT TYPE | LANDING RUNWAY | ARRIVAL TIME | AIRCRAFT IDENTIFICATION | AIRCRAFT TYPE | LANDING RUNWAY | ARRIVAL TIME |
|---|---|---|---|---|---|---|---|
| EA 275 | DC-9 | N (North) | 124347 | DL1842 | DC-8 | S | 140252 |
| RD 403 | DC-8 | N | 125534 | DL501 | B-727 | S | 141132 |
| SO 720 | TP | N | 125813 | DL1146 | L-1011 | S | 140757 |
| EA 644 | B-727 | N | 130102 | DL738 | DC-9 | N | 140628 |
| SO 510 | DC-9 | N | 130446 | PI 5 | B-737 | S | 141705 |
| EA 354 | B-727 | N | 130817 | DL948 | DC-8 | S | 140416 |
| EA 632 | DC-9 | N | 131139 | DL462 | B-727 | N | 1411[illegible]4 |
| EA 148 | DC-9 | N | 131010 | EA989 | D-727 | N | 140757 |
| EA 679 | DC-9 | N | 132220 | DL1027 | L-1011 | S | 141315 |
| EA 688 | DC-9 | N | 132037 | PI29 | B-737 | S | 142521 |
| EA 130 | B-727 | N | 131904 | PI43 | B-737 | N | 140950 |
| N 100A | DC-9 | N | 132802 | UA675 | B-737 | N | 141848 |
| EA 630 | B-727 | N | 132432 | DL201 | B-727 | N | 141238 |
| EA 270 | B-727 | N | 132633 | DL1892 | DC-8 | N | 141421 |
| NW 77 | L-1011 | S | 133334 | DL347 | B-727 | N | 141545 |
| EA 617 | B-727 | N | 133532 | DL760 | DC-9 | S | 141536 |
| EA 658 | DC-9 | N | 133046 | DL136 | B-727 | S | 141953 |
| EA 280 | DC-9 | N | 133220 | DL725 | DC-9 | N | 142550 |
| EA 122 | DC-9 | N | 132936 | DL561 | B-727 | N | 141719 |
| EA 118 | DC-9 | N | 132830 | DL942 | DC-8 | S | 142851 |
| EA 322 | DC-9 | S | 133335 | PI61 | B-737 | N | 142838 |
| EA 654 | L-1011 | N | 134034 | DL1117 | L-1011 | N | 142008 |
| EA 104 | B-727 | N | 133647 | EA631 | DC-9 | N | 143521 |
| SO 512 | DC-9 | N | 133604 | UA623 | B-737 | N | 143228 |
| EA 539 | DC-9 | S | 133811 | DL1022 | L-1011 | S | 142328 |
| EA 240 | B-727 | N | 133937 | PI35 | B-737 | N | 142928 |
| EA 678 | DC-9 | N | 133806 | DL1615 | BC-8 | S | 142631 |
| EA 531 | DC-9 | S | 134249 | OL210 | B-727 | S | 142145 |
| SO 760 | TP | N | 134312 | OL418 | B-727 | N | 142407 |
| DL 405 | B-727 | S | 135350 | EA101 | DC-9 | S | 143323 |
| DL 637 | DC-9 | N | 135648 | EA251 | DC-9 | N | 143103 |
| DL 226 | B-727 | N | 135821 | SO162 | DC-9 | N | 142704 |
| DL 529 | B-727 | N | 140101 | UA473 | B-737 | S | 143938 |
| DL 602 | DC-9 | S | 140036 | DL717 | DC-9 | N | 143347 |
| DL [illegible] | B-727 | N | 140225 | EA727 | B-727 | S | 143140 |
| DL 546 | B-727 | N | 135853 | EA135 | DC-9 | S | 145249 |
| DL 217 | B-727 | S | 140349 | EA907 | B-727 | N | 144900 |

TABLE 2-2
OBSERVED AIRCRAFT ARRIVALS
(cont'd)

| AIRCRAFT IDENTIFICATION | AIRCRAFT TYPE | LANDING RUNWAY | ARRIVAL TIME |
|---|---|---|---|
| NW 26 | L-1011 | N | 143622 |
| SO 131 | DC-9 | N | 144602 |
| EA 137 | B-727 | S | 144946 |
| OL 125 | B-727 | S | 144442 |
| SO 140 | DC-9 | S | 143745 |
| EA 255 | B-727 | S | 143901 |
| EA 265 | DC-9 | N | 144021 |
| EA 677 | B-727 | S | 144245 |
| EA 141 | DC-9 | N | 145245 |
| DL 435 | B-727 | N | 144145 |
| EA 119 | B-727 | S | 144135 |
| EA 597 | B-727 | S | 145740 |
| TW 528 | B-727 | N | 144342 |
| DL 245 | B-727 | N | 144433 |
| N 2004 | DC-8 | S | 145002 |
| EA 671 | DC-9 | N | 144722 |
| EA 323 | B-727 | S | 145134 |
| EA 282 | B-727 | S | 144803 |
| RD 401 | DC-8 | N | 145057 |
| UA 839 | B-727 | N | 145740 |
| EA 789 | DC-9 | N | 145602 |
| SO 731 | TP | N | 145400 |

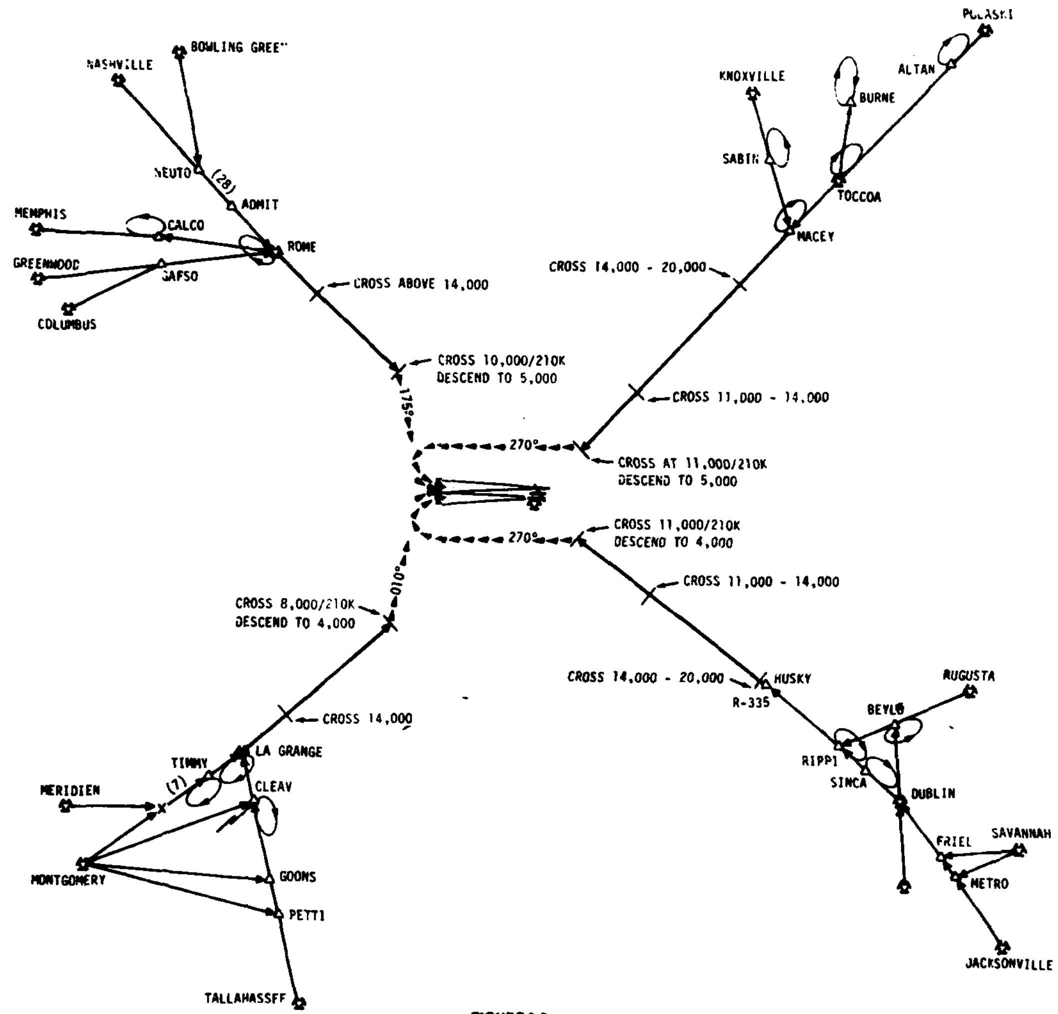



**FIGURE 2-2**
**ATLANTA RUNWAY 8/9R PROFILE DESCENTS**

until just prior to a metering fix (Macy, La Grange, Sinca, Rome) at which time a profile descent is initiated. The terminal boundary is located at the 14,000 feet altitude crossing point as shown on Figure 2-2.

### 2.2.1 En Route Traffic Flow

The organization and flow of the command traffic is predicated on the in trail separation specified by the terminal at each of the four metering fixes. The traffic is first cleared for a STAR arrival and then merged into a stream of traffic extending well into the en route airspace. As an example, if the terminal had specified 10 miles in trail, as a handoff requirement then, each aircraft is separated by 10 miles along the arrival path, with speed control and off-course vectoring used to maintain the required spacing. Holding of aircraft occurs when the approach route becomes saturated. In the event the hand off spacing is increased, then the route will immediately become saturated and holding will start at the metering fix and extend back into the en route airspace in a "domino effect" manner. A decrease in the handoff spacing does not have an immediate effect because aircraft are not available in the approach stream. Aircraft are customarily cleared for a profile descent to a specific runway prior to the metering fix, and then handed off to the terminal control just before or upon crossing the metering fix.

This implies that the decision as to which aircraft will land on what runway is predetermined, and is a function of the arrival direction. It is emphasized that the specific clearance is not "an expect further clearance", but rather, "A/C ID is cleared for a profile descent to a specific runway." The clearance limit is the area after the aircraft has turned onto base leg in the terminal area as shown on Figure 2-2.

### 2.2.2 Terminal Traffic Flow

The terminal area (TRACON) assumes control of the arriving aircraft just prior to or at the metering fix, with the aircraft having been cleared for a profile descent to a particular runway. If unrestricted by ATC, the aircraft will continue his descent on a certain radial of the Atlanta VOR until reaching a specified distance at which time a turn will be executed and descent continued. As shown in Figure 2-2, this turn will either place the aircraft on base leg, if he has arrived from the northwest or southwest, or on downwind, if he has arrived from the northeast or southeast. During the data period, the aircraft were cleared for a visual approach on the base leg or when turning onto the final approach path.

In general, because of a standing preference for the north runway, south arrivals are often rerouted, traffic permitting, within the terminal area to the north runway under TRACON control. Departure aircraft are routed outbound in the four quadrants located between the arrival flows.

In anticipation of a demand exceeding capacity, the Atlanta Terminal Radar Approach Control (TRACON) can impose an in-trail separation constraint on the en route Center to meter the flow of aircraft delivered at each of the four handoff fixes. The in-trail spacing method was selected by Atlanta because it was believed to be the only type of constraint that an en route controller could achieve with any degree of accuracy in the presence of the high traffic volume that exists at Atlanta. The number of miles in-trail is a dynamic variable manually selected by the TRACON, based upon experience, landing facility conditions and expected traffic loading. However, it is emphasized that, in practice, the selection of a specific number of miles spacing and how it varies during a traffic peak period is based solely on experience and judgment, because no automation aids are available to help the TRACON determine and adjust this metering constraint as a function of anticipated runway demand, traffic mix and distribution.

## 2.3 Data Collection and Reduction

The data was collected by manual observations and computer recordings on magnetic tape.

### 2.3.1 Manual Observations

Manually observed data was collected in the tower cab, TRACON IFR room, and the en route center. Additionally, voice recordings were reviewed for those positions in both the TRACON and center that controlled the arrival aircraft. From these recordings, it was determined which aircraft movements were affected by ATC and what portion of the arrrival route was affected. Observers in the TRACON and the Center, recorded the metering constraints and any abnormal occurrances that could affect the interrelation of the data. The tower observers recorded arrival aircraft data and confirmed that departure aircraft in combination with ground traffic did not impact interarrival aircraft spacing.

### 2.3.2 Computer Recorded Data

The computer output data consisted of NAS/SAR and ARTS III/Extractor magnetic tape recordings. These tapes contained all data that normally recorded by the two facilities, including aircraft tracking data. Utilizing this data, an aircraft's position, speed, altitude, and heading can be determined as a function of time. Because these tapes contain so much data that was not of interest, they were first preprocessed so that only time ordered tracking data remained. The next step involved the detecting when the aircraft crossed a number of preselected "fix gates" (geographic points) along its arrival route from the Center boundary to the runway threshold. Each arrival route was divided into small (approximately 200 seconds flying time) route segments between adapted fix gates. The passing of an individual aircraft through a fix gate is detected, along with the clock time, reported altitude, track heading and track speed. The reduced data then consists of a sampled profile for each aircraft as it travels from the center boundary to the runway threshold. Also, from the voice data reduction, it can be determined which portions of the profiles were affected by ATC-imposed restrictions in altitude, and speed or horizontal path. A more detailed discussion of the data reduction is presented in Appendix A.

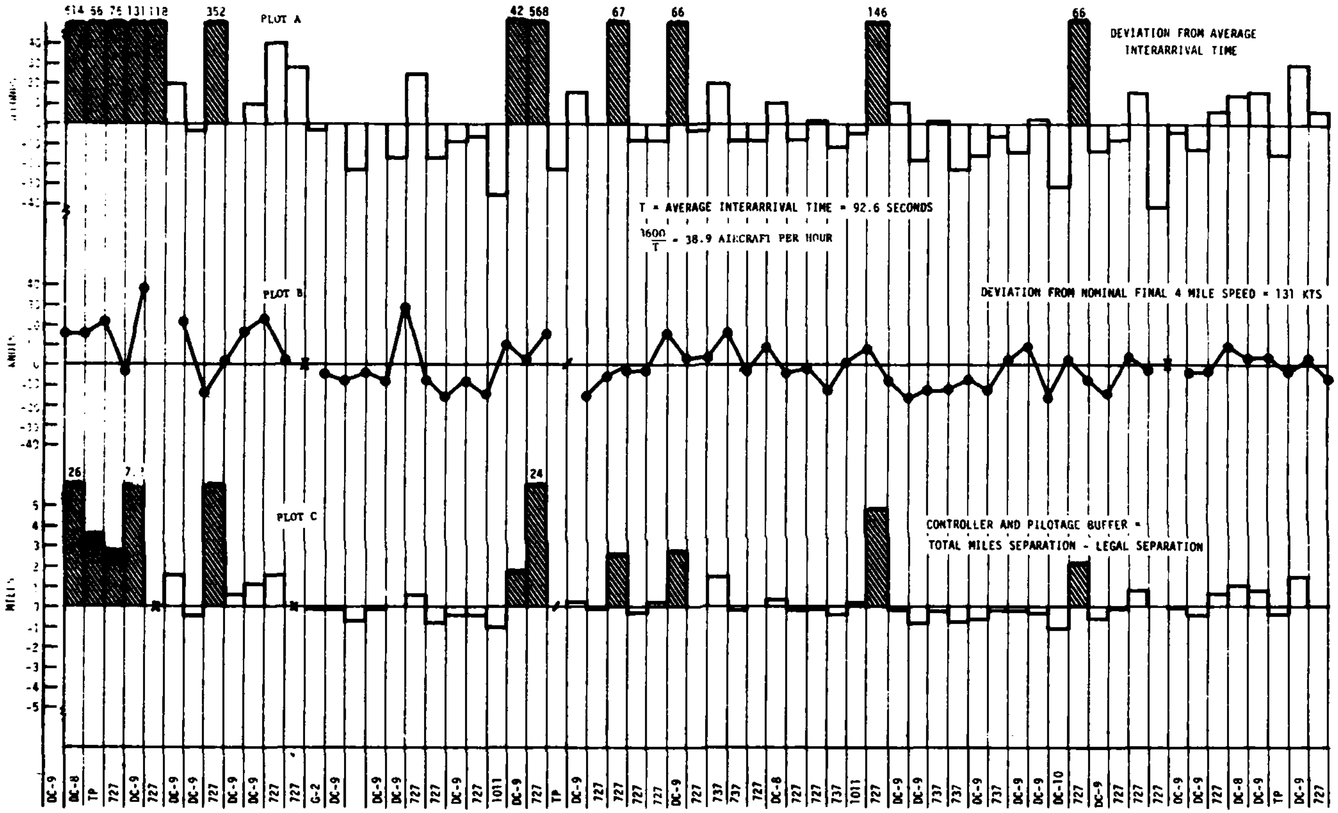
## 3. OBSERVED PERFORMANCE

This section analyses the actual runway utilization and the delays incurred by comparing the aircraft demand to actual throughput at the runway threshold.

### 3.1 Observed Capacity

The observed capacity is derived from the collected data and it is determined by the ability of the controllers to space aircraft at the runway threshold in the presence of adequate demand. The interarrival time between an aircraft pair is the difference between the arrival times at the runway threshold. For all arrival aircraft, the interarrival times for successive landings were computed. Interarrival spacings that were impacted by wide-bodied aircraft or the lack of an adequate flow of arrival aircraft (interarrival spacing 2 miles greater than that required) were discarded. A numerical average spacing of 92.6 seconds was computed from the rest of the sample. Figure 3-1, Plot A, depicts all the interarrival times as deviations from this average spacing of 92.6 seconds. This figure is based on north runway only because that runway was more heavily used. The horizontal axis defines the aircraft type. The spacing shown is the difference in time between the aircraft's threshold time and that of the aircraft in front of it. Cross-hatched areas indicate the pairs that were discarded from the computation of the average.

Plot B of Figure 3-1 depicts the deviation of the speed of the aircraft from a computed average speed of 131 knots during the final four miles. The speeds are based upon the actual time the aircraft took to travel the four miles, rather than the ATC




AIRCRAFT NOT INCLUDED IN NOMINAL DETERMINATION BECAUSE OF EXCESS SPACING RESULTING FROM LACK OF DEMAND

**FIGURE 3-1**
**DETERMINATION OF NORTH RUNWAY UTILIZATION UNDER VFR CONDITIONS**
**(AIRCRAFT PAIR SEPARATION VARIATION FROM NOMINAL)**

system radar track speed. It is interesting to note here that the deviation from the 131 knots is random and is not dependent on aircraft type.

Plot C is of interest in that it depicts the difference between the actual separation at the runway threshold and the required IFR separation. The actual separation was computed from the interarrival spacing and the speed of the trailing aircraft over the final four miles. The weather conditions during the data period was VFR; thus, the aircraft were executing visual approaches from the vicinity of the base leg. It can be observed that the aircraft generally cross the threshold within $\pm$ 1 mile of the IFR spacing, even under visual approach conditions.

The runway capacity can be calculated by using the 92.6 second average spacing between arriving narrow body aircraft. Also, from Plot A of Figure 3-1, it can be seen that the interarrival spacing associated with the two wide body aircraft is 66 and 42 seconds (146 seconds behind the other wide body aircraft reflects lack of demand). If the leading aircraft is wide bodied, the spacing is calculated as $92.6 + \frac{(66+42)}{2} = 146.6$ seconds.

By using these two interarrival spacing values, the equation describing the average hourly throughput can be written as,

$$92.6N_n + 146.6N_w = 3600$$

or

$$N_n + 1.6N_w = 38.9$$

where,

$N_n$ = Number of Narrow Body Aircraft.

$N_w$ = Number of Wide Body Aircraft.

From this relationship, the capacity for a demand of only narrow body aircraft ($N_w = 0$) would be 38.9 aircraft per hour.

The capacity with one wide body included in the arrival demand would be 38.3.

## 3.2 Individual Runway Demand and Utilization

The total average hourly demand on both runways can be determined by the relationship,

$$\frac{\text{Number of Aircraft (N)}}{\text{Time Period (T)}} = \text{Demand (D)}$$

During the total data collection period (1230Z to 1500Z), two distinct traffic flow peaks occurred. The first peak started at 1240Z and ended at 1345Z. This peak contained 29 aircraft with 24% arriving over north approach fixes and 76% from the south. Since the total data period contained 96 aircraft, this first peak represented 30% of the total sample. The average hourly demand ($D_1$) for this first peak can be calculated as follows,

$$D_1 = \frac{N}{T} = \frac{\text{29 aircraft}}{\text{1.08 hours}} = \text{26.9 aircraft/hour}$$

This demand of 26.9 aircraft per hour can be compared with a total capacity of 77.8 (2 X 38.9) aircraft per hour as described in Section 3.1. Thus, during the first peak, the total arrival demand is only 35% of total runway capacity. By allowing arrival direction to determine the landing runway (i.e., north arrivals land on north runway) it can be calculated that the individual runway demand represents 18% of the North and 56% of the South runway's hourly average capacity.

The second and larger traffic flow peak started at 1350Z and ended at 1500Z. This peak contained 70% (67 aircraft) of the total period aircraft. The demand ($D_2$) for this second period is,

$$D_2 = \frac{N}{T} = \frac{67 \text{ aircraft}}{1.17 \text{ hours}} = 57.3 \text{ aircraft/hour}$$

Comparing this demand with the total capacity of 77.8 aircraft/hour shows that 73.7% of the combined runway capacity was required during the second peak. Also, 66% (44 aircraft) arrived from the north and 34% (23 aircraft) from the south. By comparing these arrivals with the individual runway capacity (38.9 aircraft/hour), it is determined that the demand represents 113% of the north and 59% of the south runway's average hourly capacity.

In summary, from a comparison of "average hourly rate" capacity and demand, the following observations can be made:

1. During the first traffic peak of the data period, the average demand exceeded neither the total (both runways) or the individual runway capacities.

2. During the second peak, the demand did not exceed the total or combined runway capacity; however, the north arrival demand did exceed the north runway capcity.

The next comparison involves the individual runway capacity and the actual observed utilization based on average hourly rates. During the first peak, 5 (18%) aircraft landed on the south runway and 24 (82%) aircraft on the north runway. The percent utilization can be calculated as follows,

$$\frac{\text{Aircraft landed per hour}}{\text{Runway capacity}} \times 100 = \text{average utilization}$$

Thus, during the first peak the average utilization of the north runway was 62% and the south only 13%.

During the second peak, 28 (42%) aircraft landed on the south runway and 39 (58%) aircraft on the north. The north runway utilization was 100% and the south by 72%.

In summary, the following observations are made:

1. During the first peak the majority of the traffic arrived from the south but the north runway was utilized more.

2. During the second peak, the largest demand occurred from the <u>north</u> and the <u>north</u> runway was fully utilized.

Based upon this analysis of average hourly aircraft rates, it is evident that aircraft were being preferentially directed to the north runway without regard for arrival direction. The south runway was being utilized in a secondary manner. At the same time, aircraft were subjected to ATC delays by imposition of large (10 miles) in-trail separation at the meter fixes. However, the analysis based upon hourly average numbers cannot be used to evaluate the metering performance because the analysis does not take into account the actual distribution of the traffic within the time periods. In order to fully analyze the traffic flow with respect to demand, capacity and utilization it is desirable to quantize the data into smaller time increments.

Figure 3-2a and 3-2b present the runway threshold demand for the north and south runways in five-minute increments. The demands are based on the assumption that arrivals through the north fixes will use the north runway and arrivals through the south fixes will use the south runway. The demand is based upon the estimated unspaced arrival times (UAT). The actual runway arrivals during the five-minute increment or utilizations are also depicted on the same plots.

The observed average interarrival spacing was computed to be 92.6 seconds (Section 3.1) if all aircraft were narrow bodied. This spacing yields an average landing rate of 3.24 aircraft for every five-minute increment. Therefore, the five-minute runway utilization could have a sequence as follows:

4,3,3,3,4,3,3,3,4

Thus, even though the runway capacity is shown as 3.24 aircraft/five-minutes in Figures 3-2a and 3-2b, periodically the utilization could be as high as 4 per five-minutes without exceeding the runway capacity. By the same token a series of

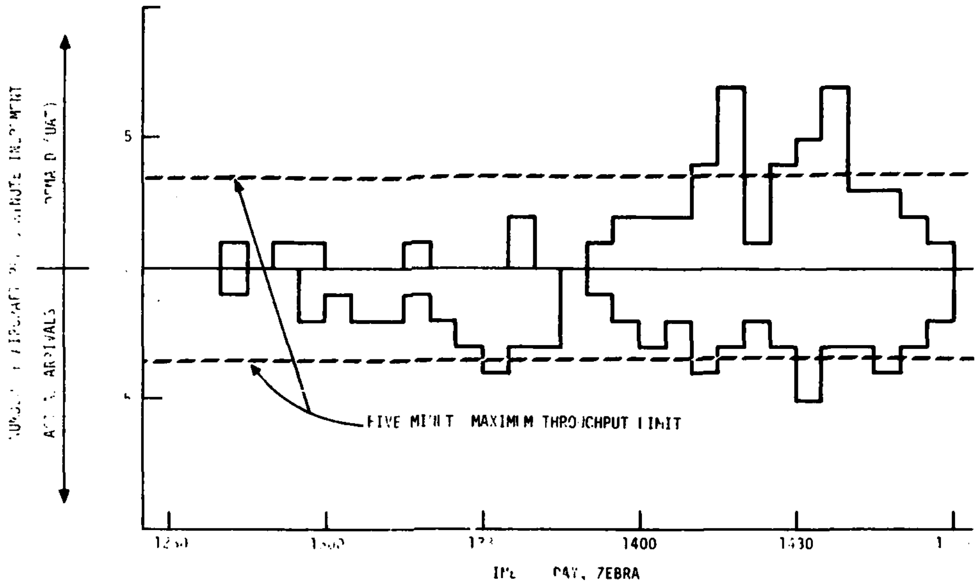



**FIGURE 3 2a**
**NORTH RUNWAY ACTUAL ARRIVALS AND DEMAND**
**BASED ON UAT**

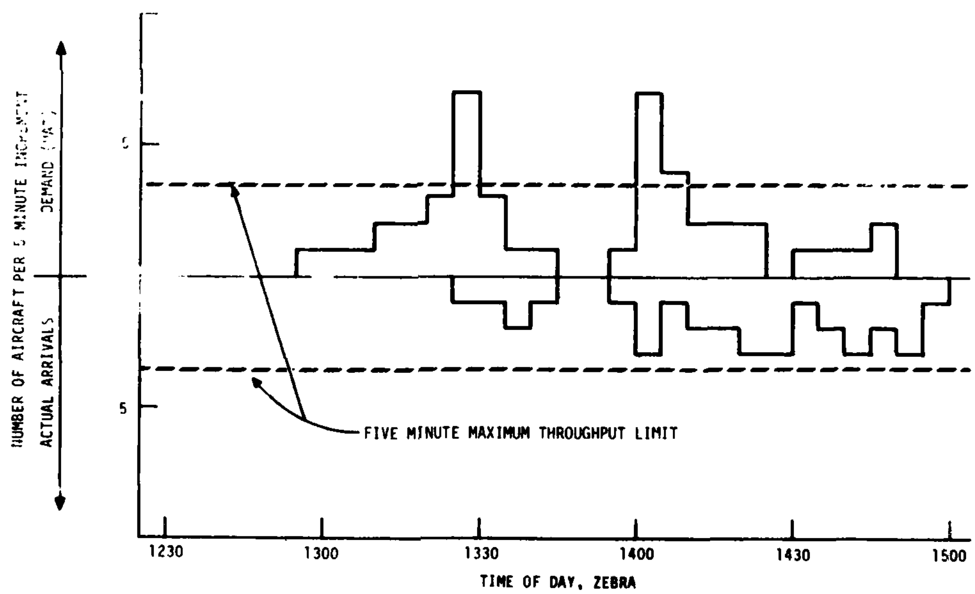



**FIGURE 3-2b**
**SOUTH RUNWAY ACTUAL ARRIVALS AND DEMAND**
**BASED ON UAT**

**FIGURE 3-2**

3 per five-minutes does not necessarily indicate underutilization. Of course, if there are wide bodied aircraft in the arrival stream, there will be a larger percentage of 3s even if the runway is fully utilized.

Examination of both the north and south runway's demands in Figure 3-2, indicates that during the first traffic flow peak (1230Z to 1345Z) the demand (area in the upper halves) is greater on the south runway; that is, more traffic arrived from the south fixes.

Within this first peak, the south runway demand exceeded capacity by at least three aircraft during the 1325Z to 1330Z increment. Examination of the north runway plot (Figure 3-2a) reveals that the demand is zero from 1320Z to 1335Z; therefore, the three south arrivals could have landed on the north runway*. Figure 3-3 depicts the composite total demand and runway utilization. During most of the first peak period the actual arrivals, (area in lower half) show that both the runways (Figure 3-2a) are grossly underutilized. However, during the maximum demand increment the north runway utilization is near maximum, while the south runway (Figure 3-2b) has at least two less than maximum. The composite utilization is considerably less than the composite capacity. However during this entire first peak, the in trail metering spacing restriction was 10 miles, at all arrival fixes. Thus, aircraft were subjected to delays while runways were being underutilized.

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* There were no departures from either of these runways.

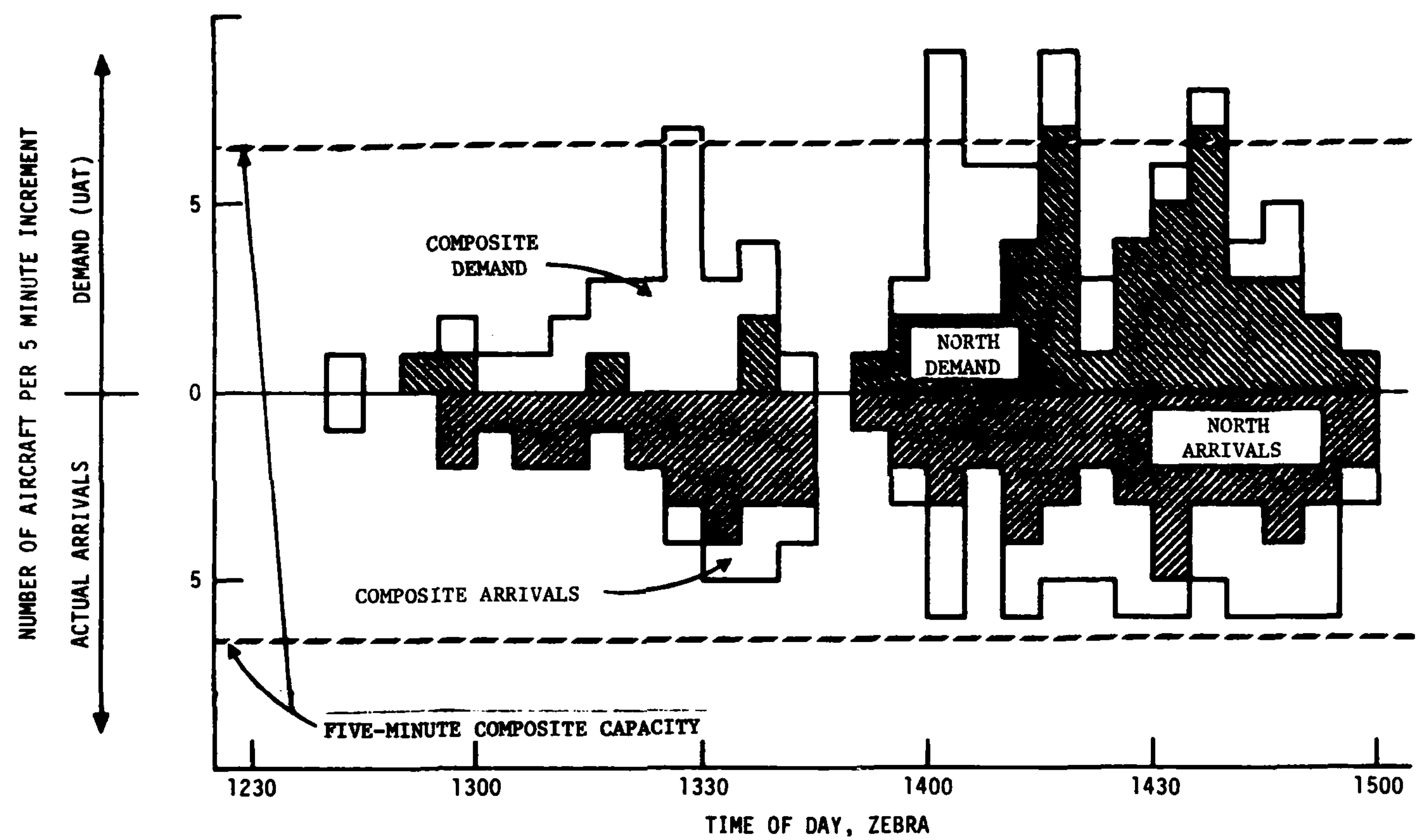



**FIGURE 3-3**
**TOTAL (BOTH) RUNWAY ACTUAL ARRIVALS AND DEMAND BASED ON UAT**

During the second peak the demand exceeded the capacity during three five-minute increments for the north runway and one five minute increment for the south runway. The south runway was not fully utilized for the second peak period either; the north runway was only periodically fully utilized. The composite demand exceeded the composite capacity during three increments. The composite utilization was generally less than 100 per cent.

In summary, the five minute quantized data shows that the traffic flow demand was not being matched to the runway capacity for both traffic flow peaks.

## 3.3 Observed Delay

The observed delay is calculated by evaluating the difference between the unspaced arrival time (UAT) at the runway threshold (the time the aircraft would have arrived if it had not been impacted by ATC metering clearances) and the actual arrival time. This difference represents the total delay encountered by an arrival aircraft, as it travels from the outer boundary to the threshold. (The breakdown of the delay between the en route and terminal airspaces will be discussed in Section 4.0 during the detailed flow analysis.) It is assumed that all delay encountered in the en route area resulted from restrictions caused by the terminal area. Observers located in the center during the data collection period confirmed that arrival aircraft were not delayed due to sector saturation, crossing or over-flight traffic or other non-terminal related effects; that is, the arrival aircraft were not delayed in the en route area except for the perceived limitations of airport capacity.

Some part of the total delay is unavoidable in providing the required separation at the runway threshold. Thus, the total observed delay is composed of this necessary delay and a delay that was not necessary or potentially correctable delay (PCD). An ideal traffic flow management system would have the capability to plan and control traffic flows such that the PCD would be zero or near zero.

Figure 3-4 depicts the total aircraft delay per five minute increment as a function of time. At the beginning of the data period (1230Z) the terminal area imposed a 10-mile in-trail spacing at all arrival fixes. Thus, even those aircraft arriving at the beginning of the first peak (1230Z to 1345Z) suffered a delay, as shown. During the first peak, 29 aircraft arrived with a total delay of 94 aircraft minutes. Therefore, each aircraft was delayed an average of 3.24 minutes, even though as shown in the previous sections, the total capacity of both runways was not exceeded.

During the second peak (1345Z to 1500Z), 67 arriving aircraft were delayed a total of 367 aircraft minutes. Each aircraft was delayed an average of 5.5 minutes. The in-trail spacing of 10 miles was not reduced to 5 miles until 1420Z, or approximately half way through the second peak. In the next section, a flow planning capability is assumed and the delays are identified into necessary delays and potentially correctable delays.

## 3.4 Summary

Throughout the total data period there exists an obvious preference for the controllers to direct traffic to the north runway. This is understandable since the north runway is closer

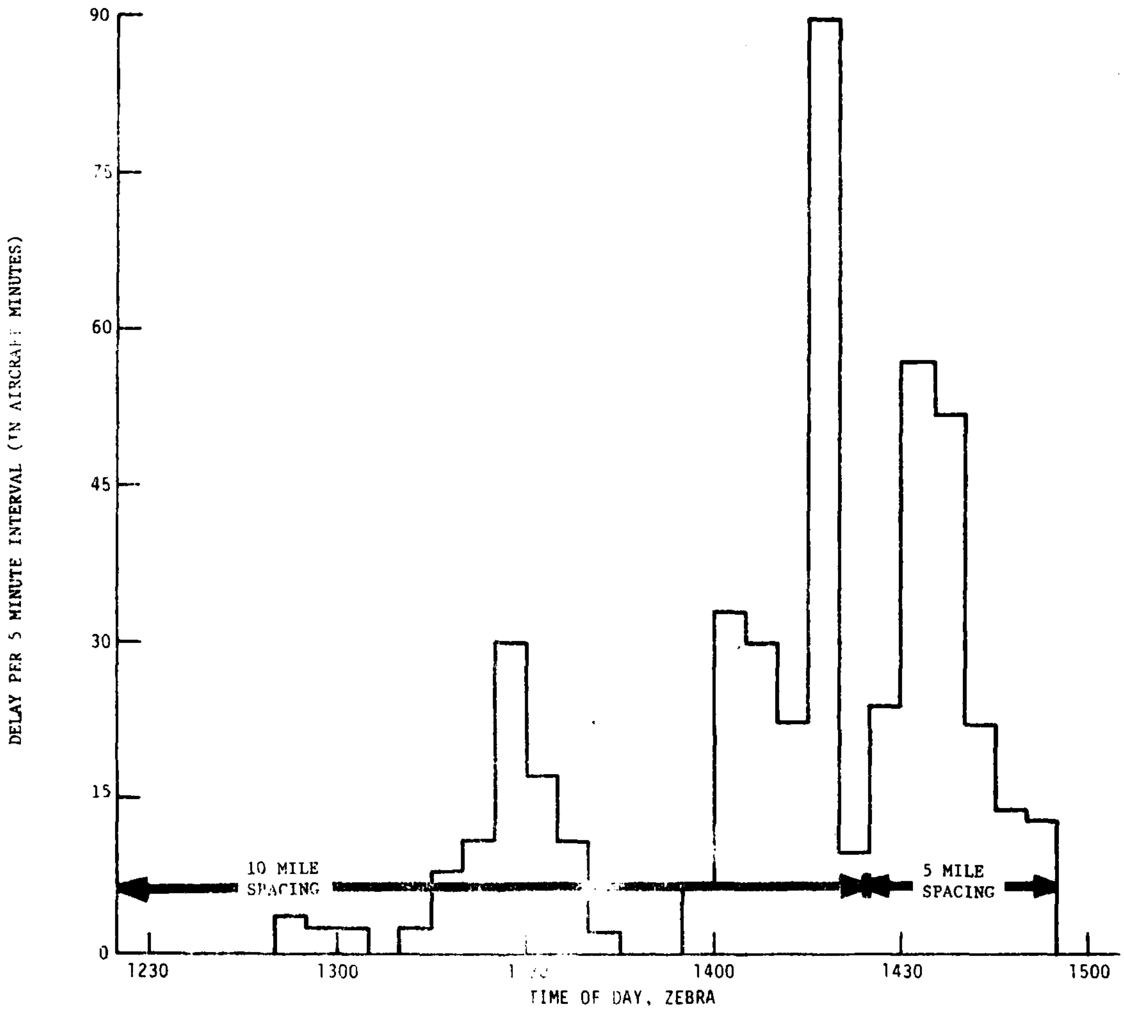



**FIGURE 3-4**
**AIRCRAFT TOTAL DELAY BASED ON ACTUAL ARRIVAL TIME AND PROJECTED ARRIVAL TIME USING UAT**

to the passenger terminal. However, it appears that this is overdone since aircraft are being delayed when the demand is less than the total airport capacity as in the first traffic peak. During the second traffic peak the demand exceeded total capacity for ten minutes, during which the north runway is fairly well utilized while the south runway was not.

The terminal's in-trail metering restriction of ten miles was put into effect too soon and relaxed too late as shown by a drop in arrivals at 1405Z, or adequate traffic was not available in the terminal area. In the absence of an efficient traffic flow planning capability, the metering was too aggressive or premature and was relaxed too late because of an inability to anticipate that adequate traffic was not flowing into the terminal area to achieve full runway utilization.

Some of the delay will be unavoidable due to the demand distribution of the traffic; however, much of the delay appears to be potentially correctable if a good flow planning technique is used. This approach is examined in the next section.

## 4. IMPROVED TRAFFIC FLOW

The previous section discussed the actual runway utilization and the delay that occurred during the observation period. The questions that arise from these observations are:

1. What portion of the delay was necessary and what portion was unnecessary? In other words, is a better flow of traffic possible to match the observed Air Traffic Control system's performance capabilities, resulting in higher runway utilization and less delay?

2. How could the traffic flow be modified to improve runway utilization and reduce potentially correctable delay?

3. What capabilities or different conditions must exist as part of the Air Traffic Control system in order to improve runway utilization and reduce delays?

The method selected to perform the analysis involves the use of a traffic flow planning technique to generate an improved flow (in terms of runway utilization and aircraft delay) which is then compared to the actual traffic flow. The improved flow is matched to the observed runway capabilities.

### 4.1 Improved Flow Assumptions

The operating procedures that were used in Atlanta at the time the data were collected imposed certain constraints on the traffic flow options. These constraints and the assumptions that were made to generate an improved flow are as follows:

1. Aircraft arriving via the same fix are merged in-trail into a common path without regard for landing runway or sequence. However, Atlanta Terminal and en route Center agreed that independent paths could be procedurally provided; but, a capability for runway assignment well in advance of terminal area entry would be required. Therefore, the following assumptions were made in deriving a better flow:

   a. Independent paths from cruise altitude to the landing runway can be defined so that aircraft landing on different runways need not be spaced in-trail on a common path.

   b. Runway assignments can be made well in advance of in-trail merging for approach on the appropriate independent path to the runway. This also implies that the north and south runways can be fully utilized so that the total airport throughput can be maximized.

   c. The aircraft nominal flying time from the center boundary to the runway threshold is the average that was computed for those flights undelayed by ATC. This assumption permits the projection of the aircraft's threshold crossing time so that the required traffic flow spacing, sequencing and scheduling requirements can be determined well in advance of terminal entry.

2. The observed traffic flow clearly indicated a preference for landing on the north runway regardless of arrival direction or the resulting amount of airborne delay. Consequently, the following assumptions were made in formulating a better flow:

   a. The preference for landing on the north runway will be preserved; but only when it does not increase the amount of in-flight delay incurred by an aircraf

   b. Increased utilization of the south runway and the resulting north runway ground crossing traffic will not increase the average interarrival spacing for landings on the north runway.

## 4.2 Improved Flow Formulation

In this section, it is assumed that a flow management technique can be developed to achieve an improved traffic flow. The result can then be compared to the actual flow in order to define differences and their effects on runway utilization and aircraft delay. Even though flow management consists of both planning and control functions, this analysis will not deal with the effects of control, but will be confined to the generation of a flow plan that is compatible with the observed control methods and performance. Thus the governing principle is that the improved flow could be achieved by the existing control environment because it is matched to the observed performance.

The first step in determining the improved flow, is to define the nominal flying time that each type of aircraft would require to travel a specific arrival route from the center boundary to the runway threshold in the absence of any ATC delays. As described in Appendix B, the nominal time was determined by comparing the reduced sampled profile fix gate data with controller voice recordings. Those segments that were impacted by ATC were eliminated from the computation. The remaining segment travel times were then summed for each arrival route and for each aircraft type in order to determine the nominal flying time from the Center boundary to the runway threshold. The runway schedule is based upon the shortest nominal flying time, via a standard arrival route, from the center boundary crossing location. The Unspaced Arrival Time (UAT) is the time that the aircraft would be projected to arrive at the runway threshold if there were no ATC delays. By unspaced, it is meant that the aircraft have not beeen separated at the runway threshold. This sequenced traffic list, as a function of time, is the total demand on the airport that must be metered and spaced so as not to violate the observed interarrival times established (in Section 3) for the final approach course. Also, the traffic list is ordered in a chronological sequence and thus, becomes the basis for a first-come-first-served (FCFS) landing assignment between both runways.

The aircraft are then assigned runways and landing times to satisfy the required inter-arrival spacing (as defined in Section 3.1) in a way that minimizes delay. Any delay that must be incurred to achieve spacing is then the "necessary delay." The spaced runway landing list defines the aircraft's Improved Arrival Time (IAT) at the runway threshold resulting from the improved traffic flow.

## 4.3 Runway Utilization

A convenient means of visualizing and comparing the actual and improved traffic flows is to construct a traffic flow diagram, as depicted in Figure 4-3. In the diagram the horizontal axis is time of day, divided into five-minute increments. The vertical scale represents number of aircraft per five minute increment. The upward solid arrows represent aircraft that could be available (based on the UAT time) at the runway threshold for landing (demand). The length of the arrow signifies the number of aircraft per five minute period. A downward arrow indicates that a certain number (determined by length) of aircraft crossed the threshold. The horizontal line connecting the head and tail of a pair of arrows indicates the number of aircraft that are being delayed while they await a landing position, i.e., queue size. Plot A in Figure 4-3 depicts the projected upspaced runway demand (up arrow) and to observed landings (down arrow) Plot B of the same figure depicts the improved flow and the same unspaced demand.

Before examining the detail flow characteristics, it is of interest to compare the maximum unspaced demand that was encountered during the two traffic peaks, the maximum throughput capacity and how they related to the en route metering constraints. In Section 3, it was pointed out that during the first peak, the total demand did not exceed the runway capacity. However, during this peak the traffic was constrained from entering the terminal area due to the 10 mile in-trail metering requirement at all fixes. During the second peak the demand exceeded the capacity for only three five-minute increments. The metering requirement was not

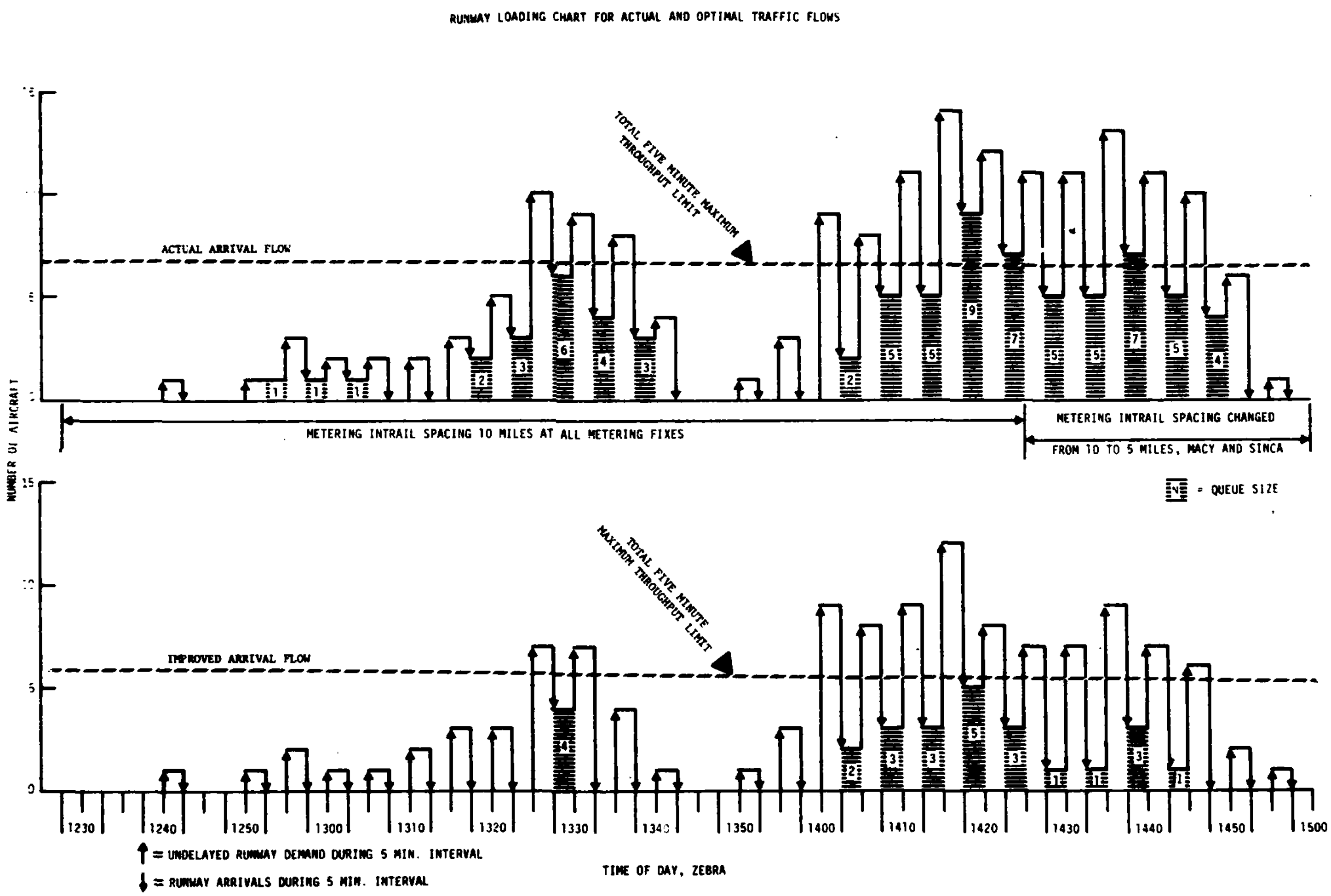



**FIGURE 4-3**
**ACTUAL AND IMPROVED ARRIVAL FLOW VS THE OBSERVED DEMAND**

reduced until half-way through the peak, which indicates that metering is not being adjusted as a function of demand. Also, the metering is magnifying a peak, since it is restricting traffic flow when there is adequate capacity, and shifting it into a later, heavier demand period.

Examination of the first traffic peak (1230Z to 1345Z) shows that in the actual case (Plot A of Figure 4-3) aircraft are being delayed or metered prematurely while the runways are under-utilized. This fact is demonstrated by the existence of a queue for eight of the five-minute periods, while the improved flow (Plot B of Figure 4-3) only requires a queue for one five-minute period. Also, the size of the actual queues are larger, reflecting more aircraft being delayed.

Very early in the second peak (1420Z), the actual queue (Plot A) builds up to almost twice the value of the improved queue. Furthermore, the change from 10 to 5 miles in-trail spacing was made too late (1425Z), since aircraft affected by this change would not reach the runway threshold until approximately 1440Z, to improve the runway utilization. The latter period is characterized by queues that are from two to five times as large as those required by the improved flow.

A comparison of the actual and improved runway loading is shown in Table 4-1. During the first peak, 23 (70%) of the aircraft arrived from the south, while 27 (82%) of the aircraft actually landed on the north runway. This compares with 21 (64%) of the aircraft landing on the north runway in the improved flow case. This implies that 18% (82% - 64%) of the aircraft were delayed unnecessarily in order to land on the north runway, since the improved flow will only allow a north runway landing

TABLE 4-1
RUNWAY LOADING AND DISTRIBUTION

| | DEMAND | | LANDING | | | | |
|---|---|---|---|---|---|---|---|
| | | | ACTUAL | | IMPROVED | | |
| | NORTH | SOUTH | NORTH | SOUTH | NORTH | SOUTH | TOTAL |
| LOW DEMAND (1230Z to 1345Z) | 10 | 23 | 27 | 6 | 21 | 12 | 33 |
| SATURATION DEMAND (1350Z to 1500Z) | 41 | 22 | 37 | 26 | 31 | 32 | 63 |

if it does not increase the amount of delay. During the second (high demand) peak, 41 (65%) of the aircraft arrived from the north, with 37 (59%) of the traffic actually landing on the north runway. This compares with a 31 (49%) to 32 (51%) split between the north and south runways in the improved flow case. This points to the better balancing of runway loading achieved by the improved flow. Again, it is implied that under-utilization occurred in the actual flow. However, runway balancing to achieve maximum utilization is only part of the problem; in that, without prior control action in the en route area, the flowing of traffic that arrives over the same fix to either runway cannot be accomplished without unnecessary delay because of the common path constraint. In summery, runway under-utilization is indicated during both the low and high demand traffic peaks, because of an over emphasis of landing traffic on the north runway and an inability to effectively balance the utilization of both runways. Of course, the load balancing problem, in turn, arises from the lack of a planning capability.

## 4.4 Delay Comparisons

Delay chart, Figure 4-4, depicts the actual, necessary and potentially correctable delays. The actual delay is computed as the difference between the unspaced arrival time (UAT) and the Actual Arrival Time (AAT) at the runway threshold. The necessary delay is the difference between the UAT and the threshold arrival time produced by the Improved Arrival Time (IAT). Therefore, the difference between the actual and necessary delays represents the unnecessary or potentially correctable delay (PCD). The vertical axis of Figure 4-4 represents total aircraft delay occurring in a five minute

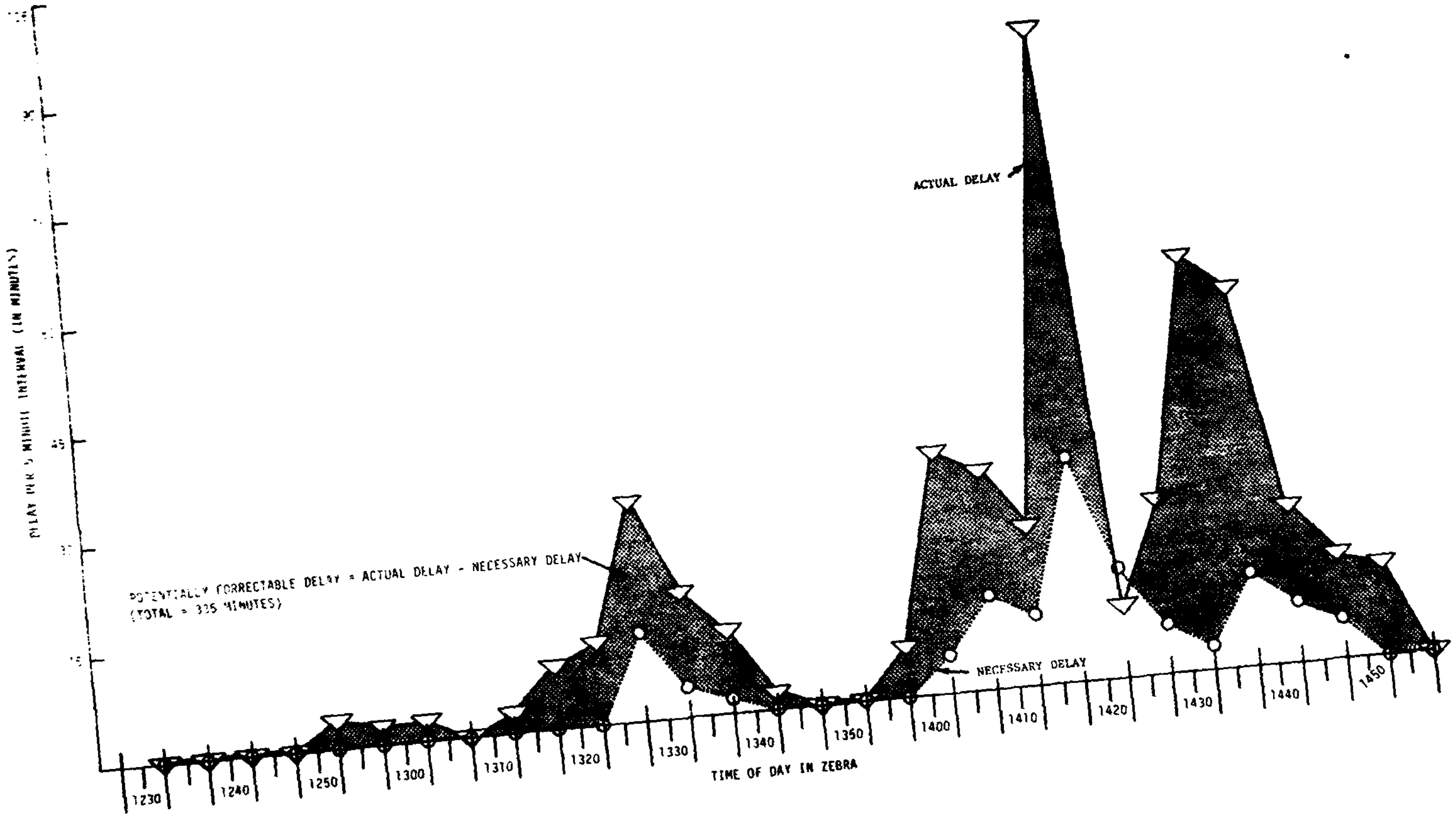



**FIGURE 4-4**
**ACTUAL AND NECESSARY DELAYS VS TIME OF DAY**

increment with the horizontal scale being the same as in previous plots. (Time of day, in five-minute increments). The area between the actual and necessary delay represents the total unnecessary or "potentially correctable delay (PCD)". The total PCD is 335 minutes compared to a total delay of 461 minutes; i.e., 49% of the aircraft were required to fly an additional 335 minutes over that required in the improved flow case.

As was discussed in the introduction, Reference 1 addresses, from a theoretical viewpoint, the possibility that a very small decrease in runway utilization of 13% can cause an average unnecessary delay increase of 4.3 minutes per aircraft; this increased delay will negate the potential fuel benefits that can be derived from the utilization of profile descents. The reason that a small change in runway utilization has a magnified effect on delay arises from the regenerative delay relationship that exists between aircraft during heavy traffic flow, i.e., all following aircraft suffer the same unnecessary delay. Both premature and excessive metering result in runway under-utilization and large unnecessry or potentially correctable delays. The results are summarized in Table 4-2. This table presents a breakdown of actual, necessary, and potentially correctable delay occurring in both the terminal and en route area for the data period. Before reviewing the information presented in the table, it should be noted that delays occurring within the en route area occur because of acceptance or flow restrictions selected by the terminal.

During the 2 1/2 hour data period, 49% of the aircraft were delayed unnecessarily for 335 minutes. The significance of the 335 minutes gains perspective upon being translated into fuel

TABLE 4-2
POTENTIALLY CORRECTABLE DELAY VARIANCE AND DISTRIBUTION

| | | FLOW COMPARISON | | | ACTUAL FLOW | | | OPTIMAL FLOW | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ELAPSED TIME PERIOD IN HOURS | NUMBER OF AIRCRAFT | POTENTIAL CORRECTABLE DELAY IN MINUTES | | | ACTUAL DELAY IN MINUTES | | | NECESSARY DELAY IN MINUTES | | |
| | | TERMINAL | ENROUTE | TERMINAL & ENROUTE | TERMINAL | ENROUTE | TERMINAL & ENROUTE | TERMINAL | ENROUTE | TERMINAL & ENROUTE |
| 0 TO 1 (LOWER DEMAND) | 33 (34%) | 59 (79%) | 16 (21%) | 75 (100%) | 74 (79%) | 20 (21%) | 94 (100%) | 15 (79%) | 4 (21%) | 19 (100%) |
| 1 TO 2 1/2 (HIGH DEMAND) | 63 (66%) | 82 (32%) | 178 (68%) | 260 (100%) | 161 (44%) | 206 (56%) | 367 (100%) | 79 (74%) | 28 (26%) | 107 (100%) |
| 0 TO 2 1/2 | 96 (100%) | 141 (42%) | 194 (58%) | 335 (100%) | 235 (51%) | 226 (49%) | 461 (100%) | 94 (75%) | 32 (25%) | 126 (100%) |

burn by assuming that an average aircraft fuel burn rate is 134 pounds per minute. This rate is based on a B-727 aircraft in a holding situation at 15,000 feet, and is utilized only for illustrative purposes. However, 52% of the data period sample aircraft were B-727s. In any event, 335 minutes translates into 44,890 pounds, or 6,600 gallons of fuel that was burned in a non-fuel efficient manner during a 2 1/2 hour data period in VFR conditions. It is of interest to note that, based upon a review of the Performance Measurement System data at the Command Center, this period is typical of an Atlanta operating day. Of additional interest, is that the PCD was almost equally distributed between en route and the terminal airspace, i.e., 58% vs. 42%. This indicates that 42% of the PCD was not being absorbed in the more fuel efficient high altitude airspace. The average PCD per aircraft was 3 minutes in the terminal and 4.1 minutes in en route or a total of 7.1 minutes. A comprison of the 7.1 minutes to 4.3, which is the theoretical amount that negates the fuel savings derived from profile descents, indicates that the actual traffic flow is not occurring in a fuel efficient manner. Again, using the 134 pounds per minute, 7.1 minutes represents 951 pounds or 140 gallons of fuel wasted on the average, per aircraft.

## 4.5 Traffic Flow Planning

In summary, the comparison of actual arrivals against a possible improved arrival flow has disclosed that premature and excessive metering occurred because the in-trail separation was selected in anticipation of a traffic peak period. The selection of the metering constraint was based upon potential controller workload rather than projected runway utilization, because the former can be perceived, while the latter is not readily available. It was also shown that the metering during the first part of the period when demand was low, delayed the traffic into the peak period. All of this, resulted in decreased runway utilization and increased delays, as shown in Figure 4-4.

Procedures used before profile-descents were predicated on aircraft arriving into the terminal area in a random manner. The terminal area accepted aircraft and performed path stretching, speed control and, in some cases, pattern holding until air space and/or controller saturation occurred. This was done both to provide phased sequencing and separation of simultaneous arrivals, and to provide delay in the case of runway saturation. For these two reasons, metering must occur during periods of both high and low demand, i.e., in one case for sequencing and spacing and in the other case, during a saturated runway demand. After controller/airspace saturation was reached in the terminal area, this same phenomena occurred in the en route area. This method was not fuel efficient, and thus a profile descent concept was devised. Because a profile descent will begin in the en routes area, a large portion of the sequencing and spacing that was done in the terminal must now be done in the en route area at an earlier time. It is then quite logical to anticipate the need for a capability within the terminal area that can derive a flow plan that meets the physical and operational constraints of the terminal and then inform the en route Center of what flow is required. Further, the flow planning capability must derive a plan which is matched to the ability of both the en route and terminal facilities to achieve a certain level of performance.

In the case of Atlanta, the improved flow was derived by using the observed controller level of performance. It was found that the three major areas that produced the undesirable PCD were Premature Metering, Common Path Constraint, and Runway Loading Imbalance. All of these problem areas indicate the need for a flow planning capability in the terminal area. Future automated terminal and en route systems will require a dynamic flow planning function that will permit the systems to operate in concert towards a common coordinated and dynamically updated flow objective. Thus, the results of the Atlanta Study indicate that a Terminal Flow Planning capability is desirable from the standpoint of achieving the total benefits inherent in profile descent procedures.

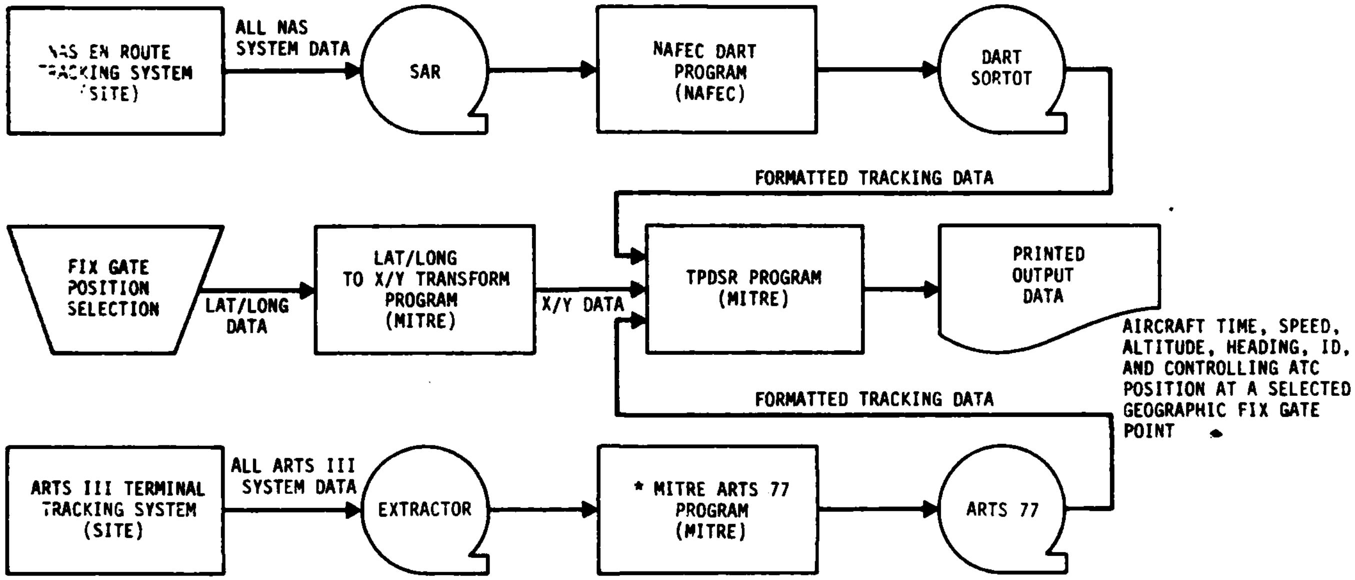
## APPENDIX A

## DATA REDUCTION TECHNIQUE

Both the NAS en route and the ARTS III terminal computer systems have data recording capabilities. The terminal system output is referred to as an Extractor tape and includes data on tracked aircraft such as identification, ground speed, time, reported altitude, track heading, location in system coordinates and controlling ATC position every four (4) seconds. The recorded output from the en route system is a System Analysis Recording (SAR) tape that includes similar data on tracked aircraft approximately every six seconds. The type for each identified aircraft is obtained from en route flight progress strips, which is also recorded on the SAR tape.

The first step in the reduction, as depicted in Figure A-1, is to have the SAR processed by a DART program at NAFEC. This program filters out all unneeded data and sorts the desired tracked aircraft into an alphabetical listing by aircraft identification and then by chronological scan-by-scan data for each aircraft group. The Extractor tapes undergo a similar processing, utilizing the ARTS 77 program at MITRE, to obtain an identical sort tape format.

The next step in the data reduction process is the selection of geographic locations along an aircraft's intended arrival route in the en route and terminal areas at which aircraft data is to be sampled. These geographic sampling areas are named "fix gates." Each fix gate has a defined width, length and heading. The width is selected to enclose the cross-track variations that are expected to occur in the aircraft ground tracks. Typically, the width is set at 10 miles in the en route




* SEE APPENDIX C, REFERENCES

**FIGURE A-1**
**REDUCTION OF RECORDED DATA ON TRACKED AIRCRAFT**

and 2 miles in the terminal area. The length is determined by the aircraft speed, so as to have a minimum of three scans occurring within a fix gate to insure that at least one scan will record a gate crossing, after allowing for missing scan data. Typically, the gate length is set at 0.5 miles close to the airport and 5 miles in the en route area. The fix gate heading is always the same as the sampled arrival route. The selection of separation between fix gates is based on experience and the type of analysis to be performed. However, it has been found that for both traffic flow and fuel consumption analysis, a fix gate separation of approximately 27 miles in the en route, 10 miles in the terminal and 3 miles in the base leg final approach regions are reasonable values.

Initially, the gate coordinates are found from aeronautical charts specified in terms of latitude and longitude, which must be converted into system X and Y coordinates, with nautical miles as the unit of measure. This coordinate conversion is required to be compatible with the NAS and ARTS III systems. The conversion can be performed by utilizing a hand held programmable calculator as outlined in Reference 1. The fix gate data are then entered into the Track Profile Data Sampling Routine (TPDSR) program as a table input, along with other sampling information, such as desired sector or control position, desired aircraft identifiers etc. Reference 2 provides a detailed account of how this program is used and what inputs must be made, in addition to the SAR and Extractor processed data. Figure A-2 is a representative output from the program. The example chosen illustrates the ability to detect that holding occurred at fix gate number 1.

A/C IDENTIFICATION = DL725

| | | | |
|---|---|---|---|
| FIXGATE NUMBER 1<br>K= 5 T= 140101 | CONTROLLING SECTOR = D<br>AC= DL725 CI= 0<br>RA(3)= 171 AA(3)= 0 | XR(3)= 326.8<br>S(3)= 328 | YR(3)= 250.2;<br>H(3)= 228; |
| FIXGATE NUMBER 1<br>K= 33 T= 140552 | CONTROLLING SECTOR = D<br>AC= DL725 CI= 0<br>RA(3)= 152 AA(3)= 0 | XR(3)= 327.5<br>S(3)= 349 | YR(3)= 249.8;<br>H(3)= 185; |
| FIXGATE NUMBER 2<br>K= 77 T= 140918 | CONTROLLING SECTOR = D<br>AC= DL725 CI 0<br>RA(4)= 140 AA(4)= 0 | XR(4)= 316.6<br>S(4)= 268 | YR(4)= 238.3;<br>H(4)= 221; |
| FIXGATE NUMBER 6A<br>K= 118 T= 141230 | CONTROLLING SECTOR = D<br>AC= DL725 CI= 0<br>RA(3)= 114 AA(3)= 0 | XR(3)= 307.2<br>S(3)= 284 | YR(3)= 226.6;<br>H(3)= 214; |
| FIXGATE NUMBER 4<br>K= 131 T= 141331 | CONTROLLING SECTOR = D<br>AC= DL725 CI = 0<br>RA(3)= 109 AA(3) 0 | XR(3)= 304.2<br>S(3)= 281 | YR(3)= 222.8;<br>H(3)= 218; |
| FIXGATE NUMBER 7A<br>K= 148 T= 141450 | CONTROLLING SECTOR = D<br>AC= DL725 CI= 0<br>RA(2)= 110 AA(2)= 0 | XR(2)= 300.3<br>S(2)= 270 | YR(2)= 218.2;<br>H(2)= 221; |
| FIXGATE NUMBER 5<br>K= 162 T= 141556 | CONTROLLING SECTOR = D<br>AC= DL725 CI= 0<br>RA(3)= 110 AA(3) 0 | XR(3)= 297.2<br>S(3)= 265 | YR(3)= 214.5;<br>H(3)= 222; |
| FIXGATE NUMBER 8A<br>K= 101 T= 141829 | CONTROLLING SECTOR = V<br>AC= DL725 CI= 0<br>RA(3)= 59 AA(3) 0 | XR(3)= 286.6<br>S(3)= 221 | YR(3)= 213.2;<br>H(3)= 259; |
| FIXGATE NUMBER 25<br>K= 258 T= 142343 | CONTROLLING SECTOR = T<br>AC= DL725 CI= 0<br>RA(3) 27 AA(3) 0 | XR(3)= 287.0<br>S(3)= 116 | YR(3)= 209.1;<br>H(3)= 91; |
| FIXGATE NUMBER 27<br>K= 285 T= 142550 | CONTROLLING SECTOR = T<br>AC= DL725 CI= 0<br>RA(2)= 12 AA(2) 0 | XR(2)= 291.0<br>S(2)= 108 | YR(2)= 209.0;<br>H(2)= 90; |

**FIGURE A-2**
**AIRCRAFT FIX GATE TRACKING EXAMPLE**

1. The symbology utilized is as follows: K, the number of the track scan which is closest to the middle of the selected scan; CI, the computer number of the aircraft; XR and YR, the system coordinates; RA and AA, the reported and assigned altitude in hundreds of feet; S and H, the ground speed in knots and the heading of the aircraft in degrees; AC, the aircraft identification. The number in parenthesis is the number of the data sets selected among all the data sets found inside the gate. Typically, for 2 or 3 points inside the gate, the number 2 would have been chosen, for 4 or 5, it would have been 3, and so on.

In summary, both the SAR and Extractor data are reduced from a large number of data points to be selected lesser number which captures a tracked aircraft's flight profile in speed, heading, altitude, time of gate crossing and flight identifier at selected geographic points.

# APPENDIX B

# UNDELAYED FLYING TIME ESTIMATION

## B.1 INTRODUCTION

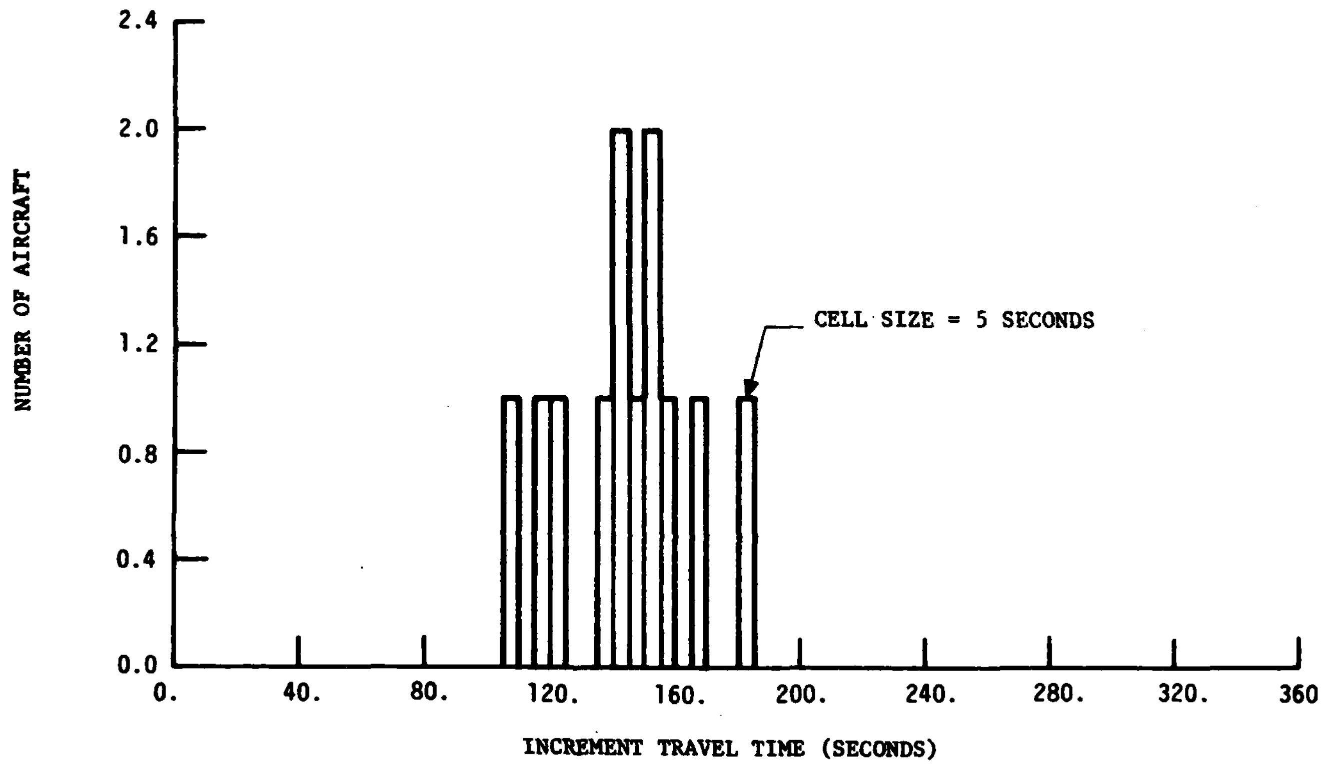
In Section 3.2, an overview of the method that was utilized to determine the undistributed estimated flying time over different routes for various types of aircraft was discussed. The purpose of this appendix is to present the detailed technique, including examples of the resulting data.

## B.2 SOURCE DATA

Appendix A discusses how the aircraft tracking data that was derived from the ATC NAS/SAR and ARTS III Extractor recordings was processed. The output defines the incremental movement of each aircraft from the center boundary to runway threshold, in terms of time, altitude, track heading, velocity and controlling ATC position.

## B.3 ELIMINATION OF ATC IMPACTED FLIGHT SEGMENTS

Controller voice recordings were reviewed for each control position that could have issued a clearance to an arrival aircraft. In the event the clearance would cause the aircraft to deviate from its normal flight in terms of speed, holding, or course vectoring or an altitude restriction; then, the aircraft ID and time were noted. This data was then compared with the incremental tracking data, and the increments that were impacted removed from the nominal flying time estimation. Each increment travel time (by aircraft type) for all arrival routes were then evaluated and plotted as depicted in Figure B-1. This example plot is for B-727 aircraft traveling the increment between fix gates 14A and 22. The number of aircraft contained with the sample is 13 with the average




*AVERAGE INCREMENT TRAVEL TIME = 147 SECONDS

**FIGURE B-1**
**EXAMPLE AVERAGE INCREMENT TRAVEL TIME DEFINITION**
**(B-727 AIRCRAFT (FOR INCREMENT BETWEEN FIX GATES 14A-22))**

TABLE B-2
TERMINAL ARRIVAL FIX TO RUNWAY THRESHOLD TRAVEL TIMES

| ARRIVAL ROUTE | NOMINAL FLYING TIME (HOURS) BY AIRCRAFT TYPE | | | | | |
|---|---|---|---|---|---|---|
| NUMBER | DC-8 | DC-9 | B-727 | L-1011 | B-737 | TURBO-PROP |
| MACY | 0.24 | 0.23 | 0.23 | 0.21 | 0.23 | 0.55 |
| SINCA | 0.23 | 0.22 | 0.23 | 0.21 | 0.22 | 0.54 |
| LAGRANGE | 0.19 | 0.19 | 0.19 | 0.18 | X | X |
| ROME | 0.19 | 0.19 | 0.19 | 0.18 | X | 0.46 |

NOTE: "X" indicates an arrival route not utilized by a particular aircraft type.

# APPENDIX C

## REFERENCES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## APPENDIX D

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