ANALYSIS OF AIRCRAFT SURFACE MOTION AT BOSTON LOGAN INTERNATIONAL AIRPORT

by

Robert Elias Alhanatis

B.S. Aerospace Engineering
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Submitted to the Department of Aeronautics and Astronautics
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Degree of

MASTER OF SCIENCE

at the

Massachusetts Institute of Technology

September 1994

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Department of Aeronautics and Astronautics
July 13, 1994

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Thesis Supervisor

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Professor Harold Y. Wachman
Chairman, Department Graduate Committee

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ABSTRACT

The purpose of this thesis is to examine the nature of aircraft surface motion on the airport surface during normal operations. Twelve hours of radar data, gathered by MIT Lincoln Laboratories from Logan airport in Boston, were made available for this study. Specifically, the data included target position reports from the ASDE-3 surface surveillance radar and the ASR-9 radar from the near terminal airspace information. This data covers a variety of runway configurations, weather conditions, traffic levels and high or low visibility conditions.

The study is divided into three sections. The first one focuses on the runway, and examines occupancy times, exit velocities, exit usage and velocity profiles of the final approach and landing phase. The second section, analyzes fourteen runway-taxiway intersections. Results are presented for the crossing times and usage of these intersections. The analysis also focuses on relating crossing times and usage to crossing direction, runway configuration and aircraft size. Finally, average taxiway velocities and the overall taxiway usage is measured. Additionally, the role that the location of the taxiway segment as well as its length, plays in the variation of these velocities are examined. Where possible, this study includes means, standard deviations and sample sizes of the variables in question.

Thesis Supervisor : Dr. Robert W. Simpson
Director, Flight Transportation Laboratory

Acknowledgments

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I would also like to thank MIT Lincoln Labs for providing the data for this thesis and in particular Jerry Welch, Ted Morin and Jim Eggert for assisting me in getting the data, answering my questions and providing me with many useful suggestions. Additionally, I would like to thank John Pararas, Dennis Mathaisel and Husni Idris for their help in developing the data processing software and the GMS interface.

I would also like to thank Professor Amadeo Odoni for his insightful remarks and Professor Peter Belobaba for teaching the Airline Management and Airline Econimics courses during my studies. I would also like to express my thanks to all my fellow classmates. My stay at the Flight Transportation Lab has been a rewarding experience thanks to them.

Finally, and most importantly, I would like to express my deepest gratitude to my parents for their continues love and support.

R. A.
Cambridge, Massachusetts
July, 1994

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Chapter 1

Introduction

1.1 Background

After forty years of regulation by the Civil Aeronautics Board, in 1978 Congress enacted the Airline Deregulation Act, which phased out economic regulation of the industry. In the years following deregulation many new carriers entered the airline industry. The old and the new airlines soon started servicing new city-pair markets, offering expanded services and competitive fares. These developments resulted in a significant increase in the overall traffic levels. In order to provide higher schedule frequencies and more efficient use of their fleet, the airlines soon abandoned the point-to-point route networks and adopted hub and spoke network systems that concentrated traffic around hub airports.

The increased passenger traffic coupled with the concentration of this traffic around, led to congestion within the available airspace and subsequent delays in these hub airports.

Due to the aforementioned reasons, the need to develop means for greater efficiencies in aircraft operations became apparent. Major efforts are undertaken today, focusing on the use of advanced technologies for airborne and ground traffic control systems in a concentrated effort to decrease the unused airspace and increase airport capacity while simultaneously maintaining or even increasing safety levels. One such area of focus is the airport surface, where especially in periods of low visibility, aircraft experience significant delays on their way to the gate or departing runway. During the last decade, various systems have been conceptualized and are currently under development which deal with problems controllers and pilots face every day on the airport surface.

The major objective of these surface traffic systems is to enhance the safety, capacity, and productivity of these airports, while at the same time reducing delays and the workload of both controller and pilot. This is accomplished via the development of advanced communications, surveillance and automation techniques for use in the control towers of major airports. Various subsystems address isolated problems such as runway incursions, taxiway guidance and surface traffic surveillance.

Airport safety is intrinsically linked to capacity. The spacing between aircraft necessarily reduces with increasing capacity, and safety suffers unless the reduction in spacing is done carefully. The suggested long term solution is a surface traffic management system that will address all these subsets of problems in an integrated manner and safely control the airport surface area. Such a system must address the capacity issues of ground congestion and effective departure sequencing through the implementation of efficient routing and sequencing of aircraft on the surface, thereby the system would decrease delays and increase airport safety. In order for such a system to be successfully developed and implemented, information about the nature of aircraft motion on the airport surface must be detailed.

1.2 Motivation

Few studies have been conducted to date on aircraft motion on the airport surface during normal operations. In 1960 the Airborne Instruments Laboratory at Cornell University published a series of reports about velocities and accelerations of aircraft at Kennedy Airport in New York. Later, in 1972 the Flight Transportation Laboratory at MIT studied the air-side activity of Boston Logan and Atlanta airports. Measurements were taken for runway occupancy times, velocity profiles along the runways, taxiway speeds and intersection delays. Unfortunately, most of the aircraft that operated during those years are not in service today. Additionally, the data was gathered solely in periods of good visibility and therefore the data of these reports is of little value today. It is therefore of vital interest to measure the surface movements of today's aircraft as completely and effectively as possible.

1.3 Scope

An aircraft engages in a series of non-uniform and complex maneuvers on its way to the gate or the departing runway. A departing aircraft for example, after getting the clearance to push back from the gate, has to follow a taxi route that will lead it to the takeoff runway. This path varies depending on the layout of the taxiway system, the current runway configuration, and the location of the gate. It might be short or long and might involve a considerable number of turns, stops, taxiway and runway crossings, and varying length segments of straight taxing. Along this route, the pilot must be constantly be aware of the position, not only of his own aircraft, but also of nearby aircraft, ground vehicles (or even terminal buildings) in order to taxi safely and avoid any collisions. The ability of the pilot to successfully taxi along the path depends on various factors. These include the type (size) of aircraft that the pilot operates, the amount of traffic at that particular instant at the airport, the surface visibility, the weather and surface conditions, and the familiarity that the pilot might have with the specific taxiway system. We must remember also, that the pilot during his taxi, is usually assisted by the ground controller who directs him along his taxi route and provides him with information about surrounding obstacles. It is important to note though, that the pilot is the one who makes the final decisions and may override the controllers directions. For example, a controller's request for a landing aircraft to use the first available exit can be ignored, or the pilot may insist on taxiing to the starting end of a runway rather than start from an intermediate point.

Such factors as the human element cannot easily be quantified and often introduce variance into the events that we want to measure, and therefore must be taken in to account in the final analysis. Among many surface motion variables that can be measured, those of interest are: the approach speed of a landing aircraft, its landing speed profile during roll-out, the runway occupancy time, the exit used, the exit velocity, the time required to cross runway intersections, and the taxiing velocities on different segments of the taxiway system. The analysis of these variables in conjunction with the major factors that affect them will be the focus of this thesis.

Chapter 2

The Measurement Task

2.1 Introduction

The first section of this chapter describes the existing runway and taxiway system at Logan airport in Boston so the reader can get a better understanding of the airport layout and better relate the measured variables. The second section, discusses the main elements of the data collection method that was employed. Finally, the last section provides information about the different days that the data was collected. Included in this information, is a description of the weather and surface conditions as well as any particular events that occurred during the collection period and which might be of interest in the later stages of the analysis.

2.2 The Runway and Taxiway System

Boston Logan International Airport lies at the edge of Boston harbor, surrounded by water in the majority of its perimeter. The commercial and residential area of East Boston is adjacent to it while the Winthrop area lies across the harbor (Figure 2.2.1).

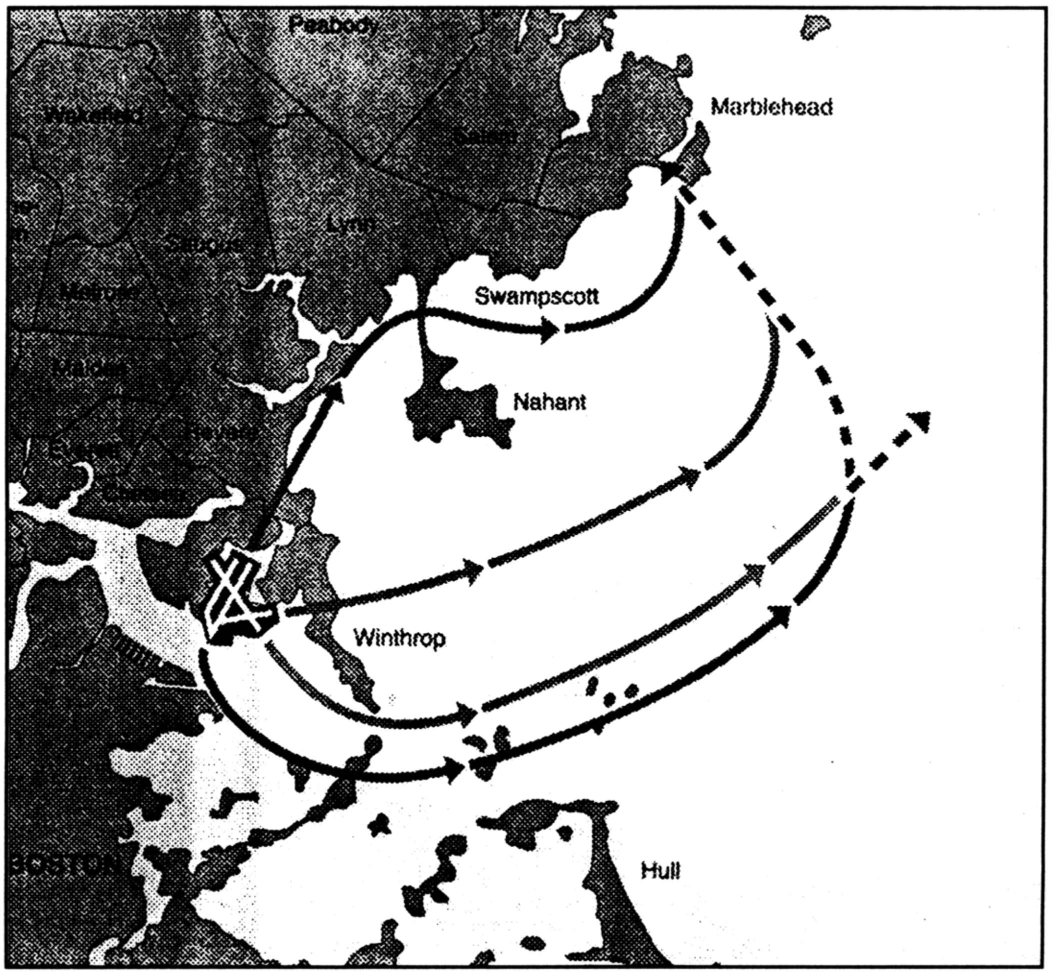


Figure 2.2.1

Logan is the dominant airport (70 % of the passenger traffic [1]) in a regional airport system that also includes airports serving Hartford, Manchester, Worcester, Hyannis, Portland, and Providence. It has five runways with four of them (4L, 4R, 33R and 27)

1 Boston Logan International Airport Capacity Enhancement Plan, October 1992 published by the FAA.

capable of handling large transport aircraft. Three of these runways (4R, 33R and 27) have instrument landing capability. The configuration of the runways is rather complex (Figure 2.2.2), as they intersect six times with each other.

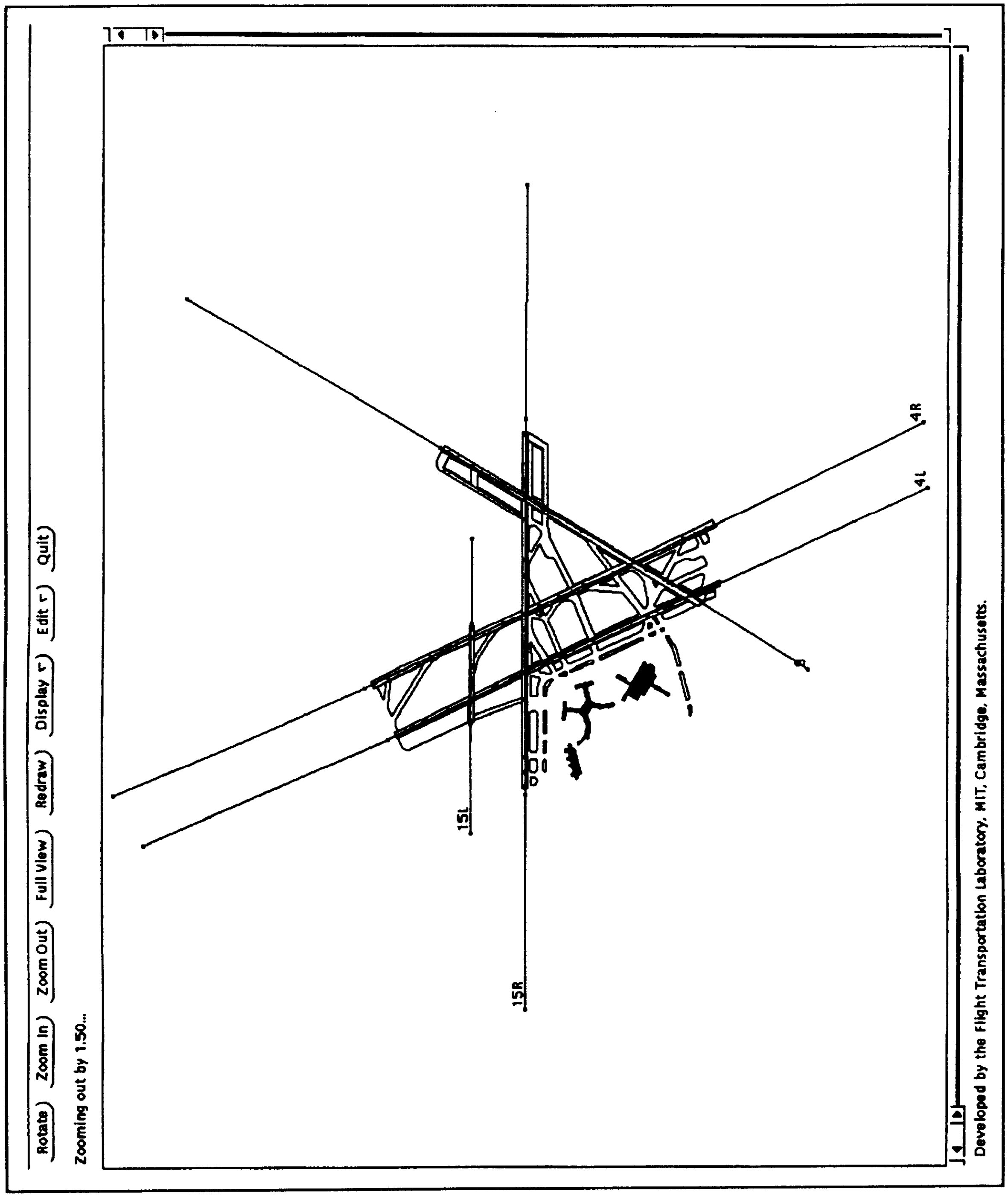


Figure 2.2.2

Typically, peak hour demand is 100 operations per hour. The serving capability depends on the runway operating configuration, and can vary from 46 operations per hour during the most restrictive IFR conditions to 120 operations per hour during good VFR weather[2] . This fluctuation is primarily due to the lack of parallel runways within adequate spacing between them for simultaneous IFR approaches under certain weather conditions. Consequently, at certain times all landings must be sequenced into a single arrival stream, thus lowering the airport serving capability. The high proportion of commuter aircraft operations at Logan further deteriorates the airport effective capacity, as larger separations maybe needed under certain runway configurations to safely accommodate these smaller sized aircraft due to the wake turbulence considerations during mixed (in terms of size) operations. In addition, in order to keep the noise levels that the nearby communities experience within reasonable levels, the Massachusetts Port Authority has imposed certain regulations that further complicate aircraft operations. Specifically, only certain runway configurations can be used at night and airlines are required to conduct a specific portion of their Logan operations in Stage 3 equipment[3] .

The configurations[4] that are used most often at Logan are:

Table 2.2

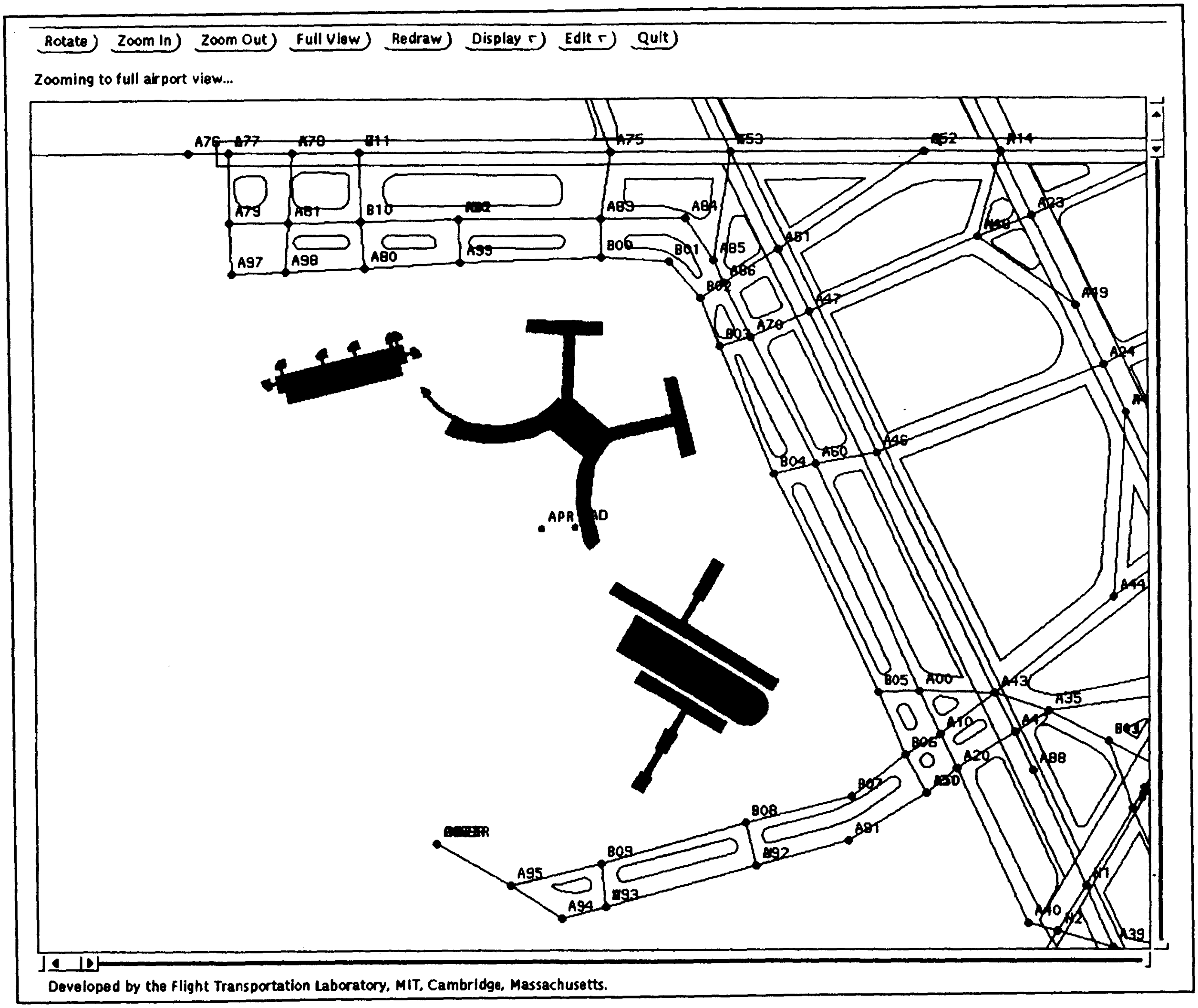
Configuration	VFR		IFR	
	Arrivals	Departures	Arrivals	Departures
1	4L & 4R	4L, 4R & 9	4R	4L, 4R & 9
2	22L & 27*	22R & 22L	22L	22R & 22L
3	33L & 33R	27 & 33L	33L	33L
4	9, 15R & 15L*	15R & 9	15R	15R & 9

* These configurations employ hold-short procedures.

2,4 Boston Logan International Airport Capacity Enhancement Plan, October 1992 published by the FAA.
3 Summary of Logan's Noise Abatement Rules and Regulations published by Massport.

Due to the complexity of the runway system, various procedures for intersection departures and hold-short arrival are often used.

The taxiway system (Figure 2.2.3) consists of two main circumferential taxi lanes (inner & outer) around the perimeter of the terminal building area with smaller taxiway segments supporting the traffic towards the gate area. Longer taxiways also exist to feed the outbound traffic to the departure runways, and the incoming traffic to the terminal area. Runways 4R, 33L/15R and 27 have additional high speed exits conveniently located so that the landing aircraft can vacate the runway as soon as possible, and then there are various common taxi paths from these exits to the gate areas. For example, the high speed exit most commonly used for runway 4R is exit 12 (link A29-A56) , and crosses runway 4L (used only for turboprop landings and takeoffs in this case) before joining taxiway N (link A74-A75) to return to the terminal area.



Rotate
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A43
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A20
A88
B07
B08
A91
B09
A95
A94
A40
A39
Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.

2.3 Data Collection

In the past, the techniques used to study the aircraft motion on the surface of airports fell into two major categories : those that involved direct observation of the traffic through a number of observers out in the airfield (the MIT study) and those involving indirect observation through the use of radar or other types of monitoring equipment.

Each one of the two methods has its own advantages and disadvantages. The indirect radar method is more complex and requires expensive equipment but is fairly accurate, imposes no interference in the traffic, and once operational can be employed for long time periods. On the other hand, the other method (direct observation) is less complex but requires a large number of observers, often in coordination with each other, which involves intense manual effort and as one might suspect, and provides changing levels of accuracy. Nevertheless, both methods require the authorization and cooperation of the local FAA and airport authorities.

Luckily, in our case the MIT Lincoln Laboratories had installed an experimental ground surveillance system that gathered data from Logan airport in Boston. Specifically, the data included target position reports from the ASDE-3 surface surveillance radar and the ASR-9 radar from the near terminal airspace traffic information. These two outputs of the surveillance sensors were integrated by a combined tracking system that also provided derived information about the velocity, heading and acceleration of the targets[1]. A simultaneous interface with the ARTS computer was often used and then information about the aircraft type and flight number was made available.

2.4 Available Data

As mentioned earlier, Lincoln Laboratory had installed a surface traffic data gathering system at Logan airport in Boston in 1993 for the development and testing of a runway status lights network (ASTA-1) to help prevent runway incursions. As much as ninety hours of traffic data were collected for this purpose. Approximately twelve of these ninety hours were preprocessed by Lincoln Labs, and made available to this study for further processing and analysis of the aircraft surface movements. These twelve hours came in the form of 10 separate blocks of data, each corresponding to an individual data gathering session. These blocks cover a variety of runway configurations, weather conditions, traffic levels, and high or low visibility conditions. A brief description of the available blocks of data follows :

Block-1

Day: Thursday, April 1, 1993

Time: 16:00-17:15 Local

Runway Configuration **Table 2.4.1**

Arrivals	Departures	Switched to	Arrivals	Departures
4R	9, 4L		4R	4R

Weather / ATIS **Table 2.4.2**

Temp	Ceiling	Visibility	Wind	Comments
n/a	500ft ovc	2 miles	50°@15knots	Rain & Fog
n/a	1800ft ovc	2 miles	40°@24knots	Rain & Fog --> Thunderstorms
n/a	1100ft ovc	2 miles	40°@ 20knots	Rain & Fog --> Thunderstorms

Block-2

Day: Friday, March 26, 1993

Time: 10:35-11:35 Local

Runway Configuration **Table 2.4.3**

Arrivals	Departures	Switched to	Arrivals	Departures
4	9		33L, 27	33L, 22R

Weather / ATIS **Table 2.4.4**

Temp	Ceiling	Visibility	Wind	Comments
55 ° F	800ft. scat	7 miles	160°@7knots	Heavy Traffic, All Taxiways OK.

Block-3

Day: Wednesday, April 21, 1993

Time: 17:35-18:35 Local

Runway Configuration **Table 2.4.5**

Arrivals	Departures
27	22R

Weather / ATIS **Table 2.4.6**

Temp	Ceiling	Visibility	Wind	Comments
65 ° F	2500ft ovc	15miles	180°@17knots	Heavy Traffic.

Block-4

Day: Tuesday, March 26, 1993

Time: 13:15-14:15 Local

Runway Configuration **Table 2.4.7**

Arrivals	Departures
15R	9

Weather / ATIS **Table 2.4.8**

Temp	Ceiling	Visibility	Wind	Comments
50 ° F	Sunny	12 miles	140°@7knots	Busy Traffic, later quieting down

Block-5

Day: Thursday, March 11, 1993

Time: 14:50-16:10 Local

Runway Configuration

Table 2.4.9

Arrivals	Departures
33L	22R, 33L

Weather / ATIS

Table 2.4.10

Temp	Ceiling	Visibility	Wind	Comments
40 ° F	5500ft	15 miles	300°@15knots	Snow in the morning

Block-6

Day: Wednesday, March 31, 1993

Time: 19:15-20:15 Local

Runway Configuration

Table 2.4.11

Arrivals	Departures
4R, 4L	9, 4L

Weather / ATIS

Table 2.4.12

Temp	Ceiling	Visibility	Wind	Comments
42 ° F	6500ft	15 miles	110°@ 8knots	Snow in the morning

Block-7

Day: Saturday, March 13, 1993

Time: 09:45-10:45 Local

Runway Configuration

Table 2.4.13

Arrivals	Departures
15R	9, 15R

Weather / ATIS

Table 2.4.14

Temp	Ceiling	Visibility	Wind	Comments
31 ° F	5000 ft	5 miles	127° @ 8knots	ILS approaches 15R
33 ° F	3800 ft	12 miles	110°@17knots	ILS approaches 15R, light snow
32 ° F	1500ftovc	1 mile	110°@15knots	ILS approaches 4R, light snow

Block-8

Day: Wednesday, April 21, 1993

Time: 19:50-20:50 Local

Runway Configuration **Table 2.4.15**

Arrivals	Departures
22L, 27	22R, 22L

Weather / ATIS **Table 2.4.16**

Temp	Ceiling	Visibility	Wind	Comments
59 ° F	2500ft scat	15 miles	225°@11knots	n/a

Block-9

Day: Tuesday, March 30, 1993

Time: 07:45-08:45 Local

Runway Configuration **Table 2.4.17**

Arrivals	Departures
4	9

Weather / ATIS **Table 2.4.18**

Temp	Ceiling	Visibility	Wind	Comments
43 ° F	700 ft	2 miles	40°@12knots	Light drizzle & Fog

Block-10

Day: Wednesday, April 21, 1993

Time: 09:00-10:02 Local

Runway Configuration **Table 2.4.19**

Arrivals	Departures
22L, 27	22R, 27

Weather / ATIS **Table 2.4.20**

Temp	Ceiling	Visibility	Wind	Comments
60 ° F	2500ftovc	15 miles	225°@16knots	n/a

Chapter 3

Data Analysis

3.1 Introduction

The first section of this chapter describes the preliminary data processing that was undertaken along with various problems that were encountered due to several data irregularities. The second section, provides a detailed runway analysis that includes information about occupancy times, exit velocities, exit use, and landing velocities profiles. The next section analyzes the intersection crossing times and the particular level of use of each intersection. Finally, an analysis of the taxiway system is presented.

3.2 Preliminary Data Processing

As soon as the ten blocks of collected data were received, all the possible ways to process and analyze the available information were considered. Each block of data consisted of information about all the targets that were picked up by the ASDE-3 and ASR-9 radar during each gathering session. Every target had its own ASDE and target ID and contained among other things, position information in terms of x and y coordinates with respect to the radar location, its derived velocity, acceleration, and heading, and the corresponding time stamp for specific data items, measured in seconds from 0:00 GMT. In addition, some targets included information about the aircraft type and airline flight number (Table 3.2.1).

Tgt:11584		Length: 287		Start time: 57995.3			End time: 58588.6	States: DEP TAX STP				
								(deg)	(knots)	(g's)		
Target ID	ASDE ID	Time	Stamp	State	ASF ID	Position		Heading	Speed	Accel.	Flight Num	Type
11584	5575	57995.375	1	TAX	g93	North: -827.07	East: 242.13	10.7	13.9	0.0874	SR188	B747
11584	5575	57997.126	2	TAX	g93	North: -827.22	East: 249.34	31.3	10.1	-0.0552	SR188	B747
11584	5575	57998.878	3	TAX	g93	North: -802.69	East: 252.97	14.8	17.9	0.113	SR188	B747
11584	5575	58000.629	4	TAX	g93	North: -793.17	East: 256.41	14.9	15.1	0.0166	SR188	B747
11584	5575	58002.382	5	TAX	g76	North: -783.10	East: 258.79	12.3	12.5	-0.042	SR188	B747
11584	5575	58004.134	6	TAX	g76	North: -769.83	East: 263.59	17.1	14	0.0116	SR188	B747
11584	5575	58005.885	7	TAX	g76	North: -756.49	East: 267.36	16.9	15.2	0.0215	SR188	B747
11584	5575	58007.637	8	TAX	g76	North: -742.40	East: 271.39	16.4	16.4	0.0215	SR188	B747
11584	5575	58009.388	9	TAX	g76	North: -732.36	East: 276.04	22	13.9	-0.0348	SR188	B747

Table 3.2.1 : Typical sample information about a target inside a block of data.

The individual position reports for every target, constituted a very large amount of information, and in order to be useful, had to be related again to the surface layout of the airport. A graphical replay of the information of the available data was needed since it would enable us to visualize the actual aircraft motion, check the analysis output, and explain any possible counterintuitive findings.

Recently, the Flight Transportation Laboratory at MIT had designed and developed an aircraft Ground Motion Simulator (GMS) to realistically simulate airport ground activity. The GMS simulates the environment at any arbitrary airport and provides high quality graphic views, in color on UNIX workstations. This system has an internal aircraft position generator that provides the simulation with motion updates. It was decided to use the GMS system for visualization purposes, after bypassing its position generator function and writing the necessary code to provide it with the actual aircraft motion information from the Lincoln Laboratory data.

As a second step, the Logan airport geometrical layout along with its features (terminal buildings, hangars, etc.) had to be inputted in the GMS system (Figure 3.2.1). Next, the underlying network of nodes and links had to be inserted in GMS format data files in order to define the runways and taxiways of the airport (Figure 3.2.2). Table 3.2.2 lists the series of nodes that define every taxiway. The next step was to write the computer code that will associate every aircraft position with an airport link in order to be able to automate the data reduction process. Various computer subroutines were also written to perform other preliminary analyses of the recorded data. As a result, computed values were obtained for approach speeds, exit velocities, intersections crossing times, and various taxiway velocities. A more complete discussion of these values, and their significance will start in the next chapter. During the analysis process various routines had to be modified in order to overcome some irregularities in the collected data.

Taxiway	**Series of Nodes**									
U	B08	A92								
V	B09	A93								
X	A50	A20	A42	A35	A36					

Y	A55	A56	A29								
INNER	A97	A98	A80	A99	B00	B01	B02	B03	B04	B05	B06
	B07	B08	B09	A95	A96						
OUTER	A97	A79	A81	B10	A82	A83	A84	A85	A86	A70	A60
	A00	A10	A20	A50	A91	A92	A93	A94	A95	A96	
Z	A80	B10	B11								
N2	A71	A72									
B	A20	A40	N2	A39	A37	A31	A25				
S1	A37	B14	A38								
C	B04	A60	A46	A24	A18	A17	A16	A12			
S2	A33	A32	A31								
D	A18	A19	A01	A02	A04	A07	A90	A06			
NA	A73	A59									
E	B06	A10	A43	A44	A09	A08					
NB	A63	A64									
S2A	A32	A26									
F	B03	A70	A47	A48	A23	A22					
G	A21	A18									
S01	B14	B13									
H	A49	A48									
J	A48	A14									
K	A98	A81	A78								
L	A79	A77									
N	B00	A83	A75	A74	A73	A71	A69	A66	A63	A62	
DA	A02	A03									
P	A44	A45									
DB	A04	A05									
Q	B02	A86	A51	A52							
R	A66	A65									
IO0	A99	A82									
S	B05	A00	A43	A35	B13	A34	A33	A27			
I01	B06	A50									
T	B02	A86	A85	A53							
Runway											
4R	22L	A61	A62	A64	A65	A57	A29	A14	A23	A49	A24
	A45	A09	A28	A27	A26	A25	A87	4R			
4L	22R	A68	A67	A72	A59	A54	A53	A51	A47	A46	A43
	A42	A88	N1	A39	4L						
15R	33L	A11	A12	A13	A01	A21	A22	A14	A52	A53	A75
	B11	A78	A77	A76	15R						
15L	33R	A58	A57	A55	A54	A74	A89	15L			
9	27	A15	A06	A05	A03	A13	A17	A08	A28	A36	A34
	A38	B14	N1	N2	9						

Table 3.2.2

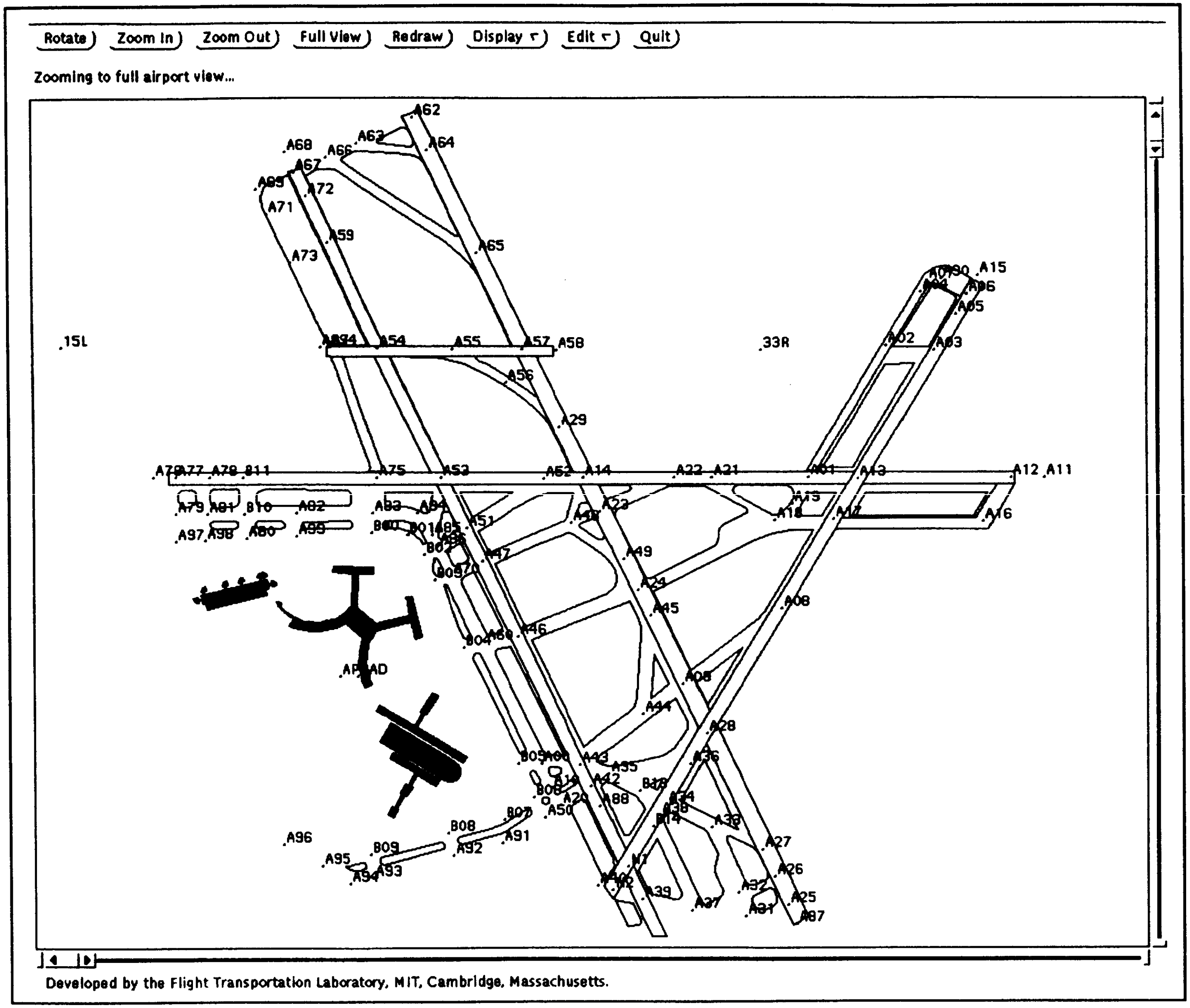

Rotate
Zoom In
Zoom Out
Full View
Redraw
Display
Edit
Quit
Zooming to full airport view...
15L
33R
Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.

Figure 3.2.1

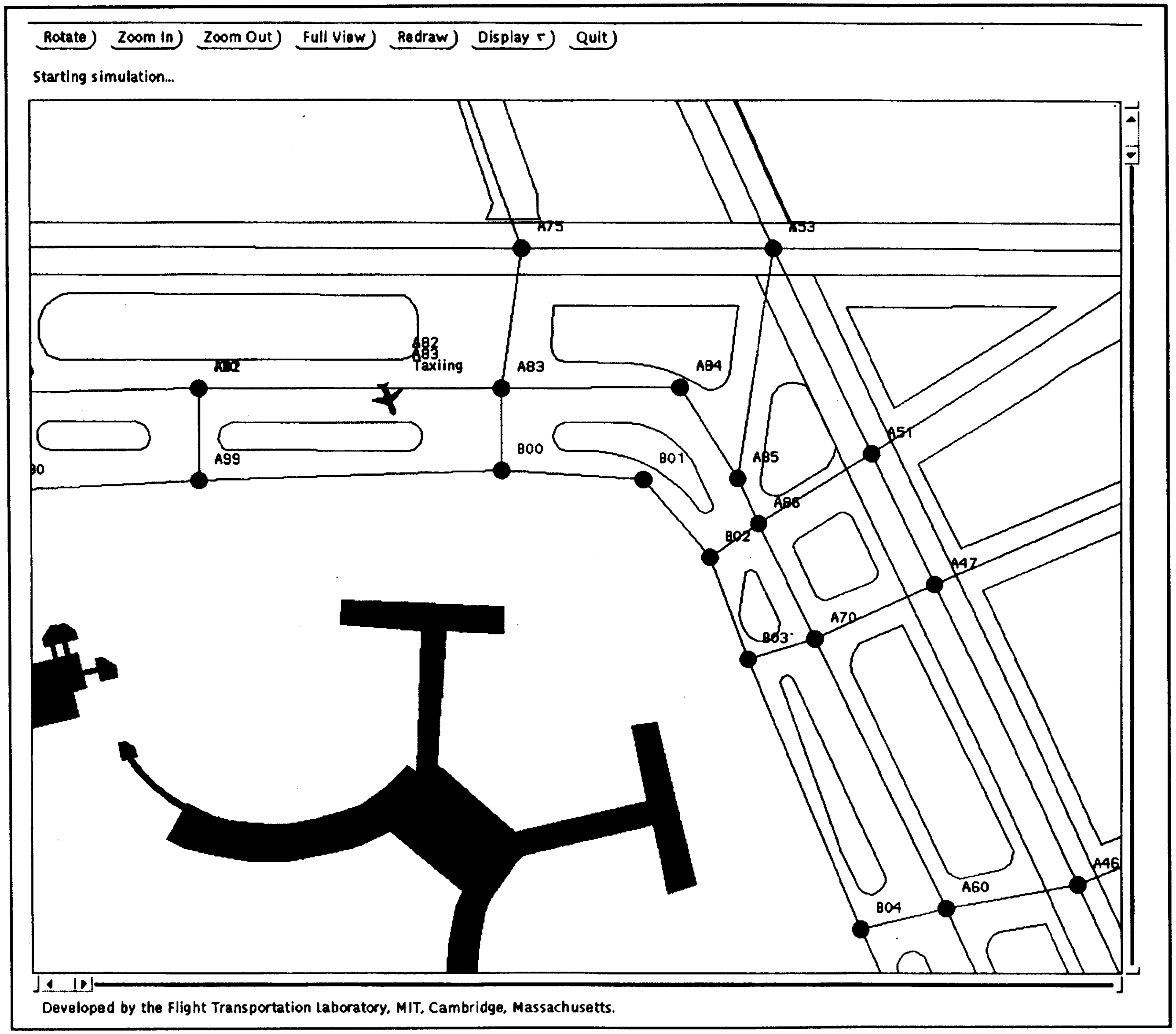

Rotate
Zoom In
Zoom Out
Full View
Redraw
Display
Quit
Starting simulation...
A75
A53
A82
A83
Taxiing
A83
A84
A99
B00
B01
A85
A51
A86
B02
A47
A70
B03
A46
A60
B04
Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.

Figure 3.2.2

3.3 Data Irregularities

Due to the performance of the radar tracking system on the surface of the airport, frequently during the gathering session, an aircraft target was dropped and then picked up later on by the radar. The result was that in the data file, two different targets with separate IDs (identification numbers) could in fact have been the same aircraft, and the intermediate information about the aircraft movement between the time that the aircraft was dropped from the radar and then picked up again was not available. Another irregularity was the fact that not all targets had information about the aircraft type or flight number. This limited the classification of results according to aircraft size to only those targets where that information was available. In addition, this prevented us from identifying targets that were not aircraft but rather other ground vehicles moving on the airport surface and therefore might have infected our results if they were on the runways or taxiways. Indeed, Blocks 3, 8 and 9 did not include any information about aircraft types and flight number because the required computer tap was not in service during the collection period.

3.4 Runway Analysis

3.4.1 Runway Occupancy Time During Landing

Runway occupancy time is the time over which a runway is effectively blocked (occupied) to any other traffic by a single landing or departing aircraft. As such, it potentially affects the traffic capacity of that runway. In the case when the runway is used only for landings, the runway occupancy time and its potential variations currently do not significantly affect the overall runway capacity as the inter-arrival radar separation standards of the approaching aircraft cause spacing which is almost always greater than the occupancy time. On the other hand, if the runway is used for mixed arrivals and departures, the landing occupancy time becomes more critical. In that case, the shorter the landing occupancy time, the more the time allowed to insert a takeoff between landings. This results in higher runway operational capacity, and smaller delays for the departing aircraft.

Average Occupancy Time During Landing

Runway	Data Block	Figure
4R	1,6,9	1, 2, 3
4L	n/a	n/a
22R	n/a	n/a
22L	8, 10	4, 5
27	2, 3, 8, 10	6, 7, 8, 9
9	n/a	n/a
33R	n/a	n/a
33L	2, 5	10, 11
15R	4, 7	12, 13
15L	n/a	n/a

Table 3.4.1.1

The following tables (3.4.1.2 to 5) correlate each exit link of every runway from the GMS airport layout (Figure 3.4.1.1 to 3) to an exit number for the graphs that follow.

Exit Number		Link
Runway 27	**Runway 9**	
1	12	A06-A90
2	11	A05-A04
3	10	A03-A02
4	9	A13-A01
5	8	A17-A18
6	7	A08-A09
7	6	A09-A28
8	5	A36-A35
9	4	A34-B13
10	3	B14-A37
11	2	N1-A39
12	1	N2-A40

Table 3.4.1.2

Exit Number		Link
Runway 33L	**Runway 15R**	
1	14	A12-A16
2	13	A13-A17
3	12	A01-A19
4	11	A21-A18
5	10	A22-A23
6	9	A14-A23
7	8	A14-A48
8	7	A52-A51
9	6	A53-A51
10	5	A53-A85
11	4	A75-A83
12	3	B11-B10
13	2	A78-A81
14	1	A77-A79

Table 3.4.1.3

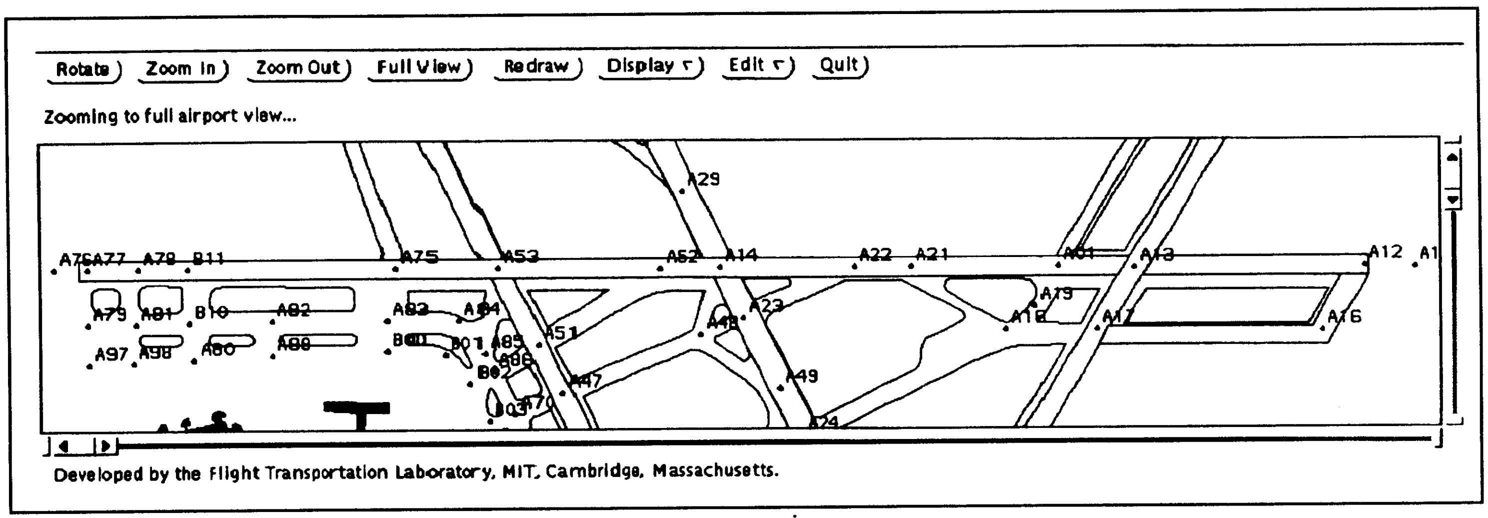


Figure 3.4.1.1 Runway 15R/33L

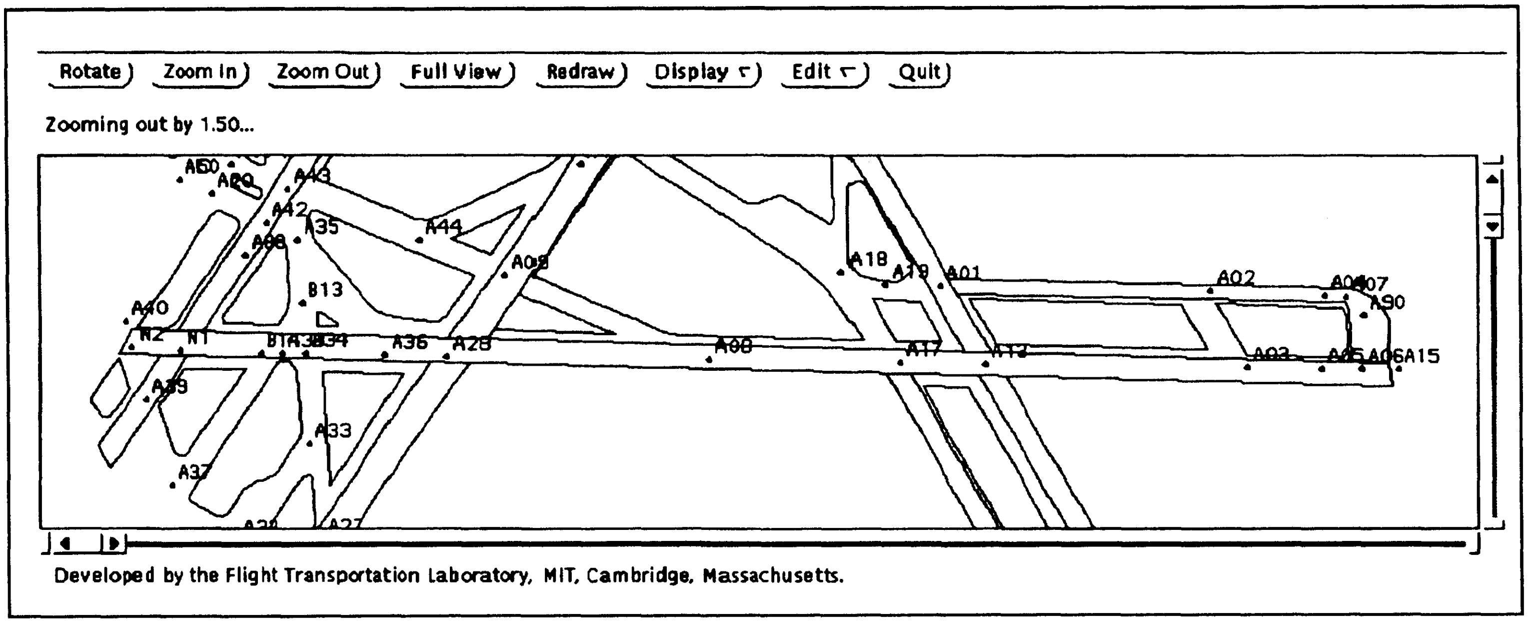


Figure 3.4.1.2 Runway 27/9

Exit Number		Link
Runway 4L	Runway 22R	
1	14	A39-N2
2	13	N1-N2
3	12	A42-A20
4	11	A43-A10
5	10	A43-A00
6	9	A46-A60
7	8	A47-A70
8	7	A51-A86
9	6	A53-A75
10	5	A53-A85
11	4	A54-A74
12	3	A59-A73
13	2	A72-A71
14	1	A67-69

Table 3.4.1.4

Exit Number		Link
Runway 4R	Runway 22L	
1	16	A12-A16
2	15	A26-A32
3	14	A27-A33
4	13	A28-A36
5	12	A09-A44
6	11	A45-A44
7	10	A24-A46
8	9	A49-A48
9	8	A23-A48
10	7	A14-A48
11	6	A14-A52
12	5	A29-A56
13	4	A57-A55
14	3	A65-A66
15	2	A64-A63
16	1	A62-A63

Table 3.4.1.5

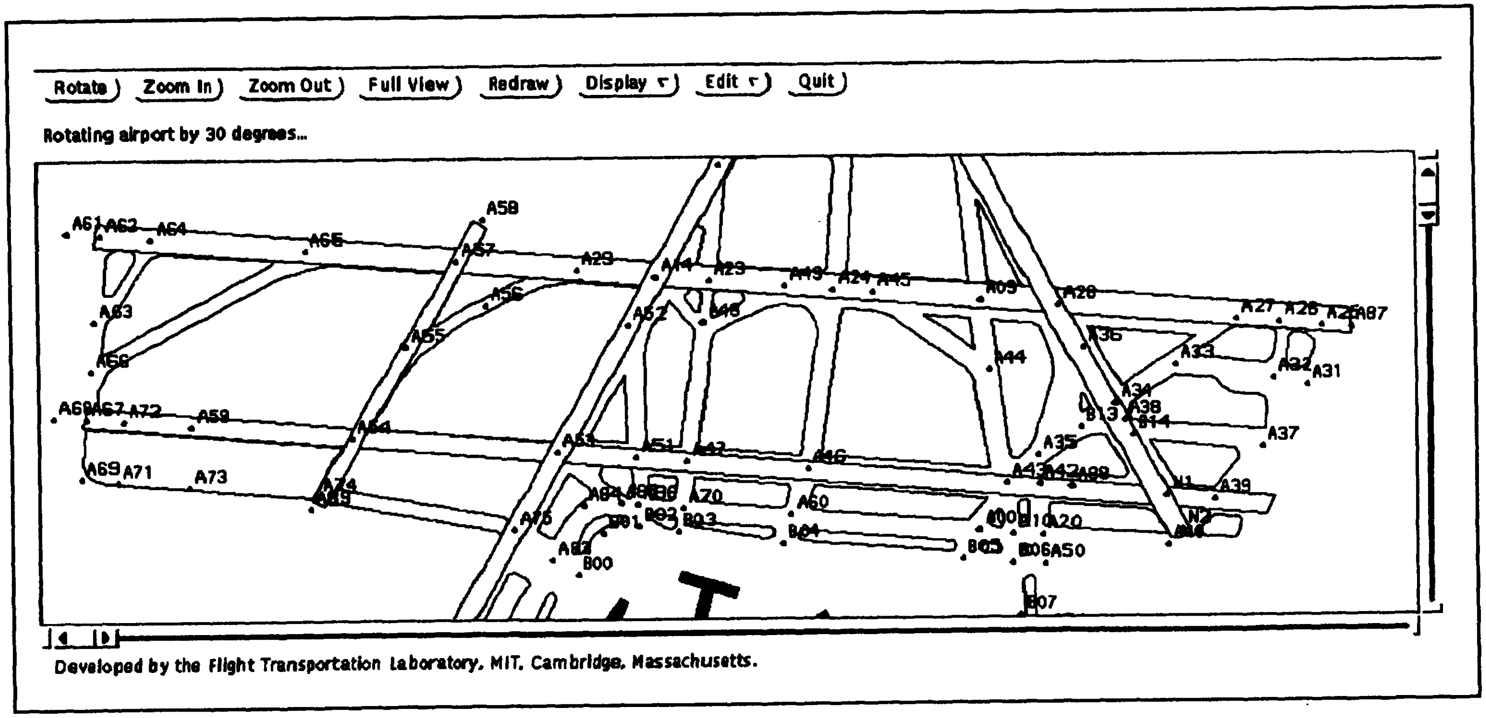


Figure 3.4.1.3 Runways 4R/22L, 4L/22R , 15L/33R

The occupancy time during landing is measured from the moment the aircraft is over the runway threshold until the time it has turned in the exit and its tail has crossed the runway edge. Since our aircraft motion data was in the form of a series of discrete radar hits (approximately every 1.7 sec on the surface), the time between the first hit inside the first runway link and the first hit inside the exit link was used. In this way the size of the error was minimized. As expected before the analysis of the results, occupancy time tends to increase with the distance of the exit location from the runway threshold. This is normally true except in some cases (Figure 3.4.1.4 Exit 12 in Runway 4R and Figure 3.4.1.7 Exit 11 in Runway 22L) where the particular angle of these exits allow aircraft to exit with higher speeds, and therefore maintain a higher average landing velocity resulting in occupancy times similar to exits that are located much closer to the threshold.

Figures 3.4.1.4 through 3.4.1.16 are graphs of the average occupancy time during landing for all aircraft types over a single runway and exit for every block of collected data. It seems there exits a relationship between aircraft weight and occupancy time. We observe that usually, the standard deviation of the occupancy times are quite small (5-10 seconds) for aircraft using the first exits, unlike for those using exits that are located further down the runway. Runway 27 under configuration 2 (arrivals 27 and departures 22R) displayed the lowest occupancy time (35 seconds) for aircraft exiting at high speed from exit 6 (Figures 3.4.1.9, 10, 12). In data block 8 (Figure 3.4.1.11), with similar weather conditions but at night (20:00-21:00), most aircraft used exit number 8 (low speed) and the occupancy times were significantly larger (53 seconds). The heavier aircraft tend to land with higher velocities and require longer landing distances and therefore exit further down the runway resulting in higher occupancy times. However aircraft using a given exit have similar occupancy times, independent of aircraft size.

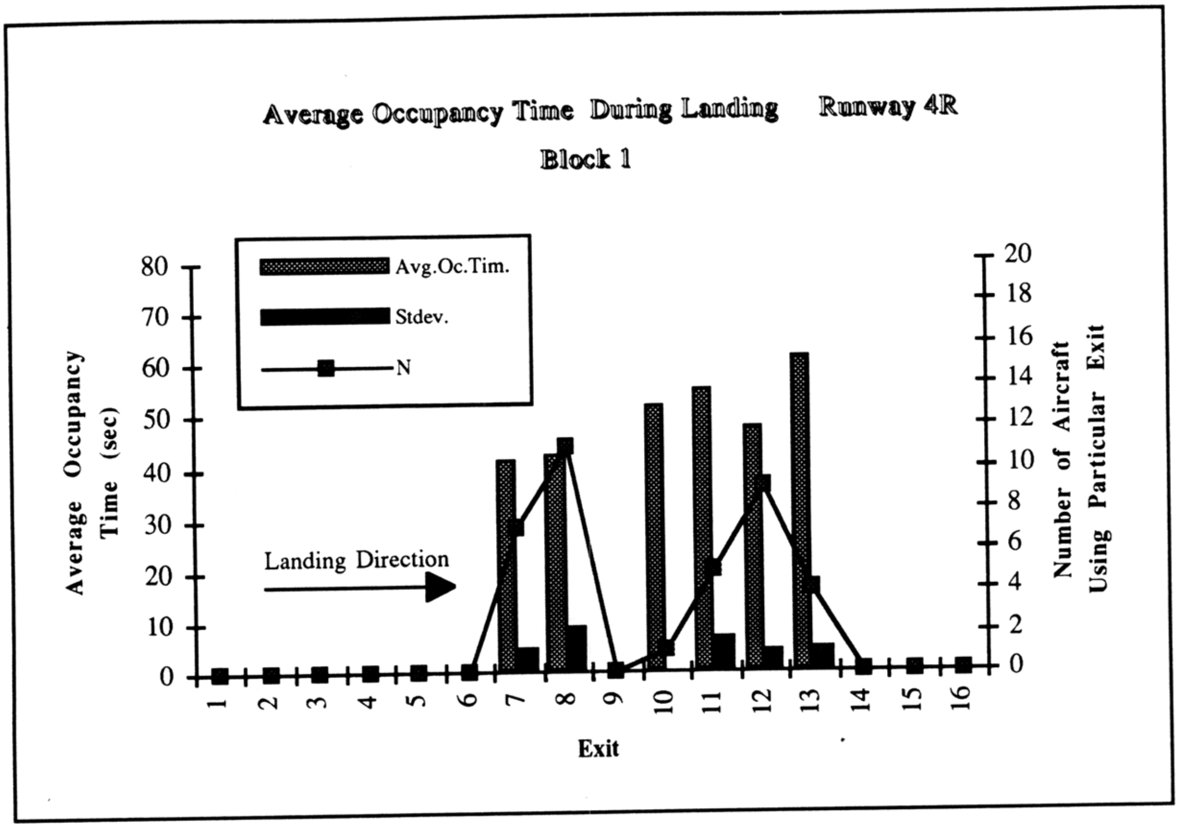


Figure 3.4.1.4

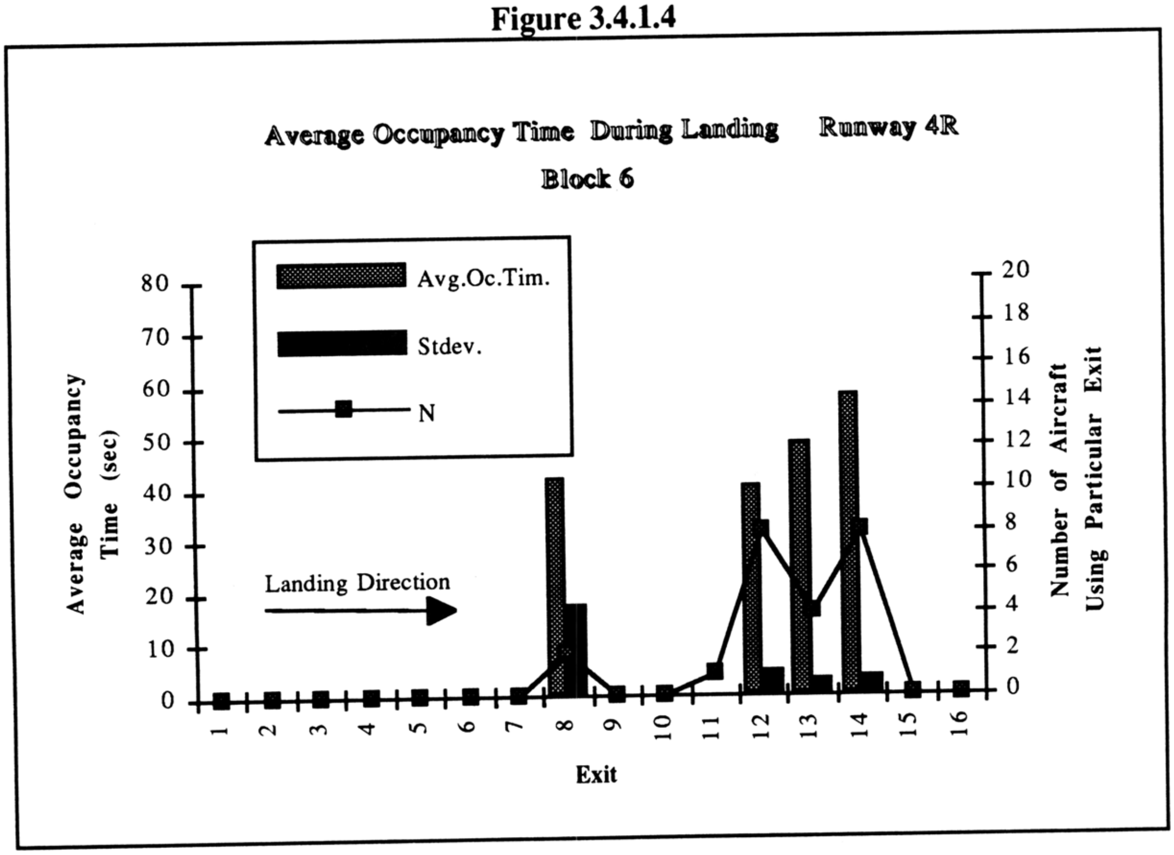


Figure 3.4.1.5

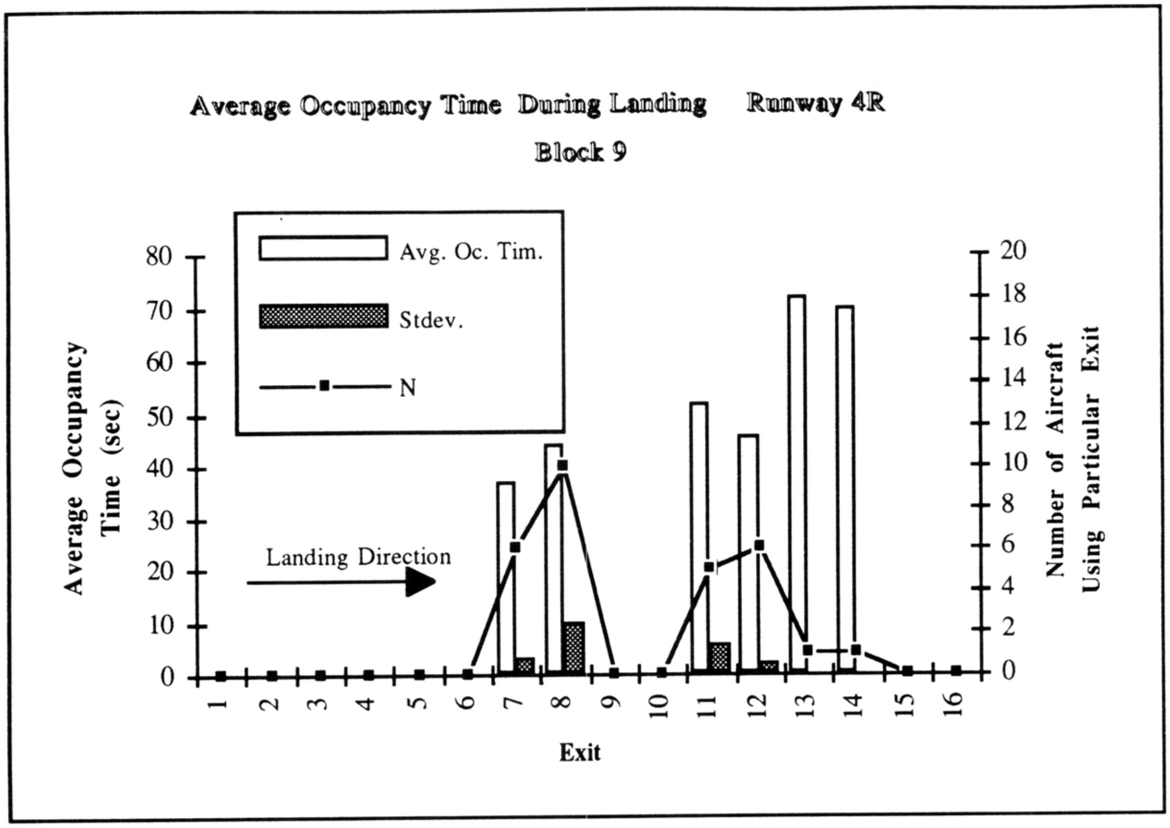

Average Occupancy Time During Landing Runway 4R
Block 9
Avg. Oc. Tim.
Stdev.
N
Average Occupancy Time (sec)
Number of Aircraft Using Particular Exit
Landing Direction
Exit
0
10
20
30
40
50
60
70
80
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 3.4.1.6

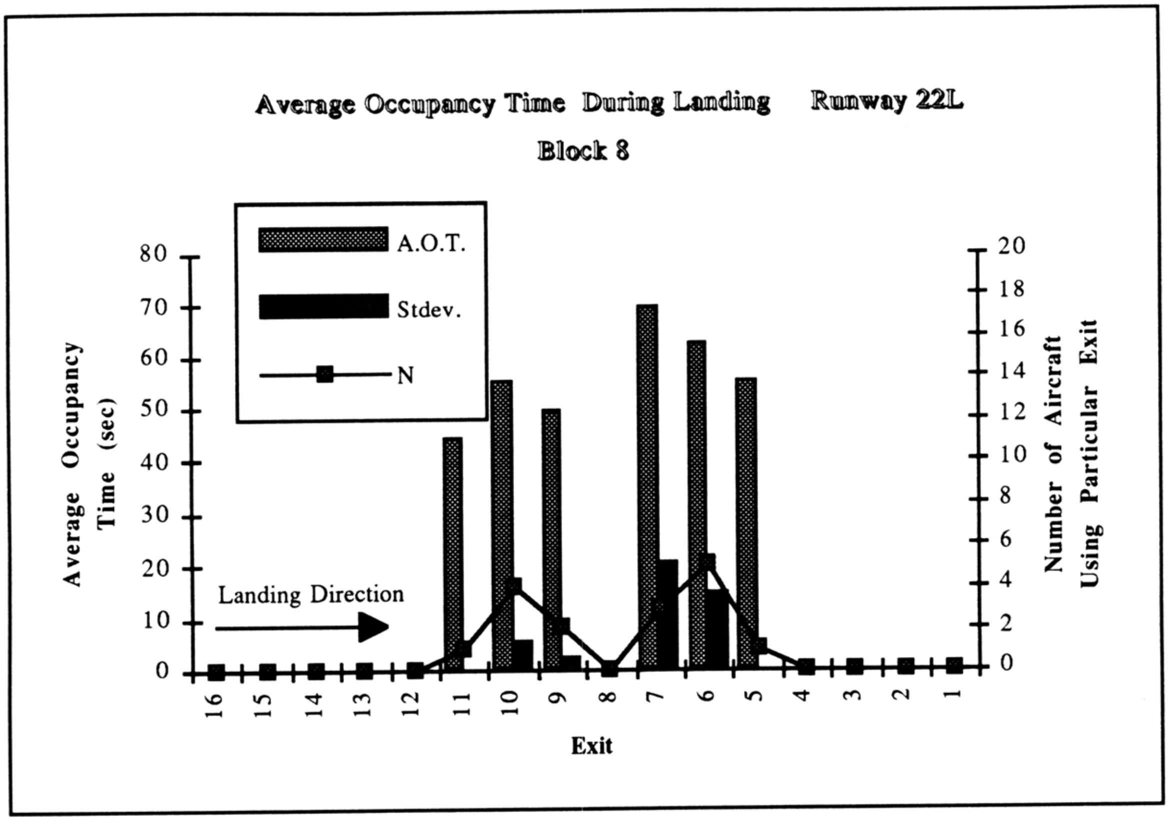


Figure 3.4.1.7

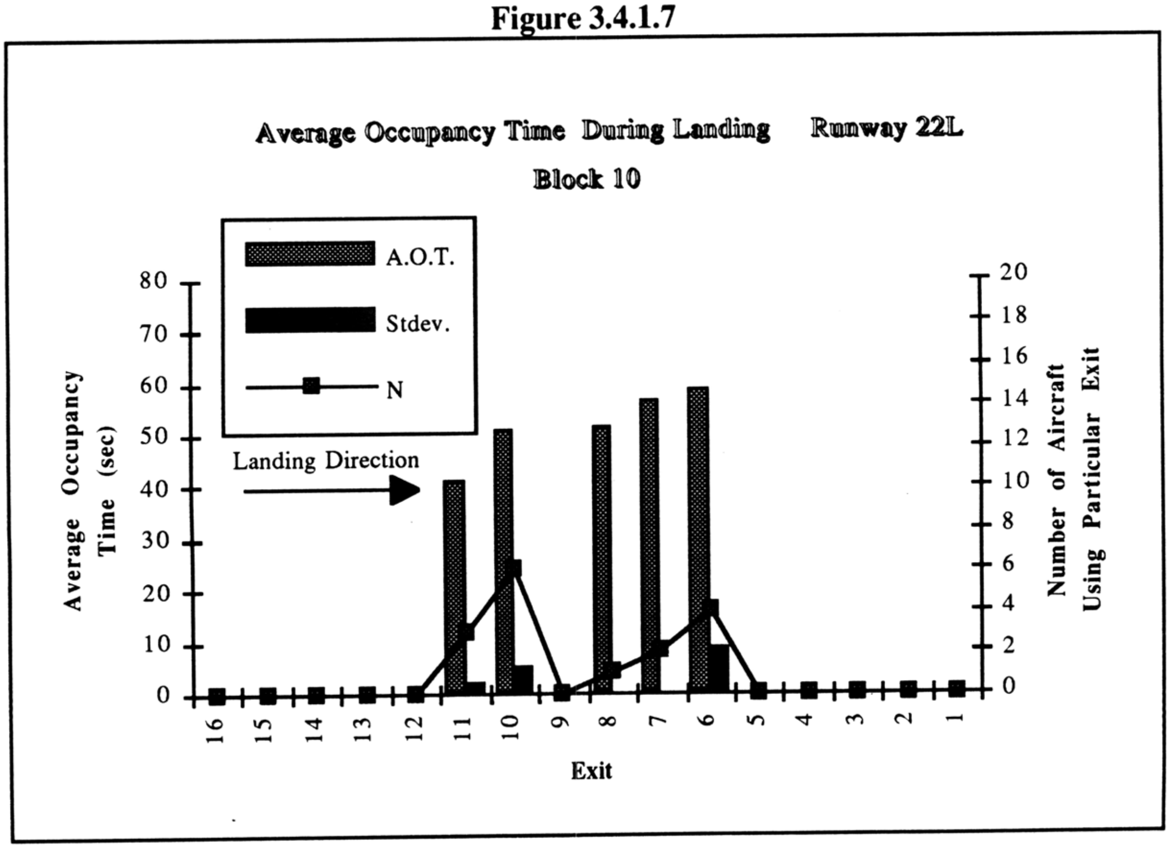


Figure 3.4.1.8

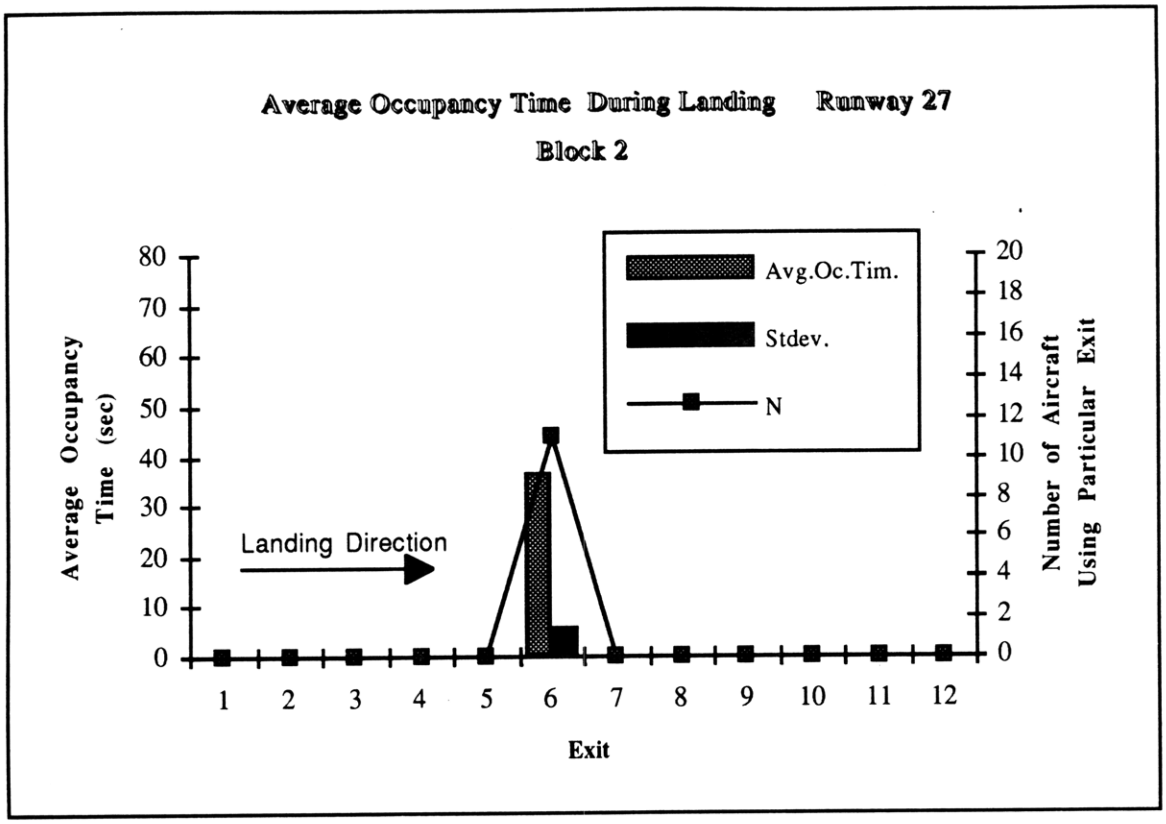


Figure 3.4.1.9

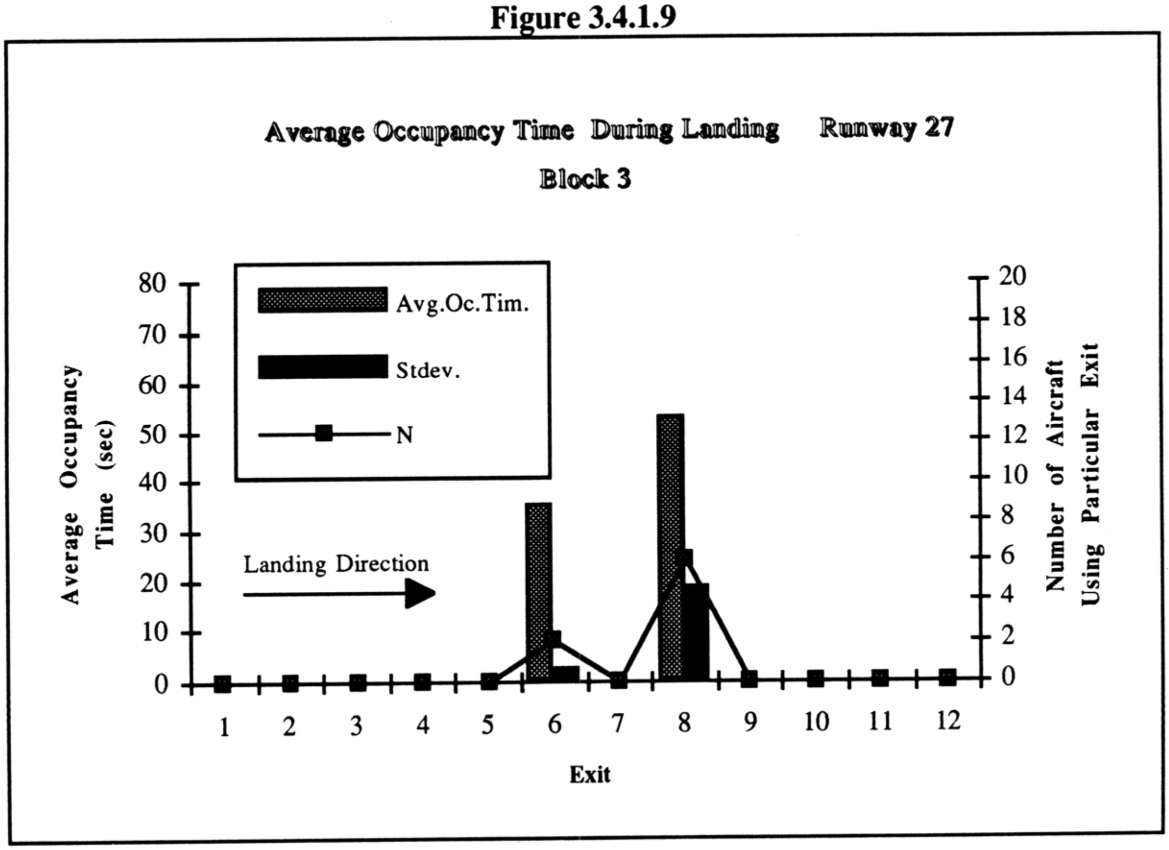


Figure 3.4.1.10

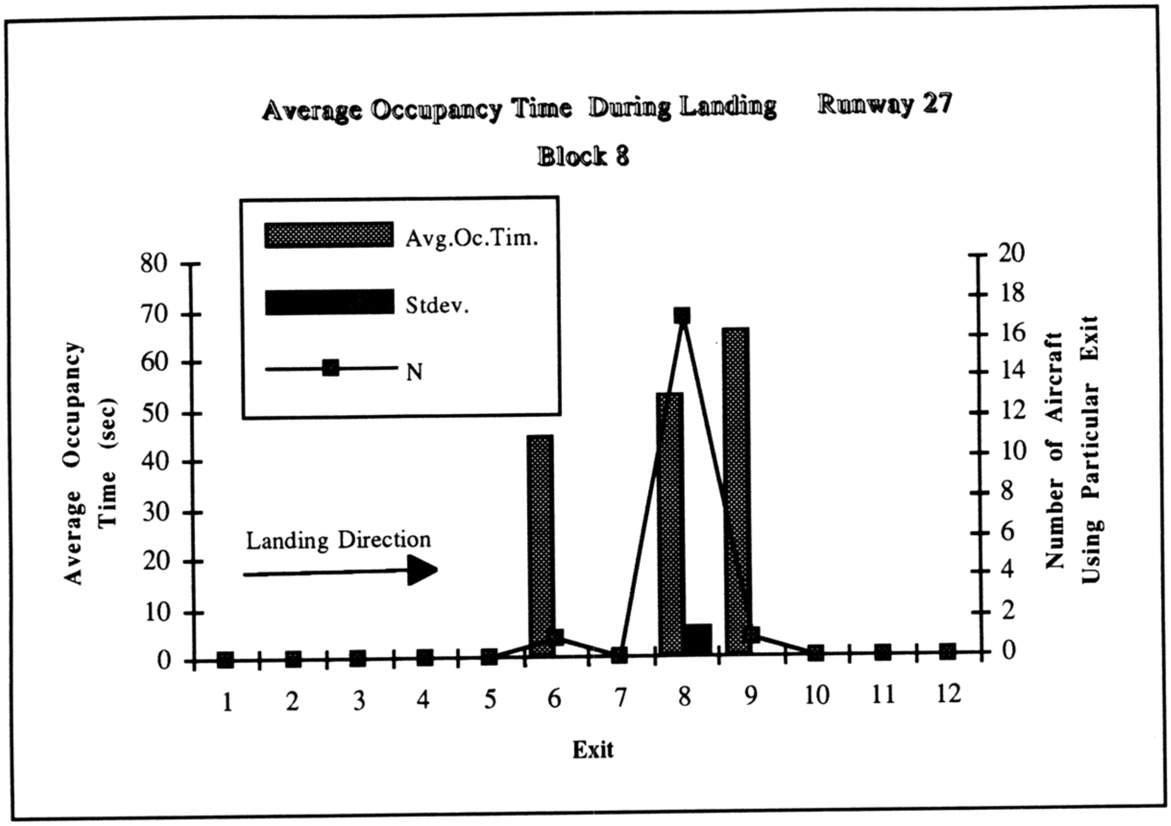


Figure 3.4.1.11

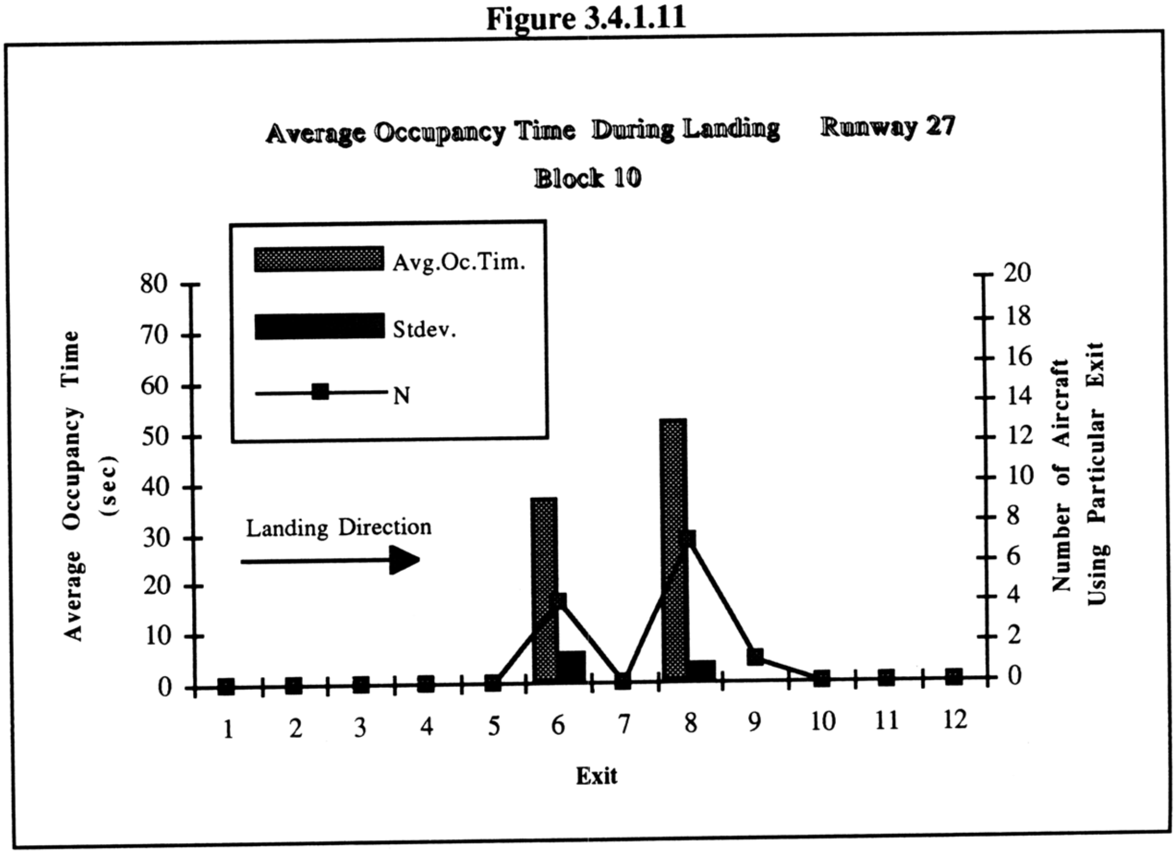


Figure 3.4.1.12

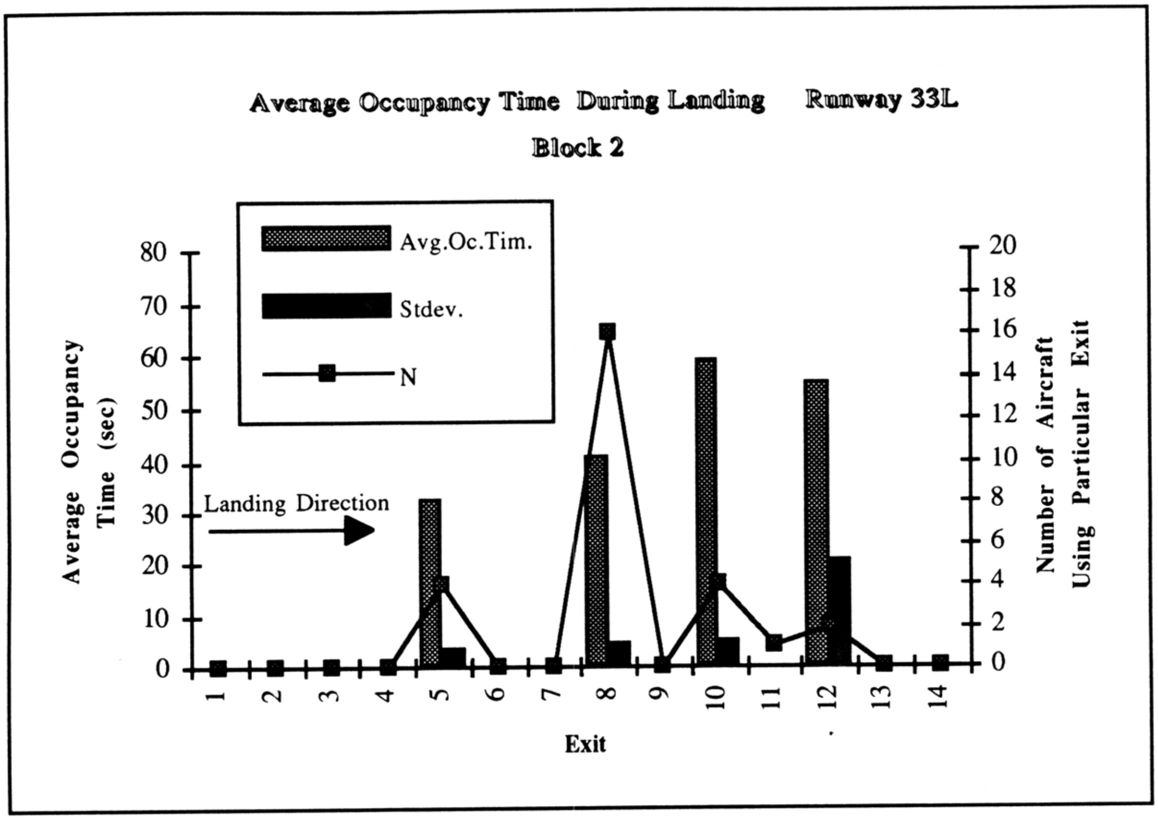


Figure 3.4.1.13

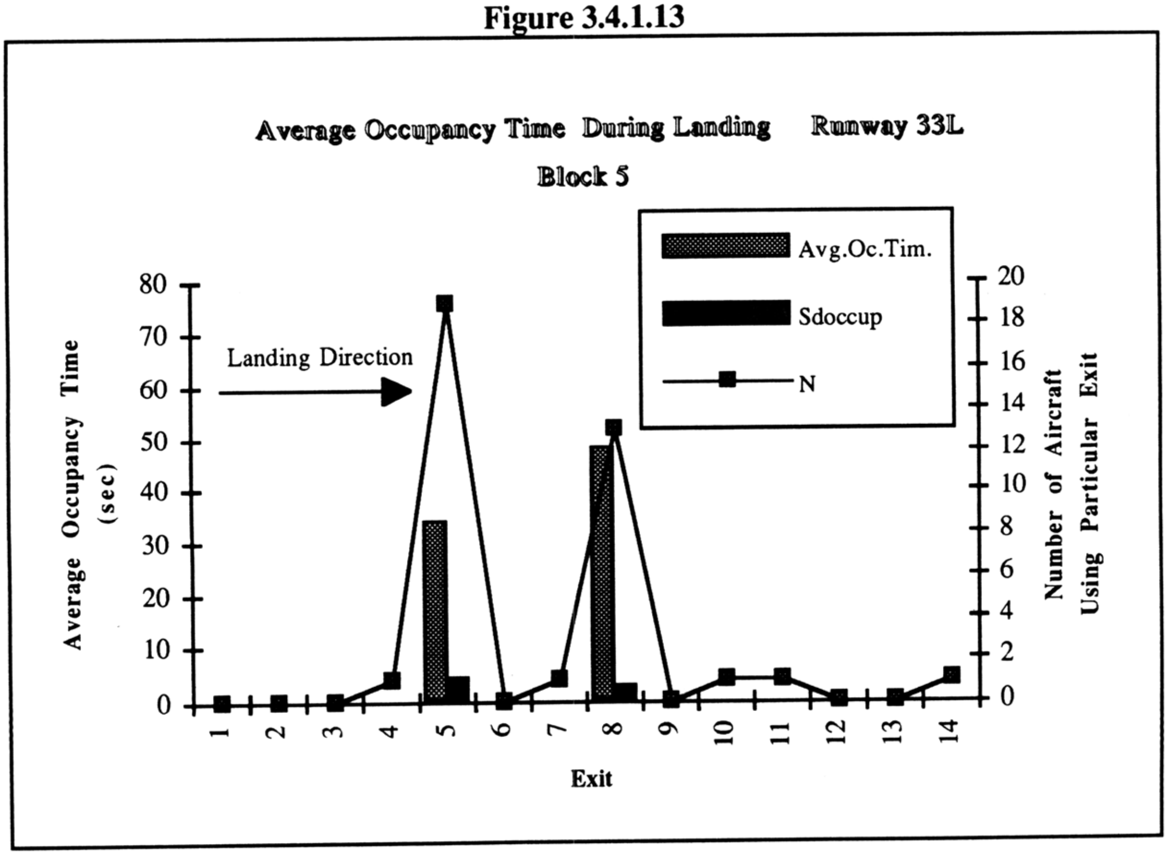


Figure 3.4.1.14

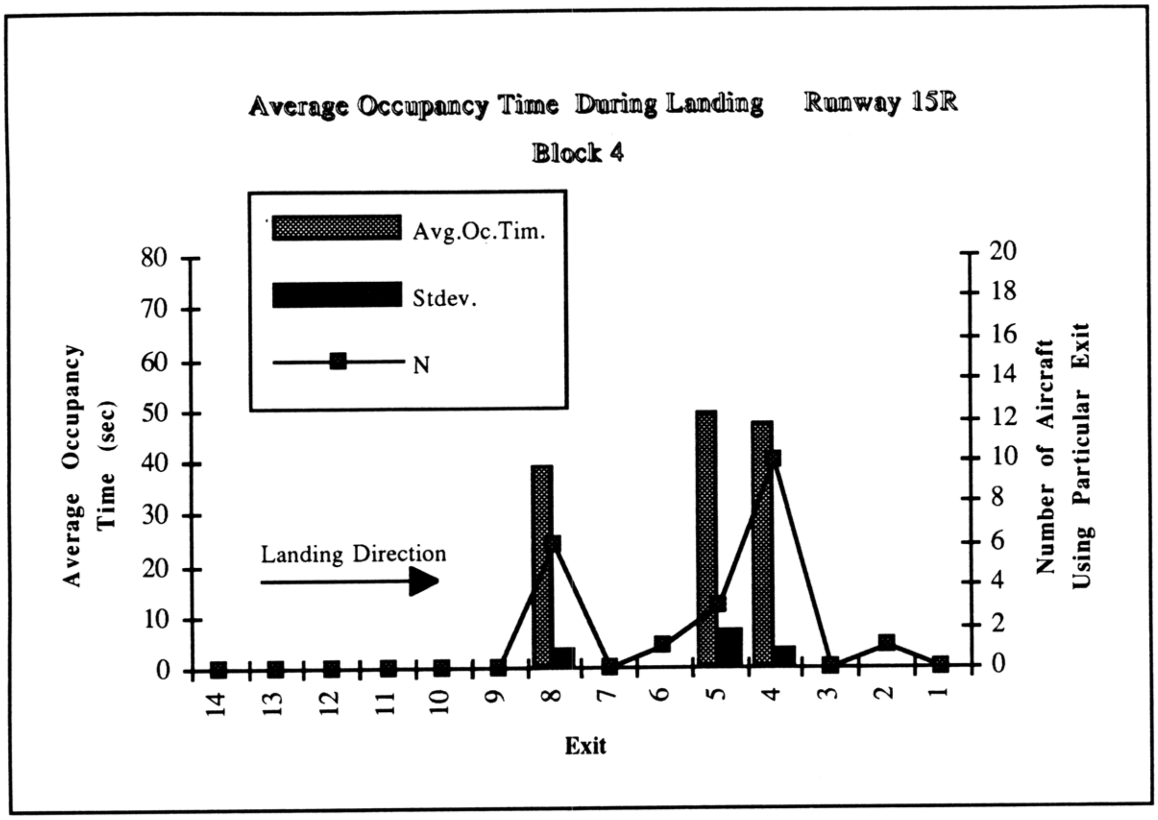


Figure 3.4.1.15

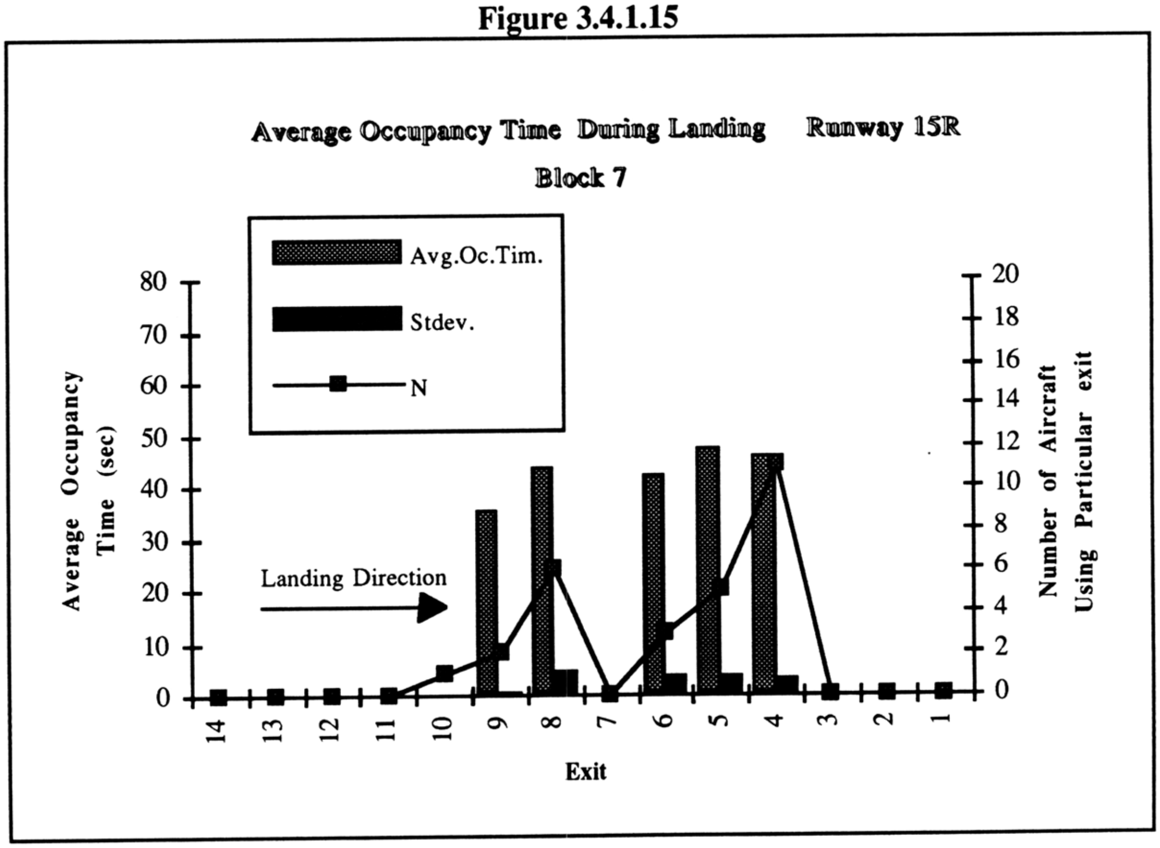


Figure 3.4.1.16

3.4.2 Exit Use

Figures 3.4.2.1 through 3.4.2.13 represent graphically the exit use both for all aircraft that landed in every runway and for each aircraft (weight) class in every data block that information about the aircraft types were available. If information was available during data collection, the exit use per particular aircraft class is presented. Each aircraft is classified according to its weight into one of the following three classes :

Class	Weight Range ('000 LB)
Heavy	300-900
Large	12.6-299
Small	0-12.5

Table 3.4.2

The major observations are that, as expected, the probability of exit is related to the aircraft size (weight class). Hence, heavier aircraft tended to use exits that are located further away from the runway threshold while smaller sized ones required shorter landing distances and exited earlier.

A second factor that affected exit use was the specific turning angle of the exit. This angle (which could have been acute, right, or obtuse) provides a measure of the difficulty of using each exit. As a result, independent of runway, most aircraft tended to prefer the use of obtuse angled (high speed) exits.

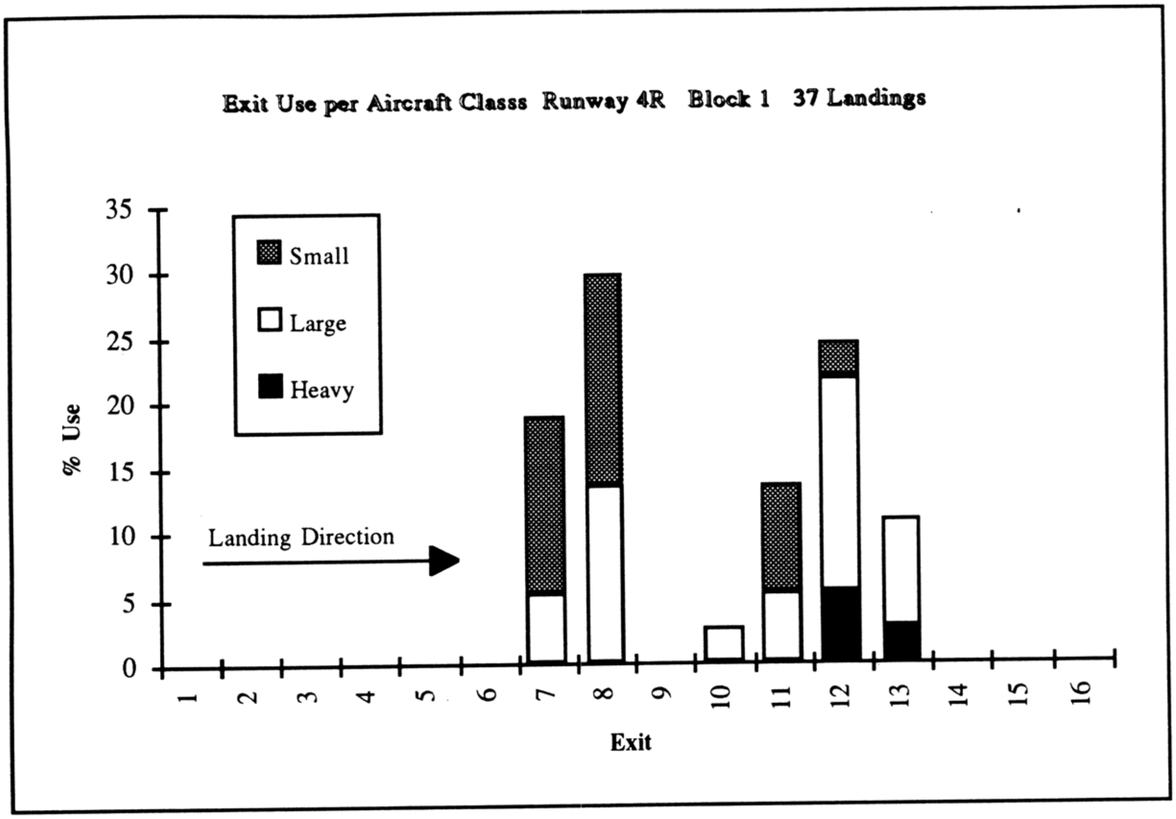


Figure 3.4.2.1

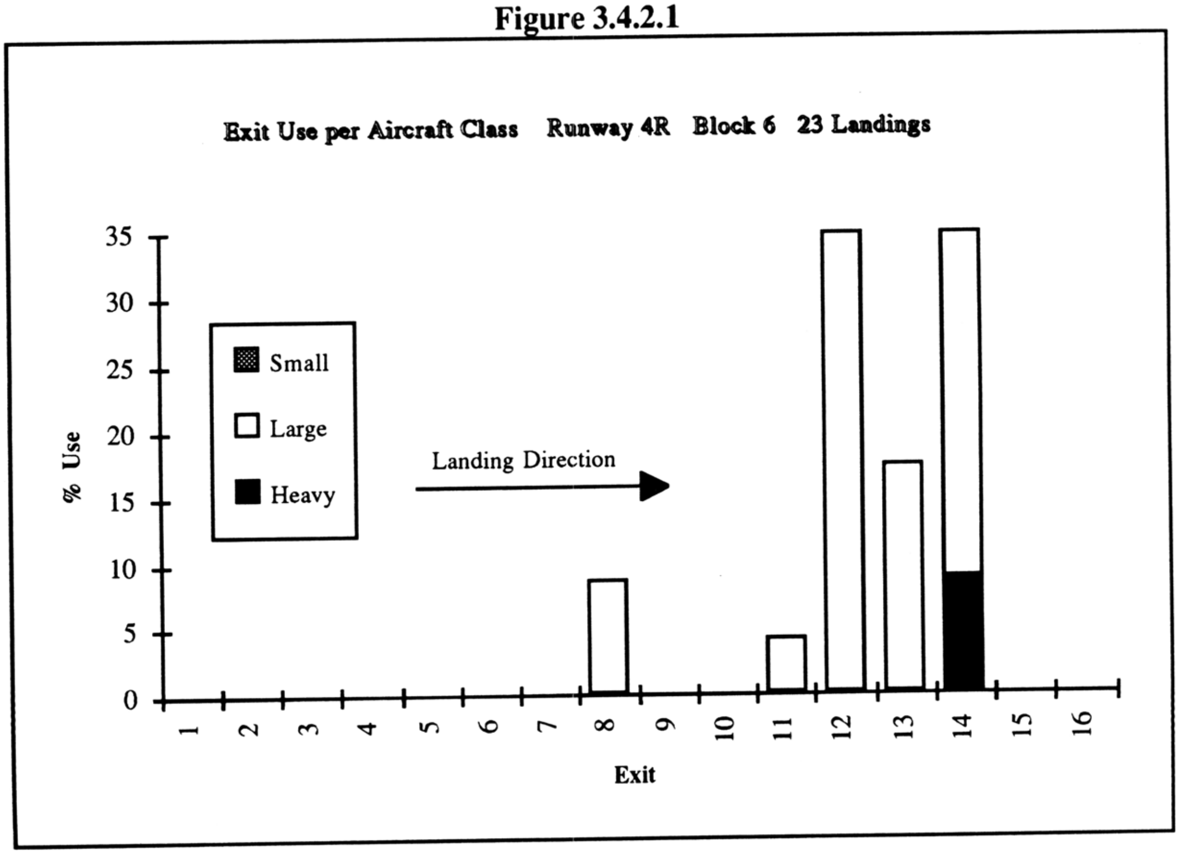
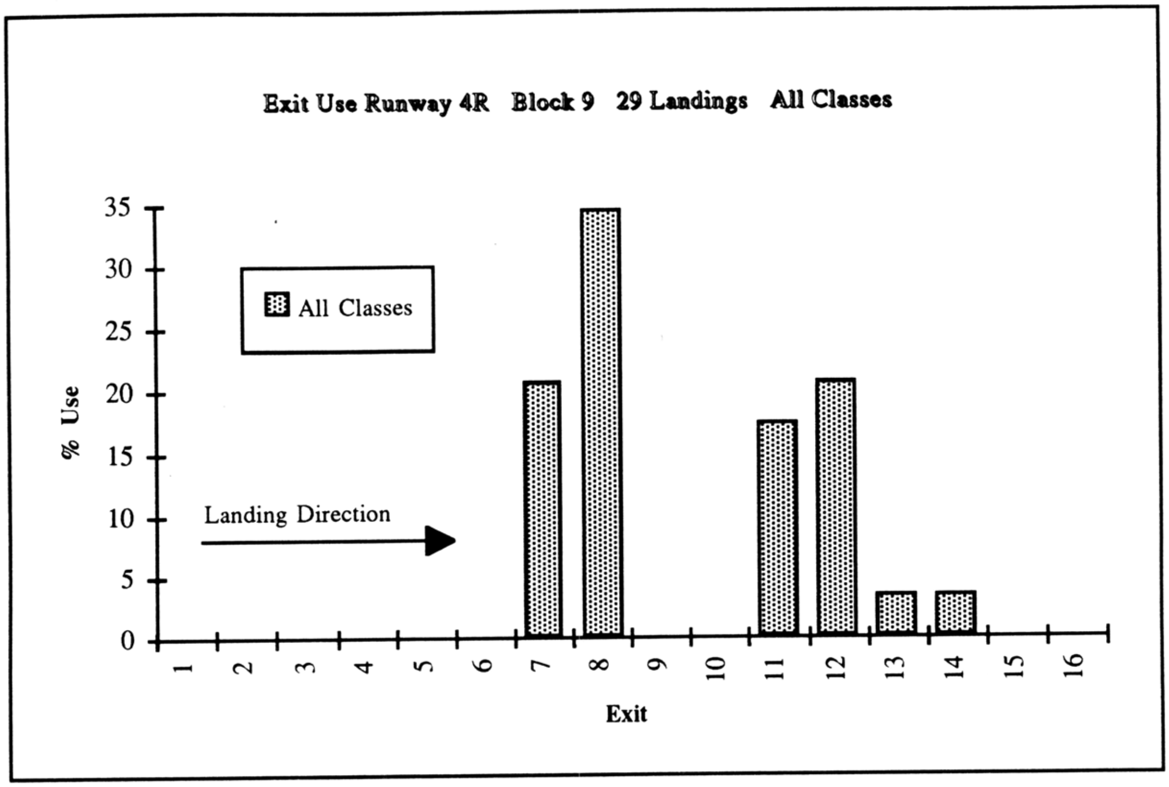


Figure 3.4.2.2



Exit Use Runway 4R Block 9 29 Landings All Classes
All Classes
% Use
35
30
25
20
15
10
5
0
Landing Direction
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Exit

Figure 3.4.2.3

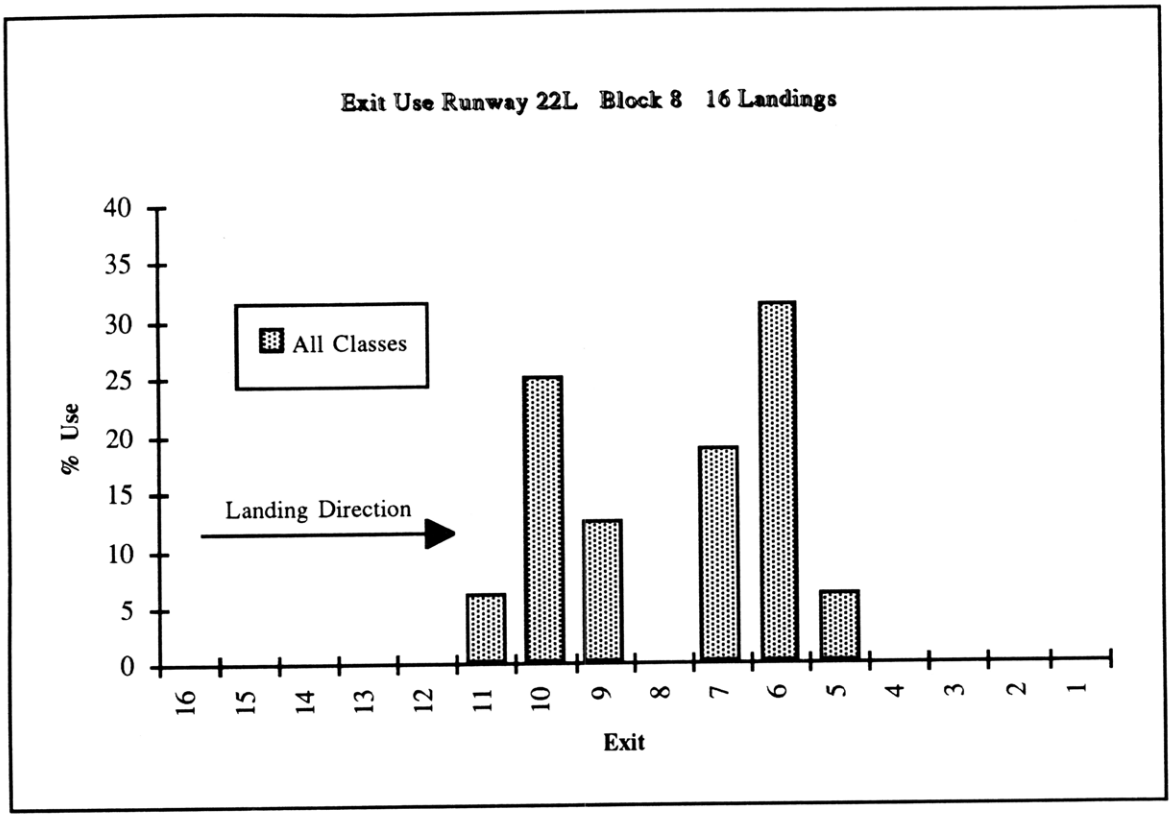


Figure 3.4.2.4

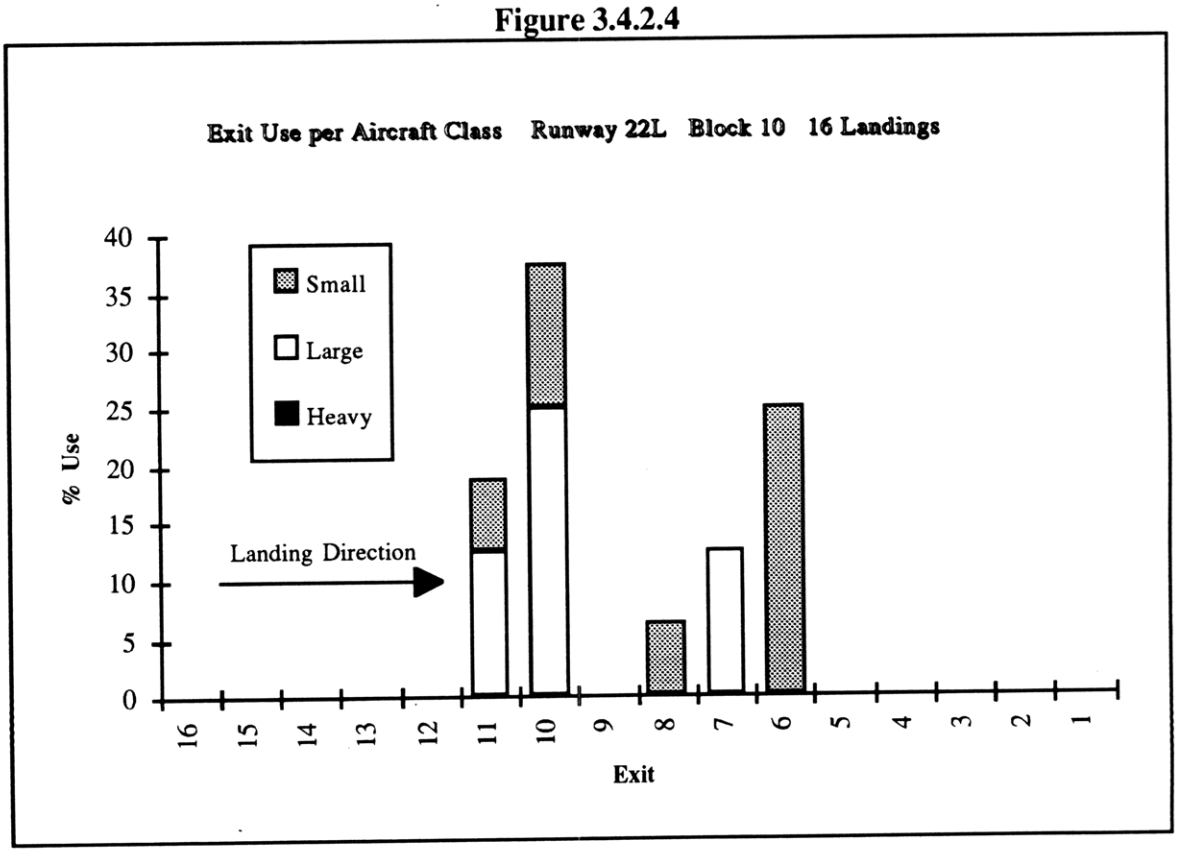


Figure 3.4.2.5

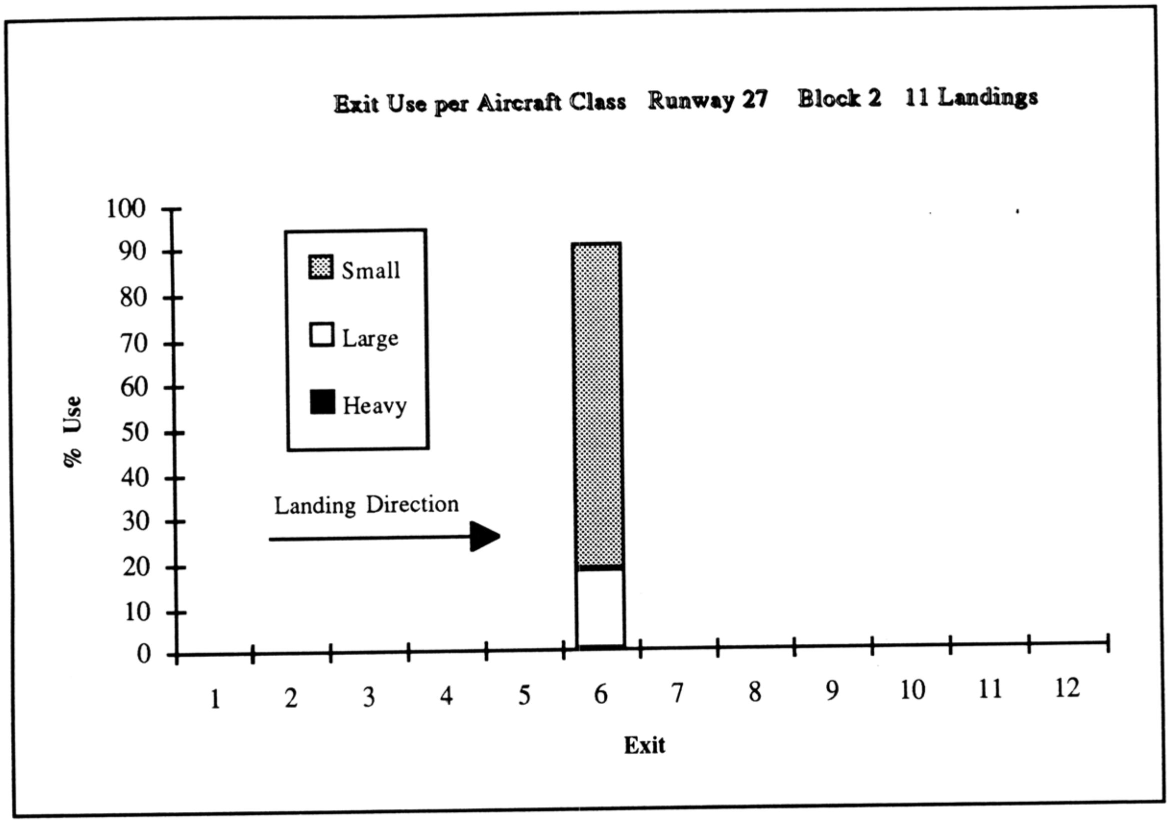


Figure 3.4.2.6

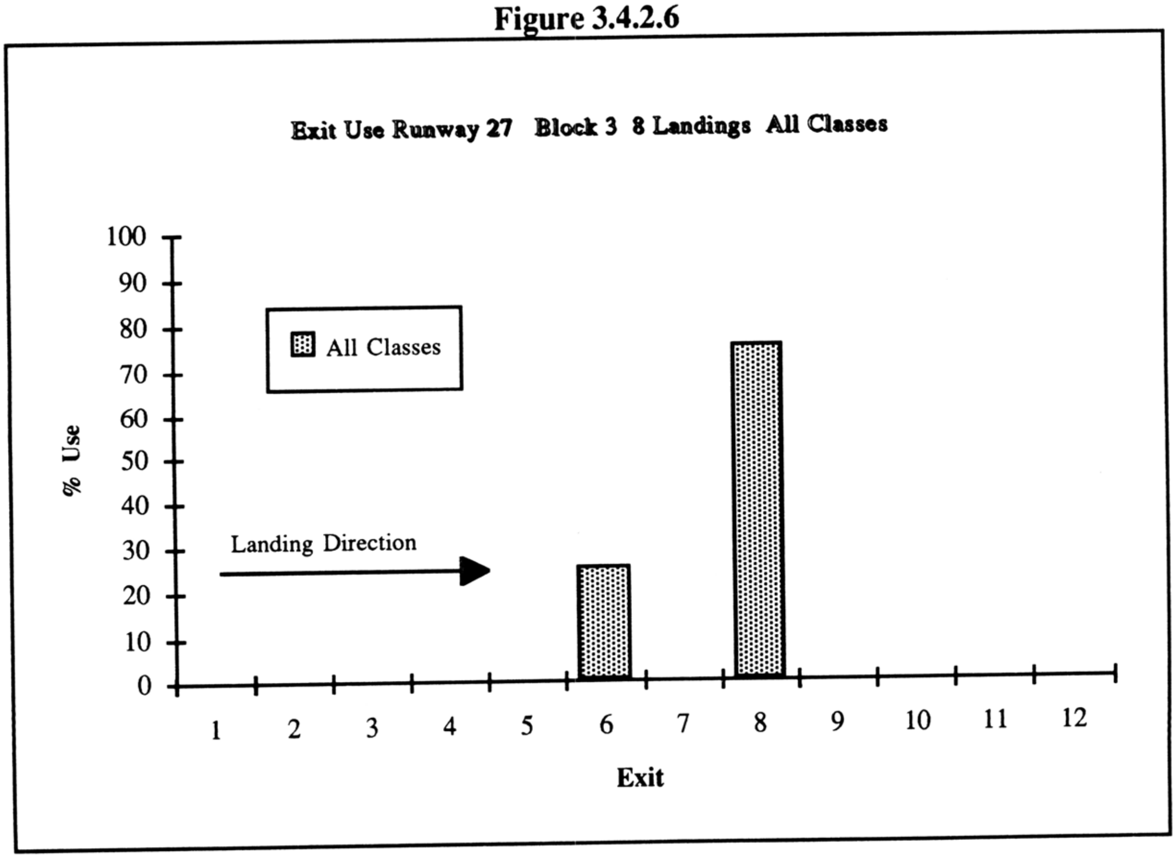


Figure 3.4.2.7

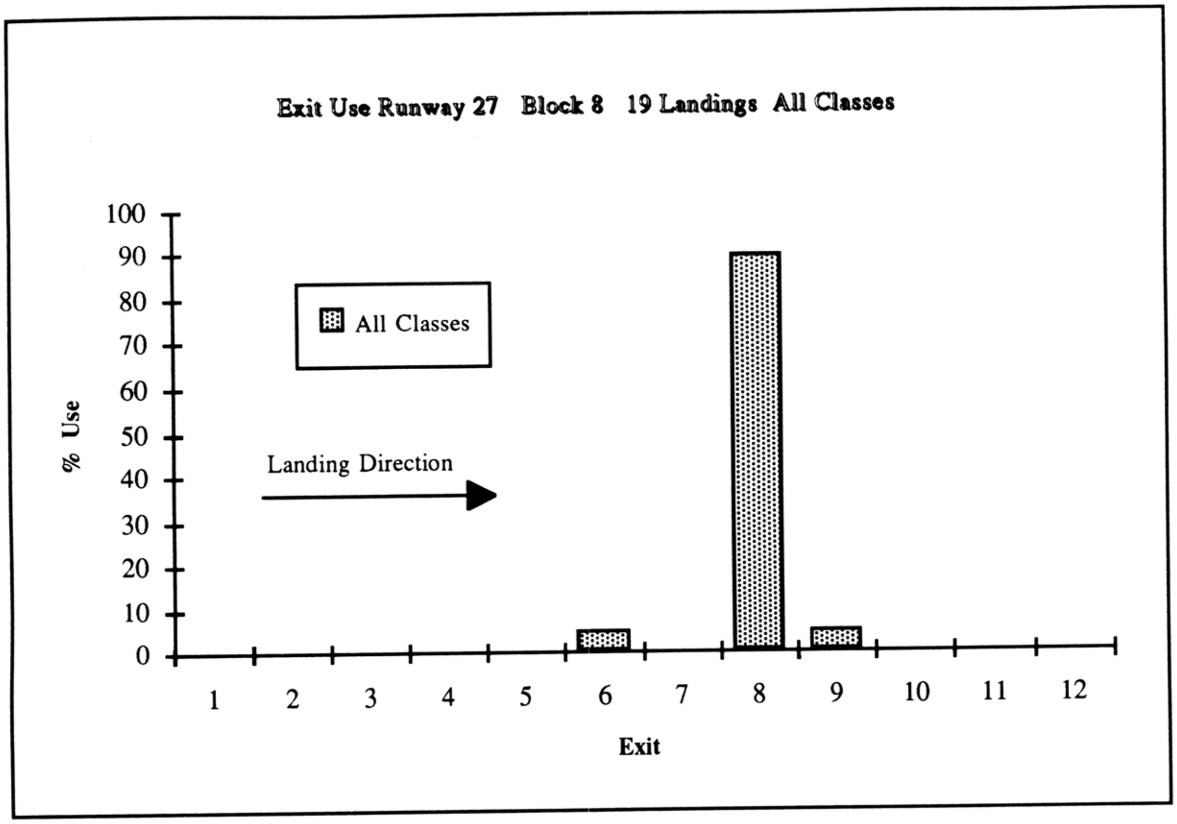


Figure 3.4.2.8

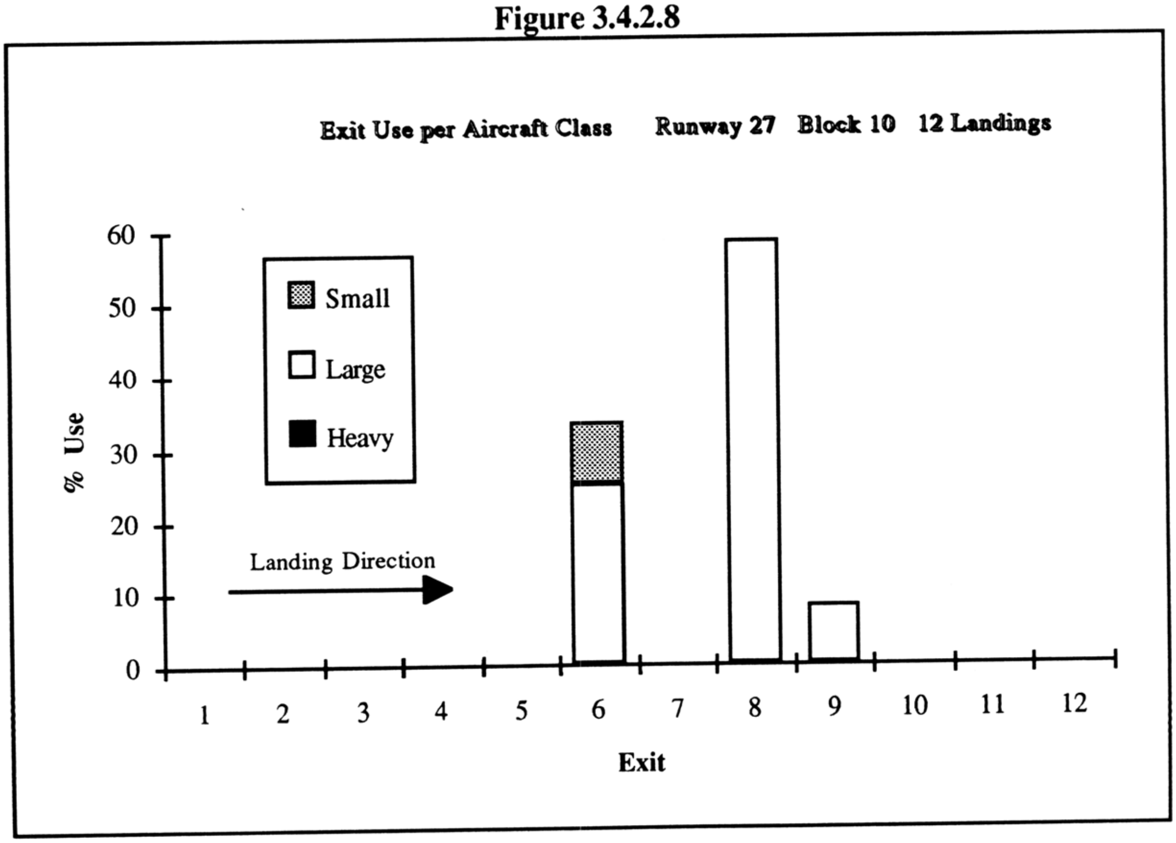


Figure 3.4.2.9

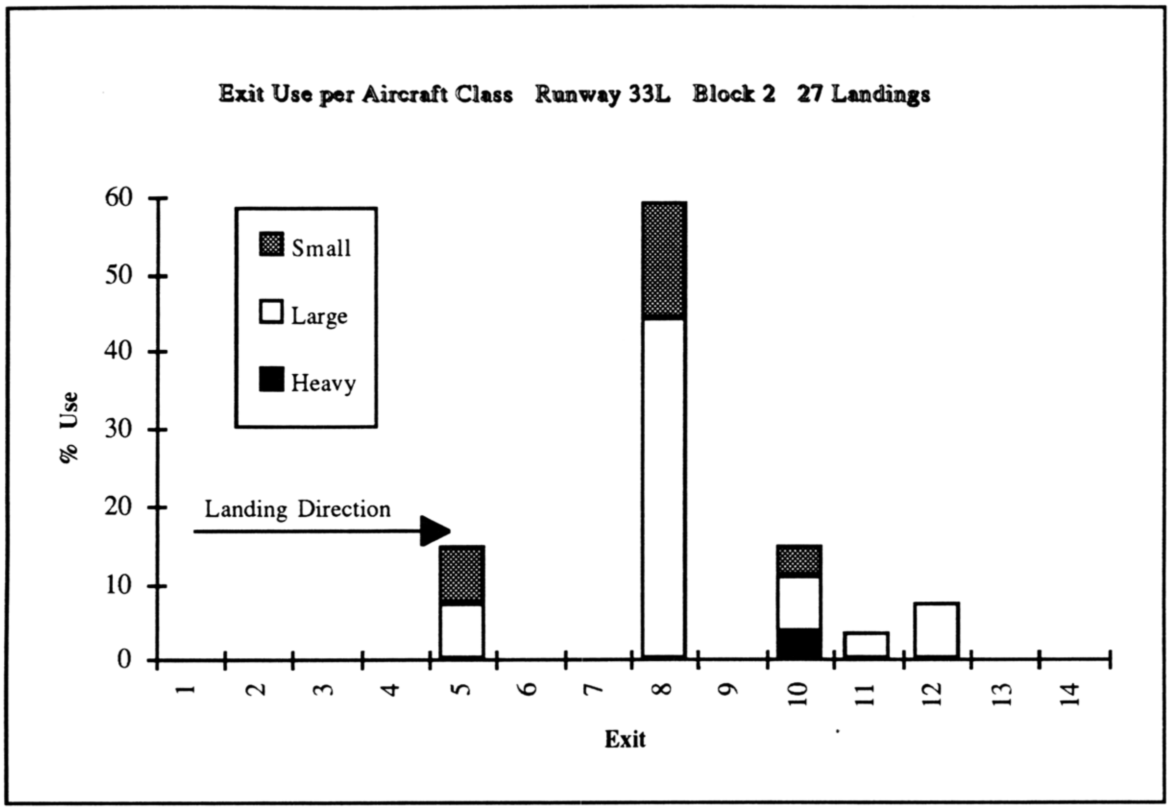


Figure 3.4.2.10

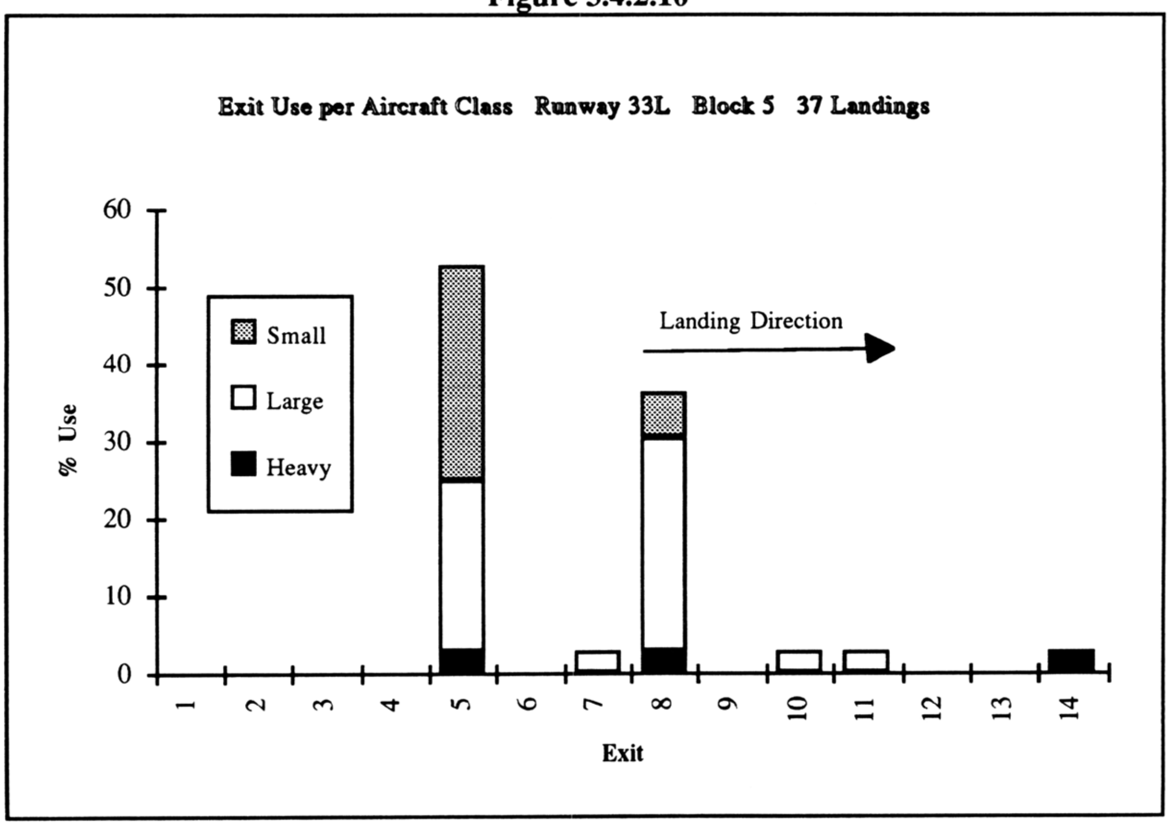


Figure 3.4.2.11

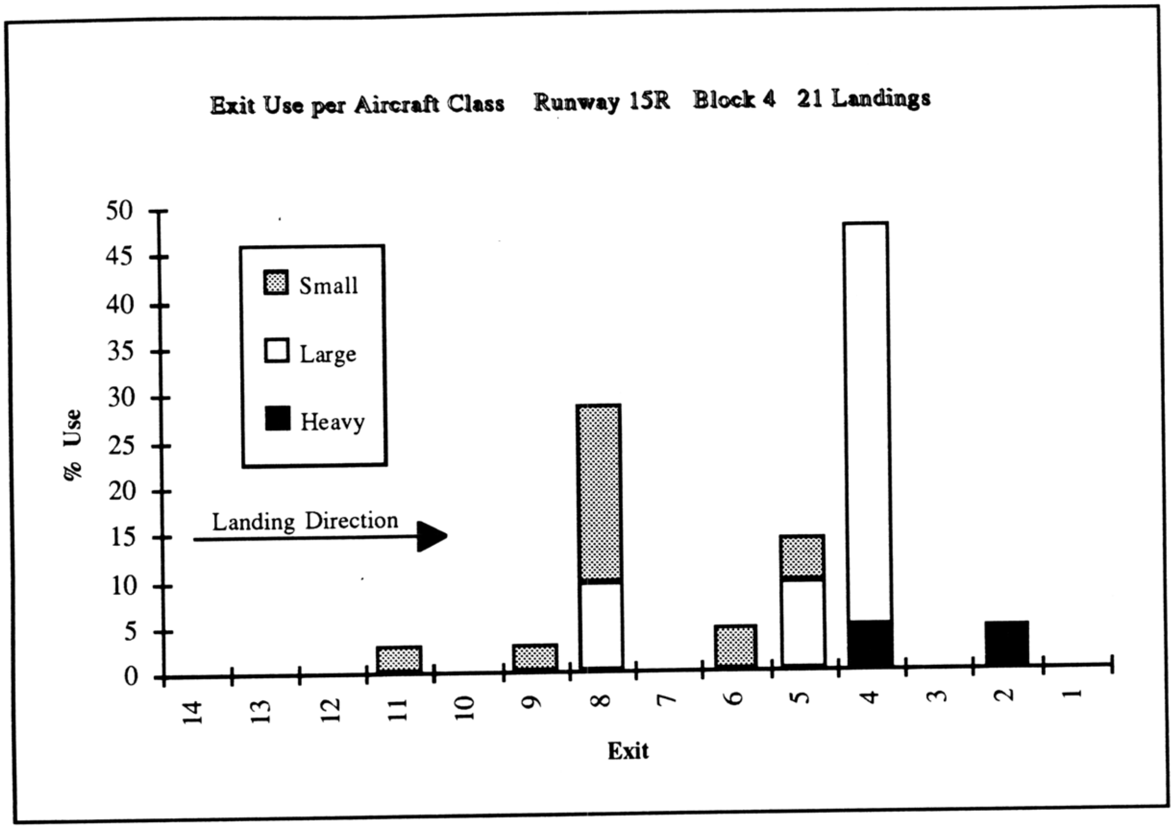


Figure 3.4.2.12

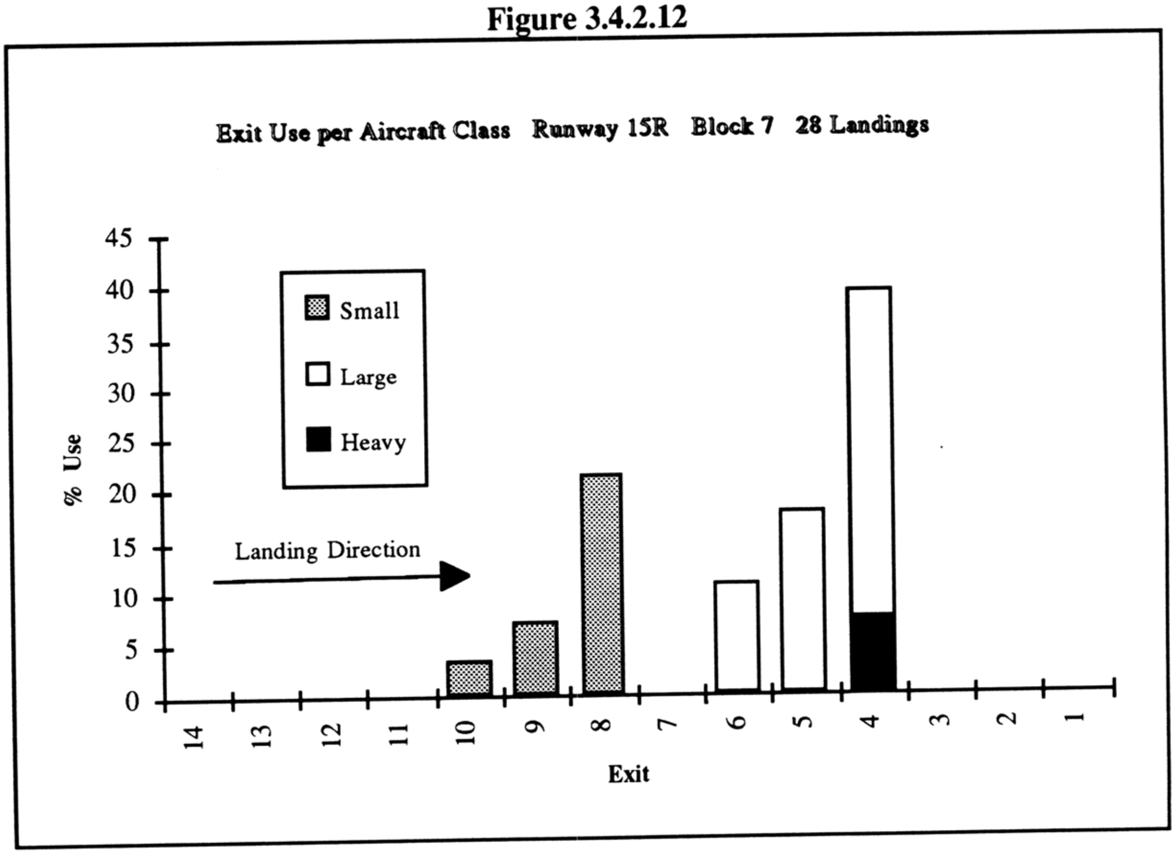


Figure 3.4.2.13

3.4.3 Exit Velocities

The angle of every exit plays a significant role in the exit velocity of the aircraft. As figures 3.4.3.1 through 3.4.3.13 show, whenever the landing aircraft are using the obtuse angled exits the exit velocities are significantly higher than the other ninety degrees or acute angled exits. However, this is only true for high speed exits which are accompanied with long exit segments and give the pilot room to brake (exit 6 runway 27: 38 knots and exit 5 runway 33L : 40 knots). Exit 8 of runway 4R, although it is obtuse angled, the short exit segment that follows does not allow high exit velocities. Each figure presents, using columns the average exit velocity, and with a line, one high and one low value which corresponds to the average exit velocity plus or minus one standard deviation (see figure legend). The letter **H** denotes a high speed exit.

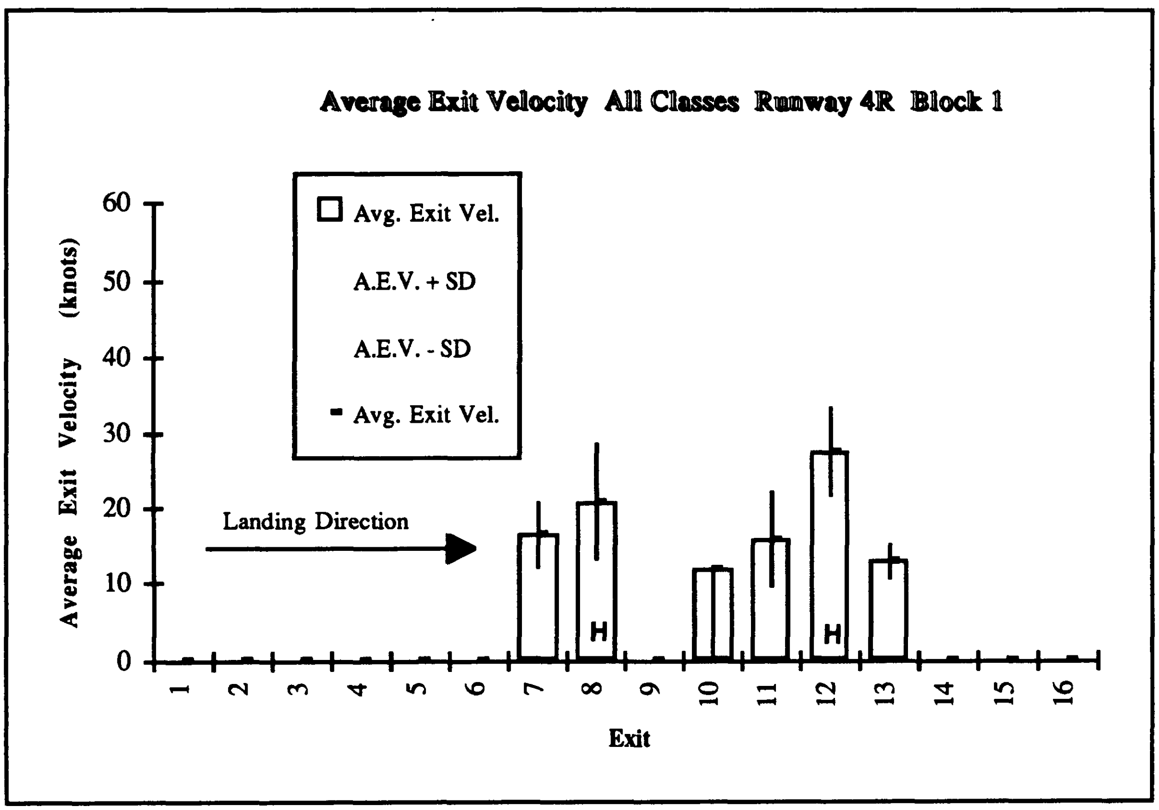


Figure 3.4.3.1

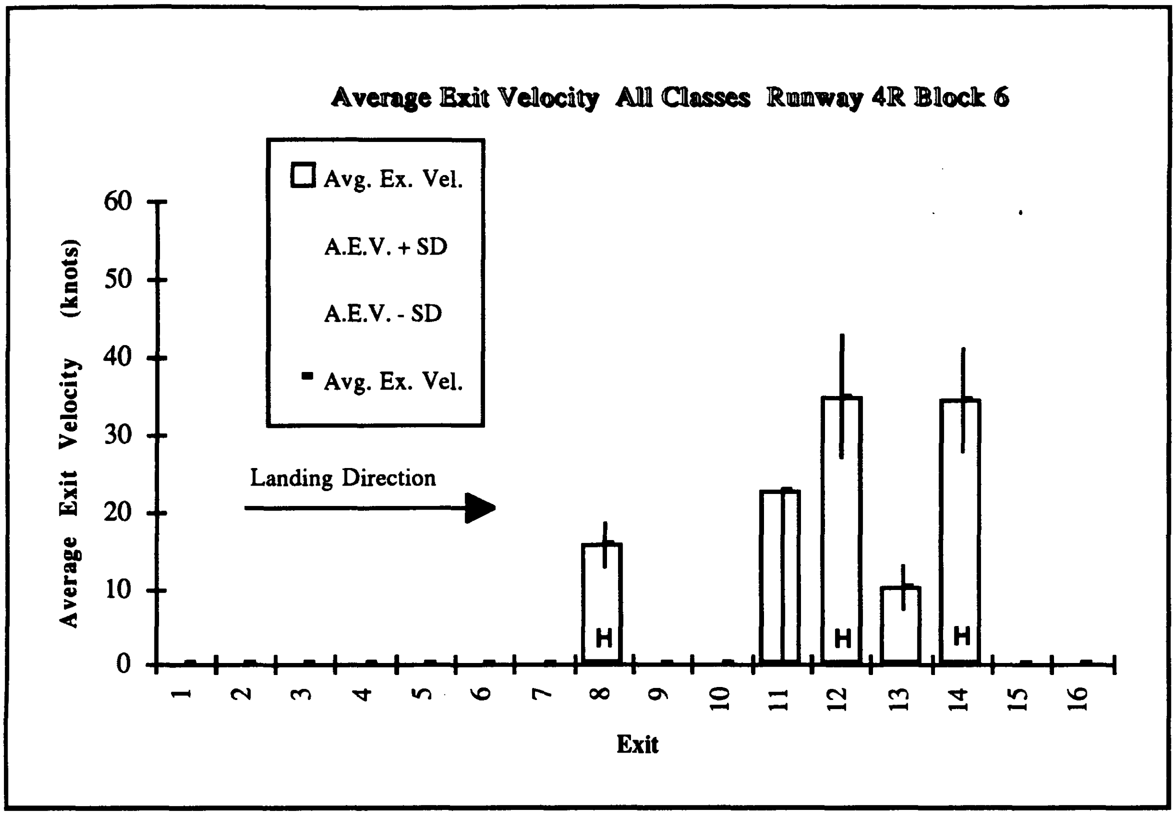


Figure 3.4.3.2

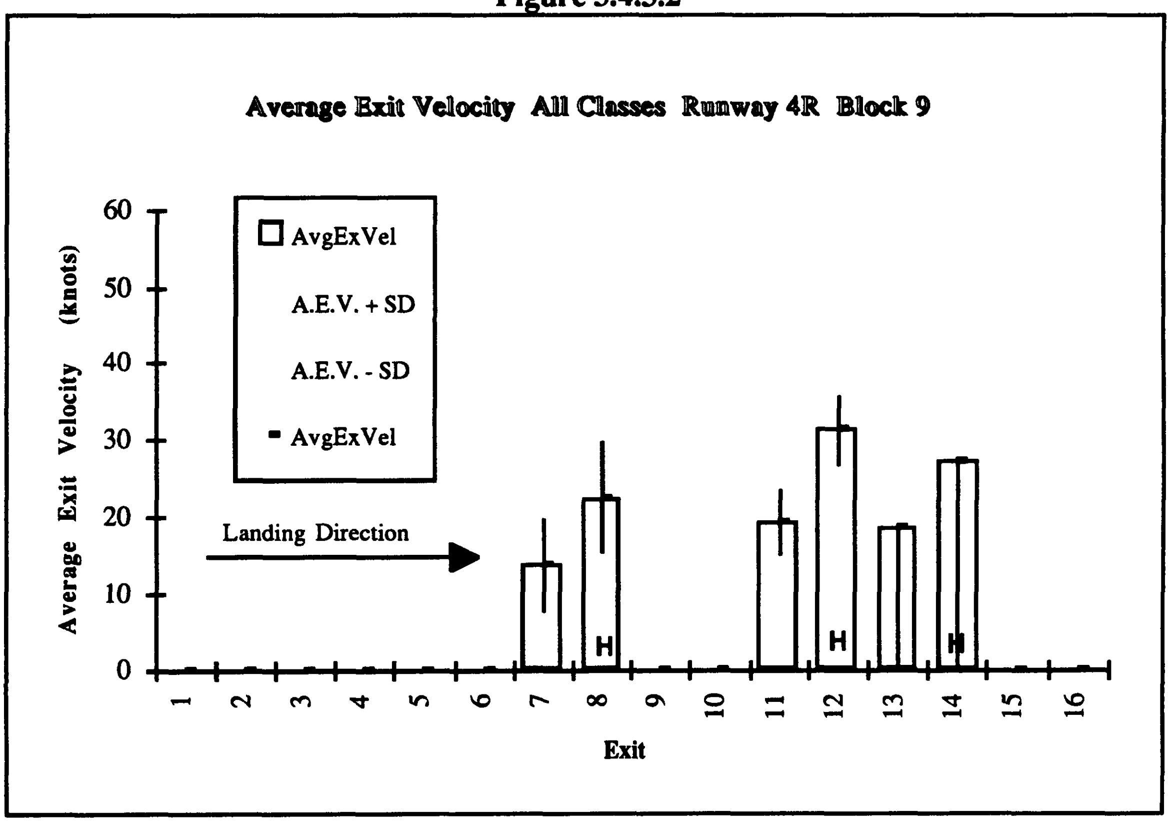


Figure 3.4.3.3

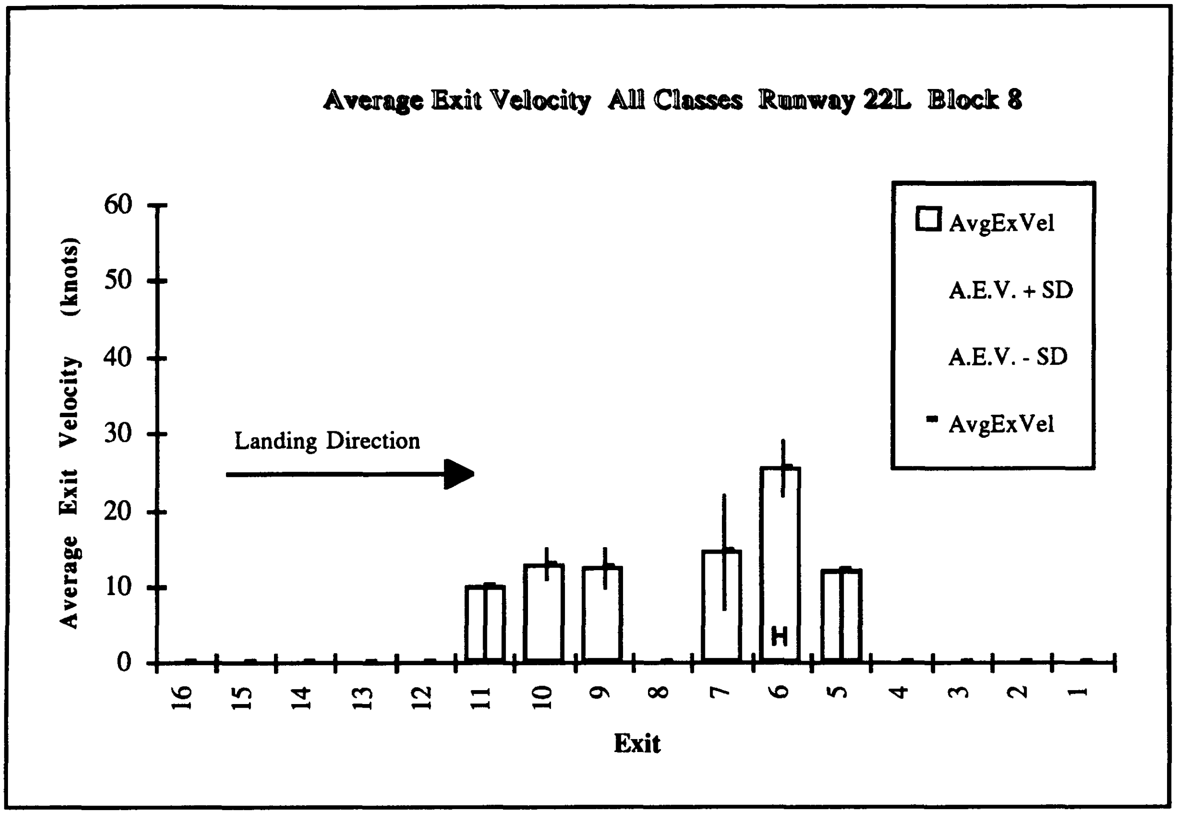


Figure 3.4.3.4

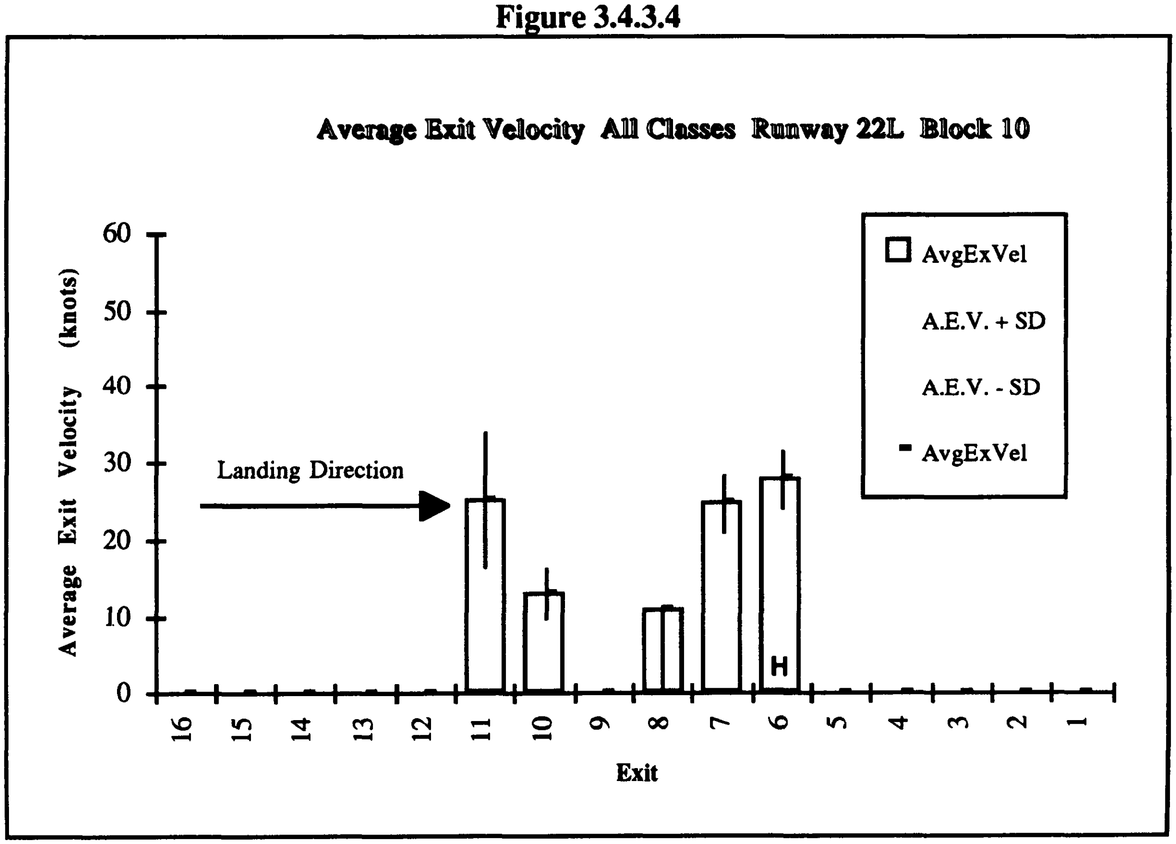


Figure 3.4.3.5

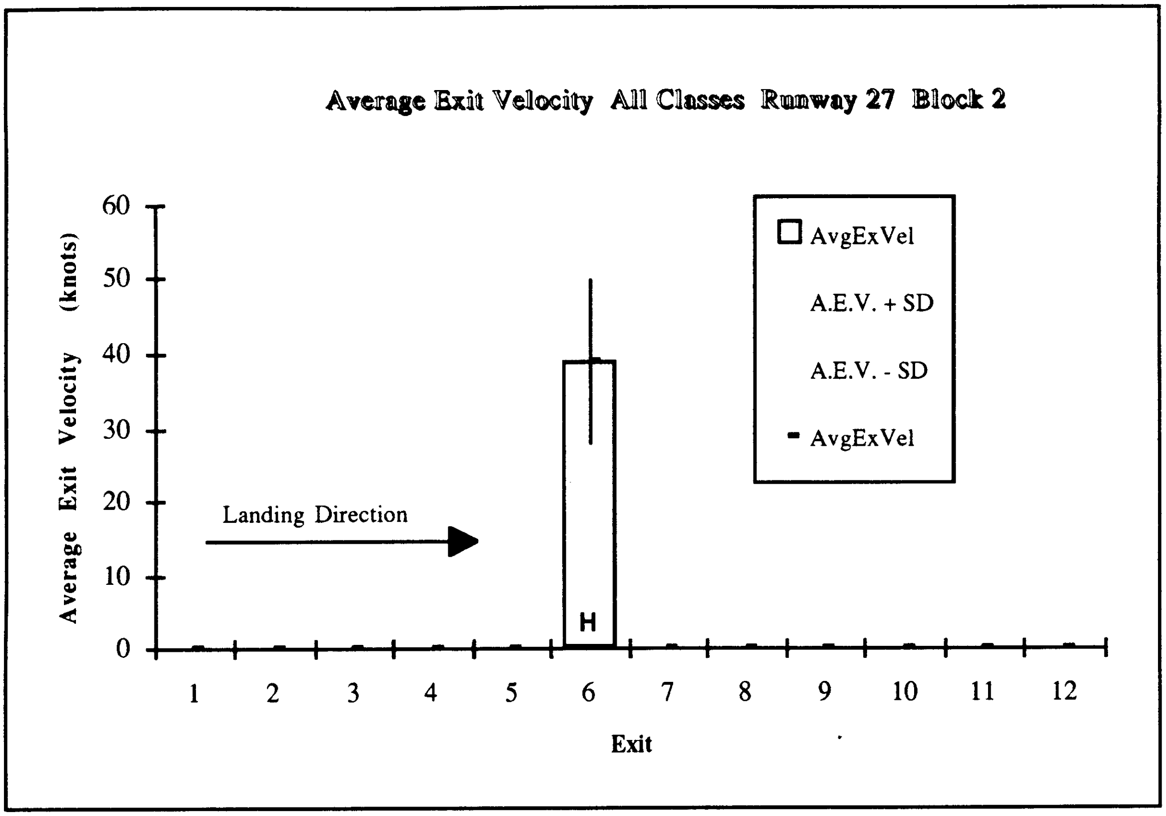


Figure 3.4.3.6

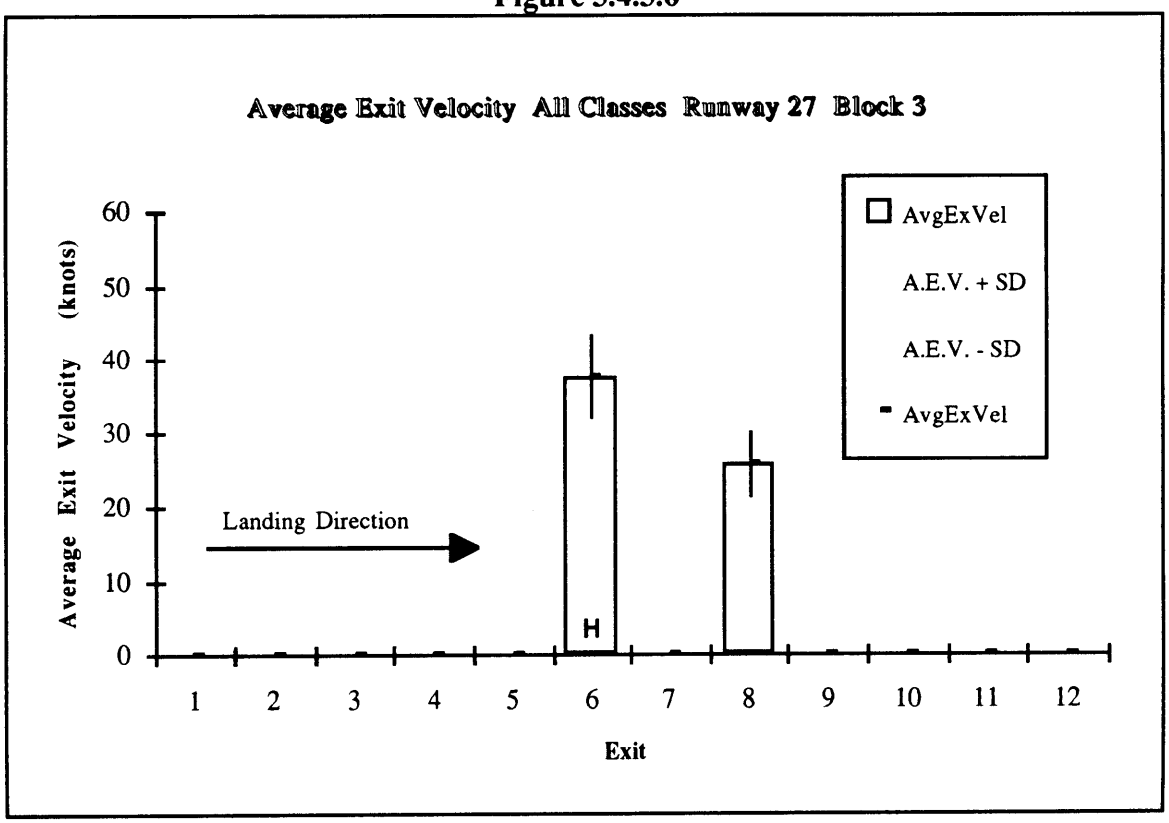


Figure 3.4.3.7

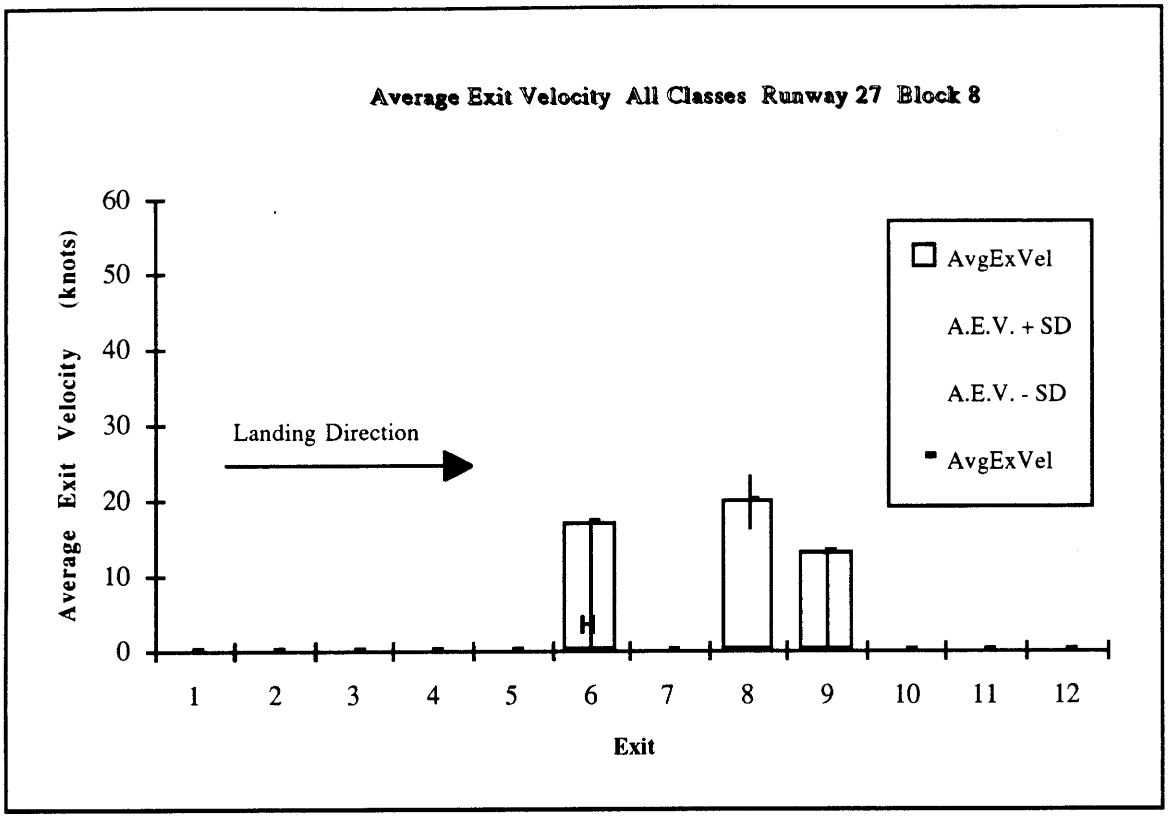


Figure 3.4.3.8

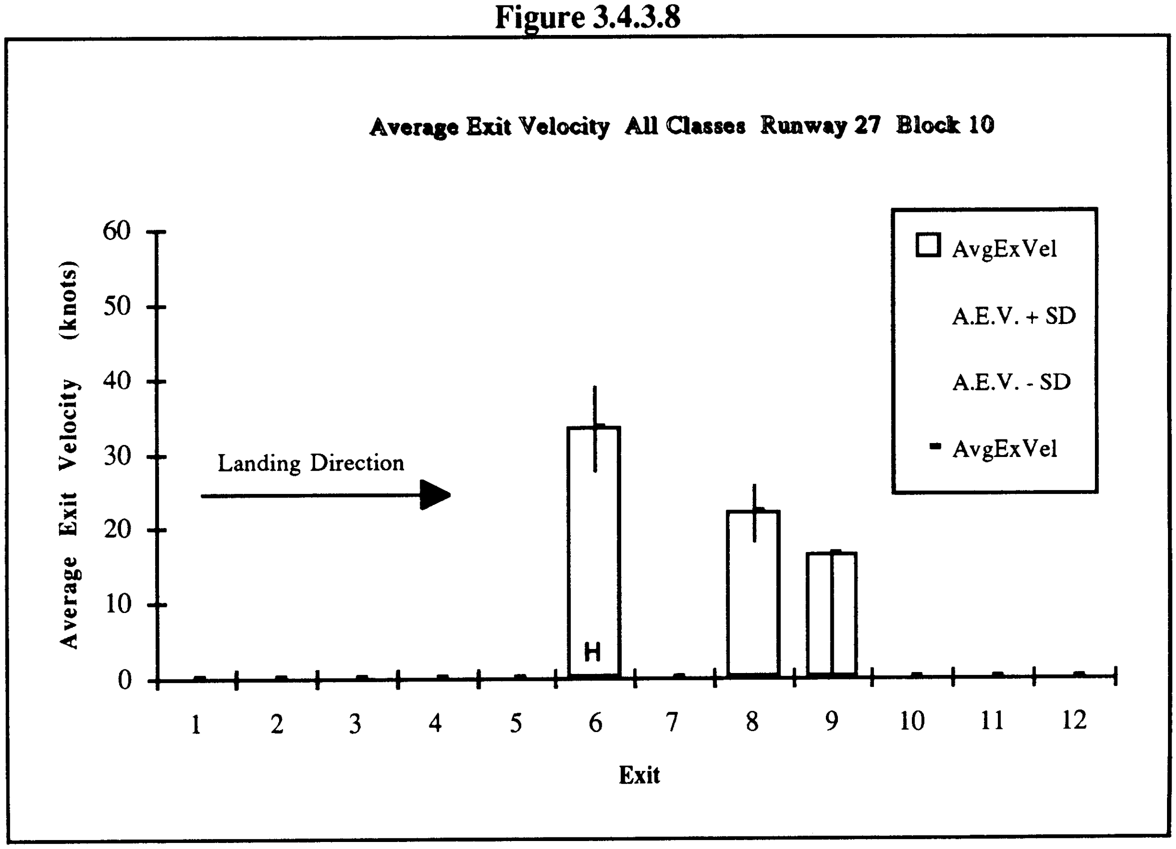


Figure 3.4.3.9

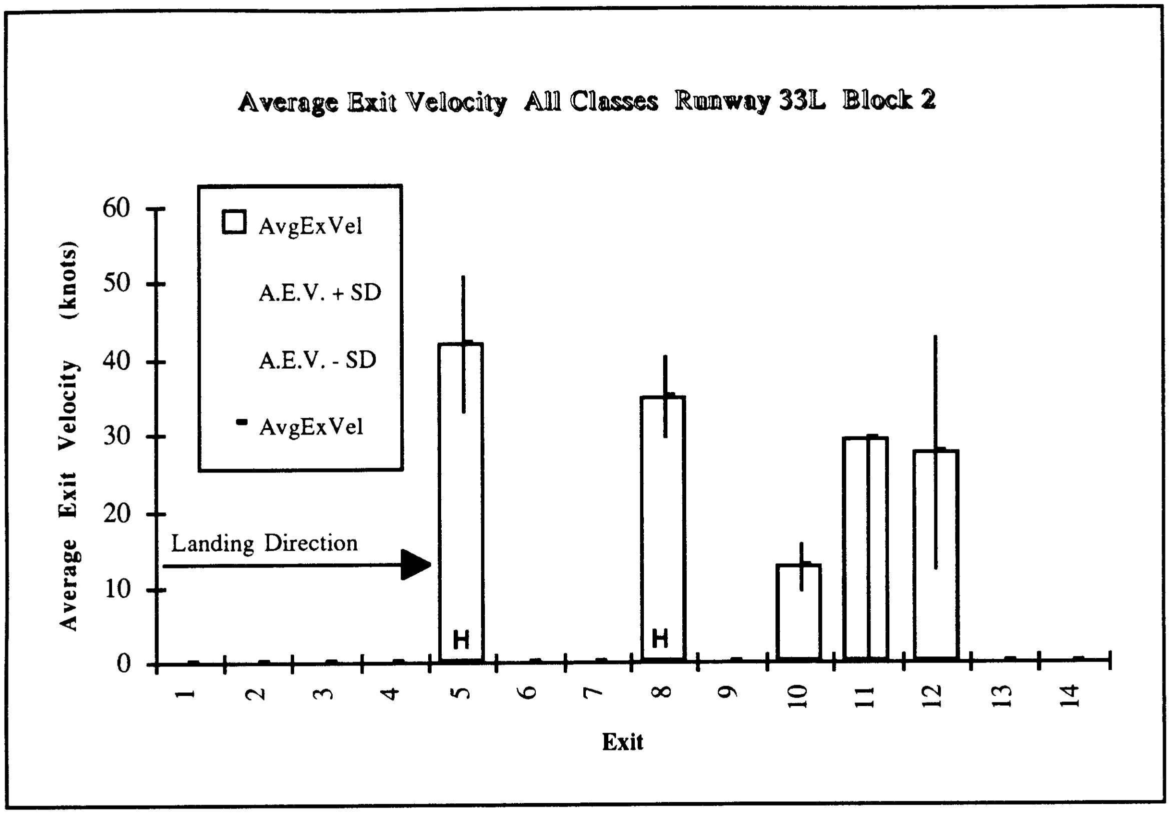


Figure 3.4.3.10

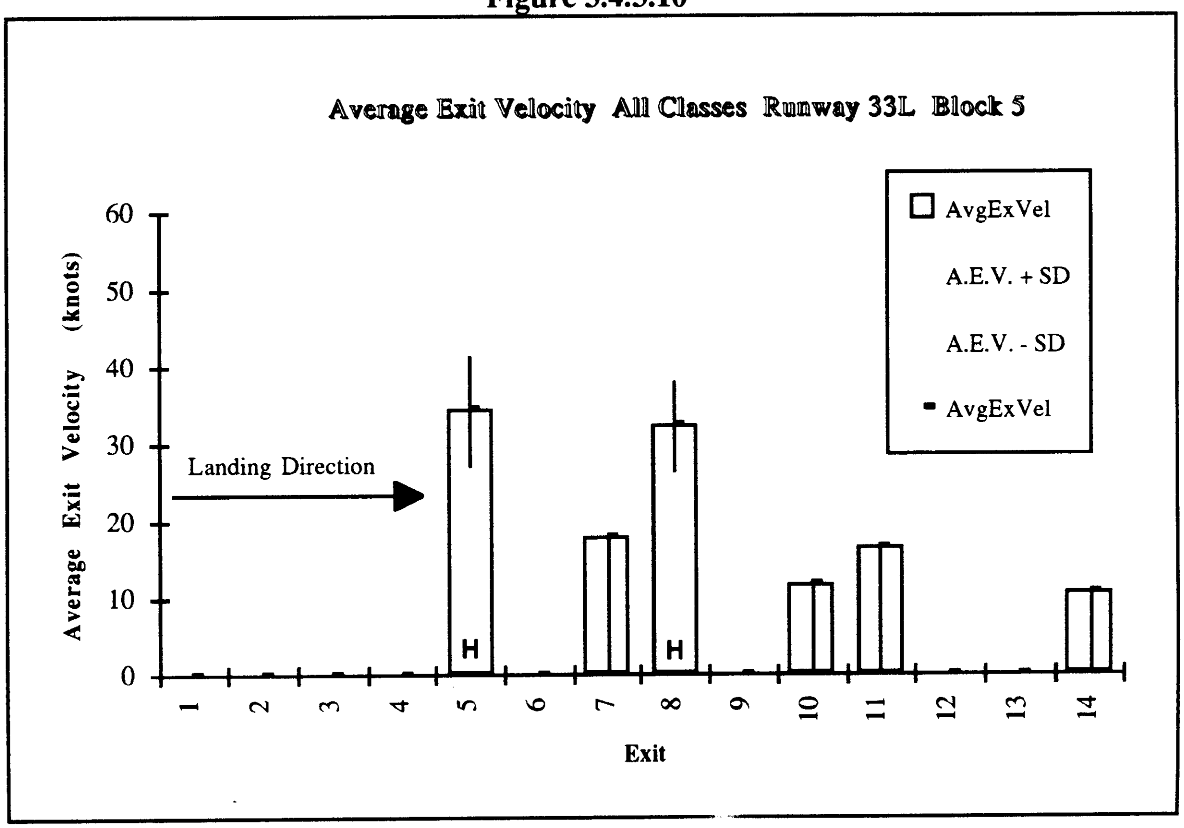


Figure 3.4.3.11

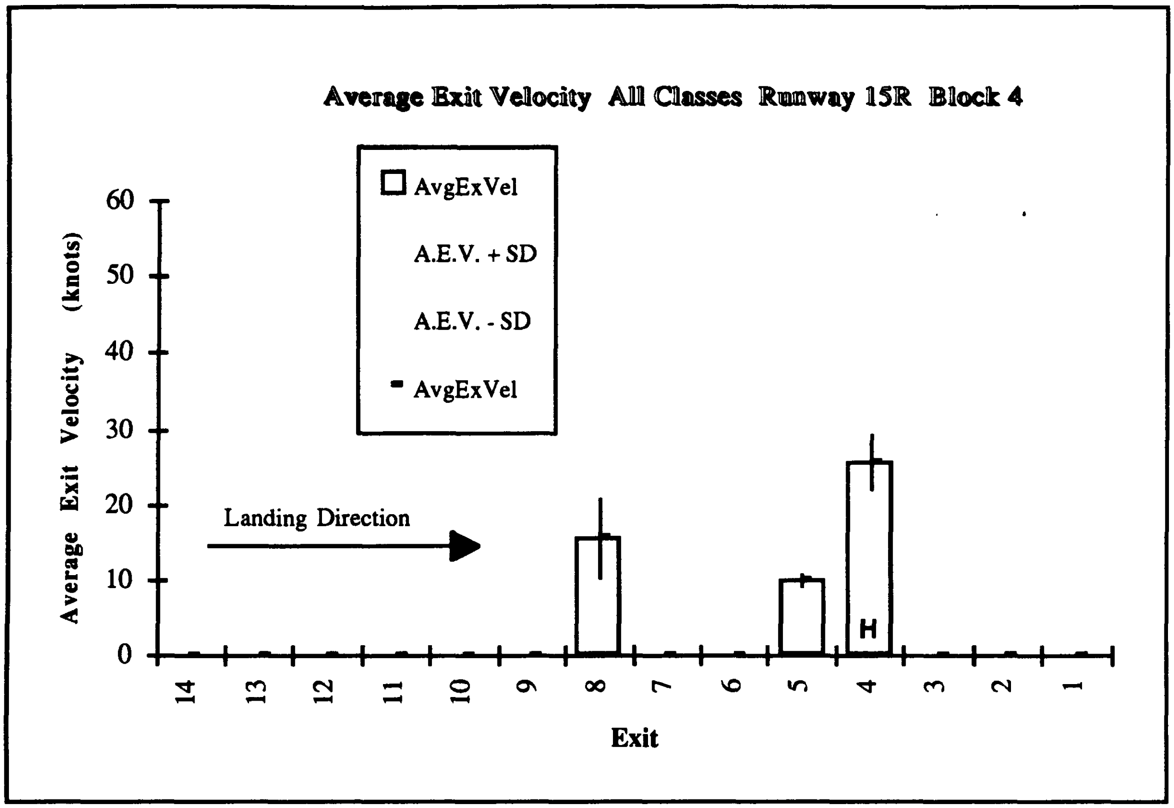


Figure 3.4.3.12

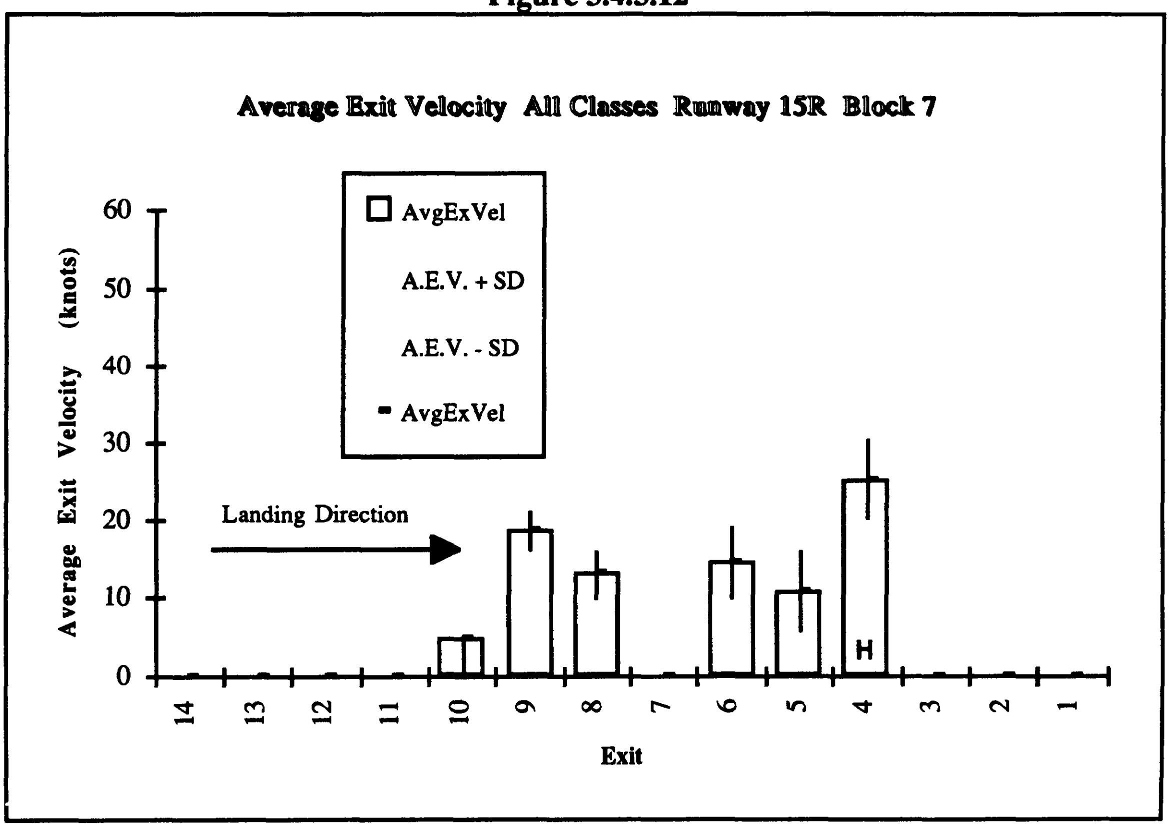


Figure 3.4.3.13

Figures 3.4.3.14 through 3.4.3.22 show the average exit velocities per aircraft class. These velocities vary from aircraft class to aircraft class but the variation is not consistent and no conclusions can be drawn in favor of one class or another.

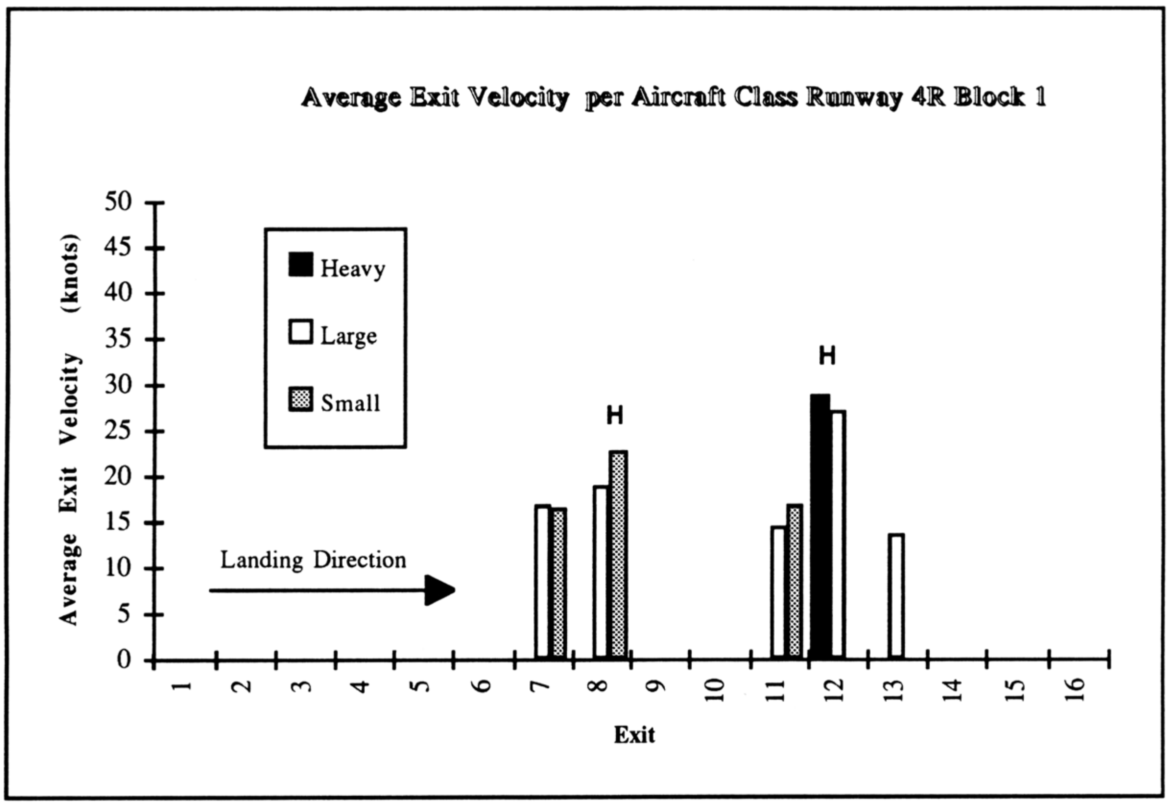
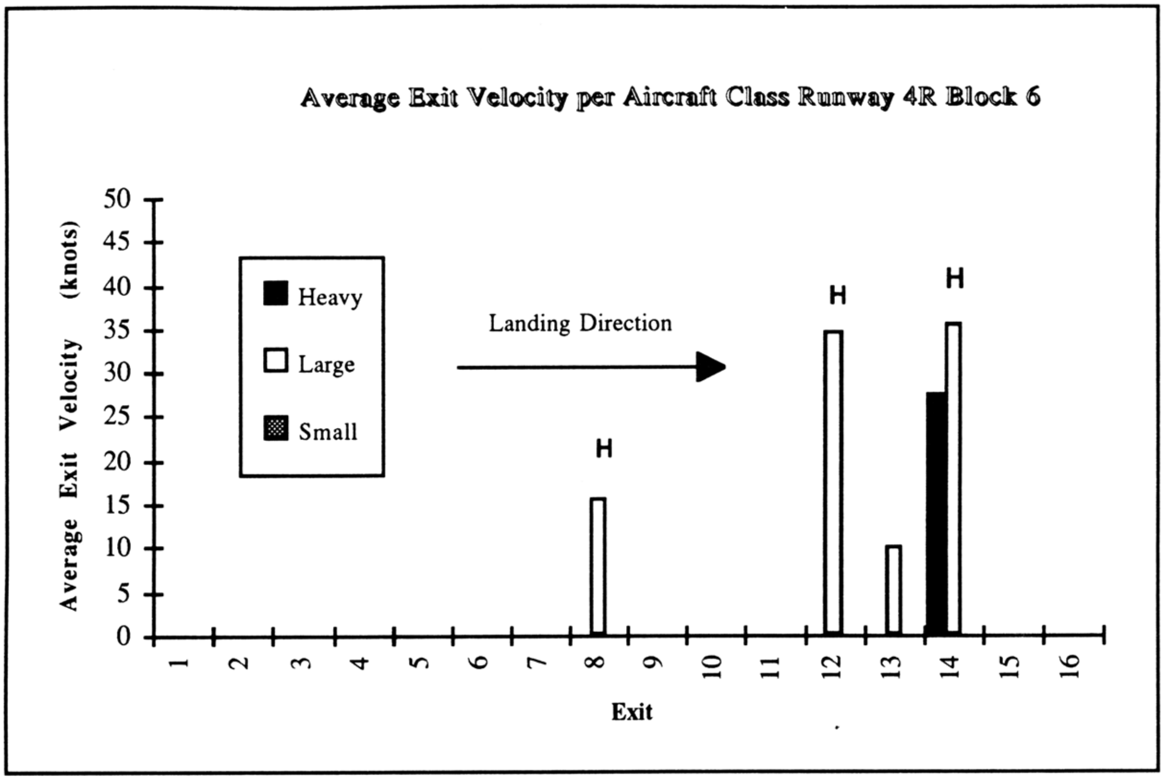


Figure 3.4.3.14



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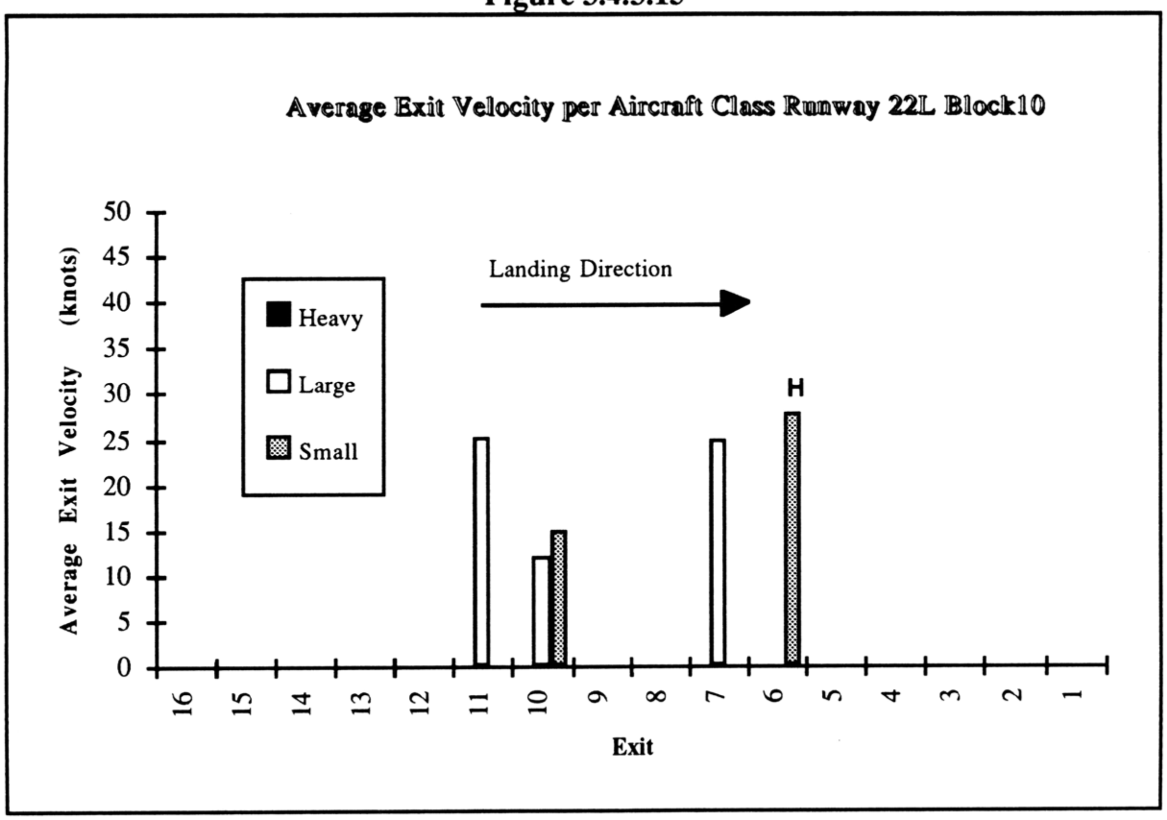


Figure 3.4.3.16

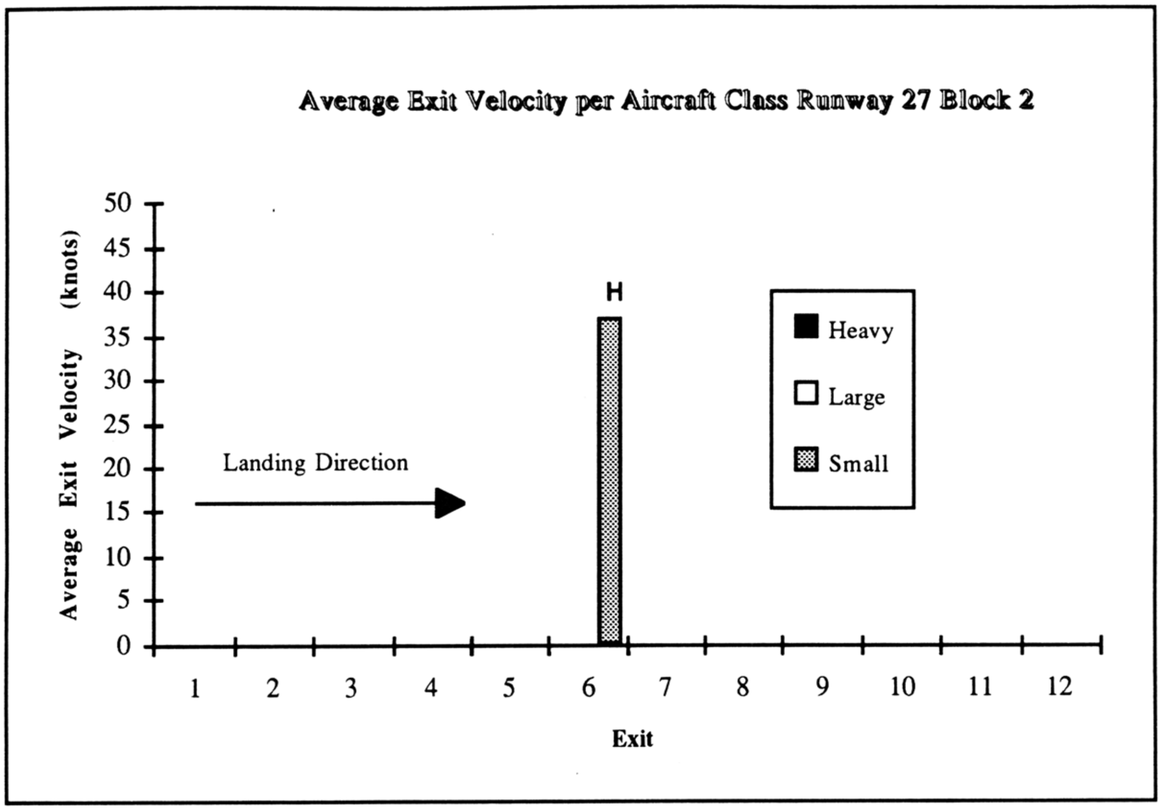


Figure 3.4.3.17

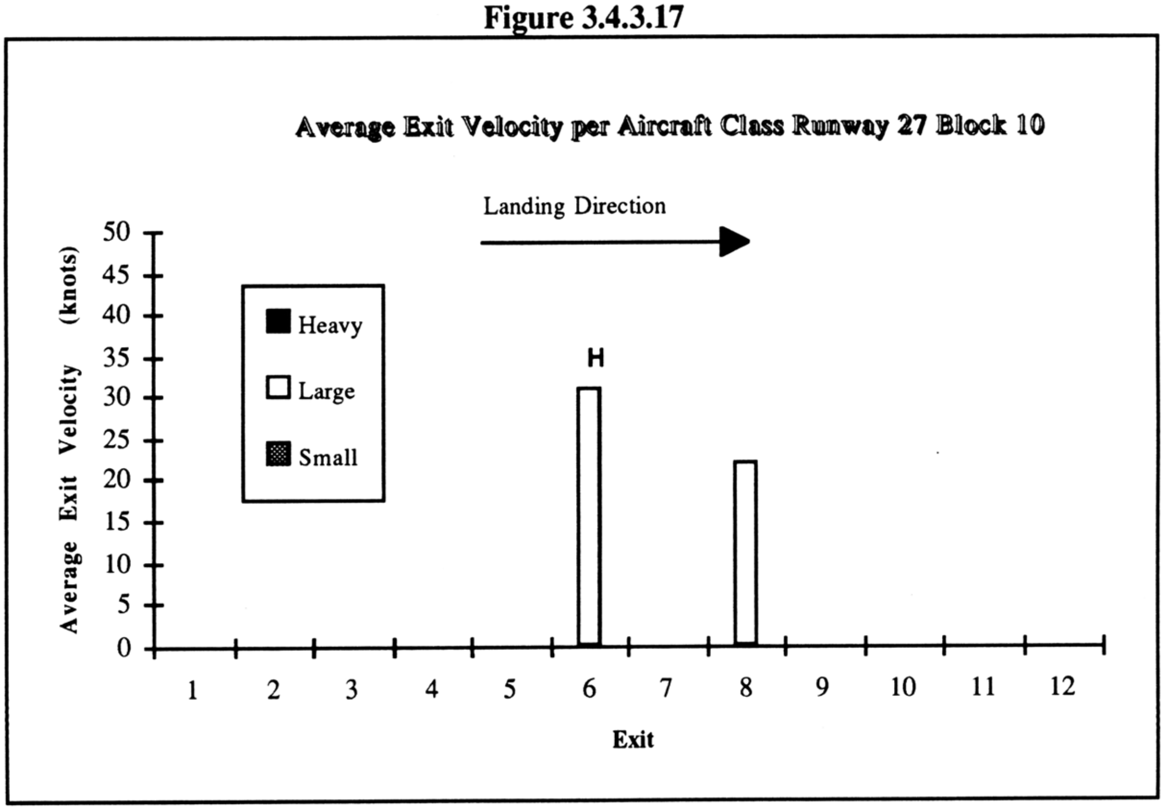


Figure 3.4.3.18

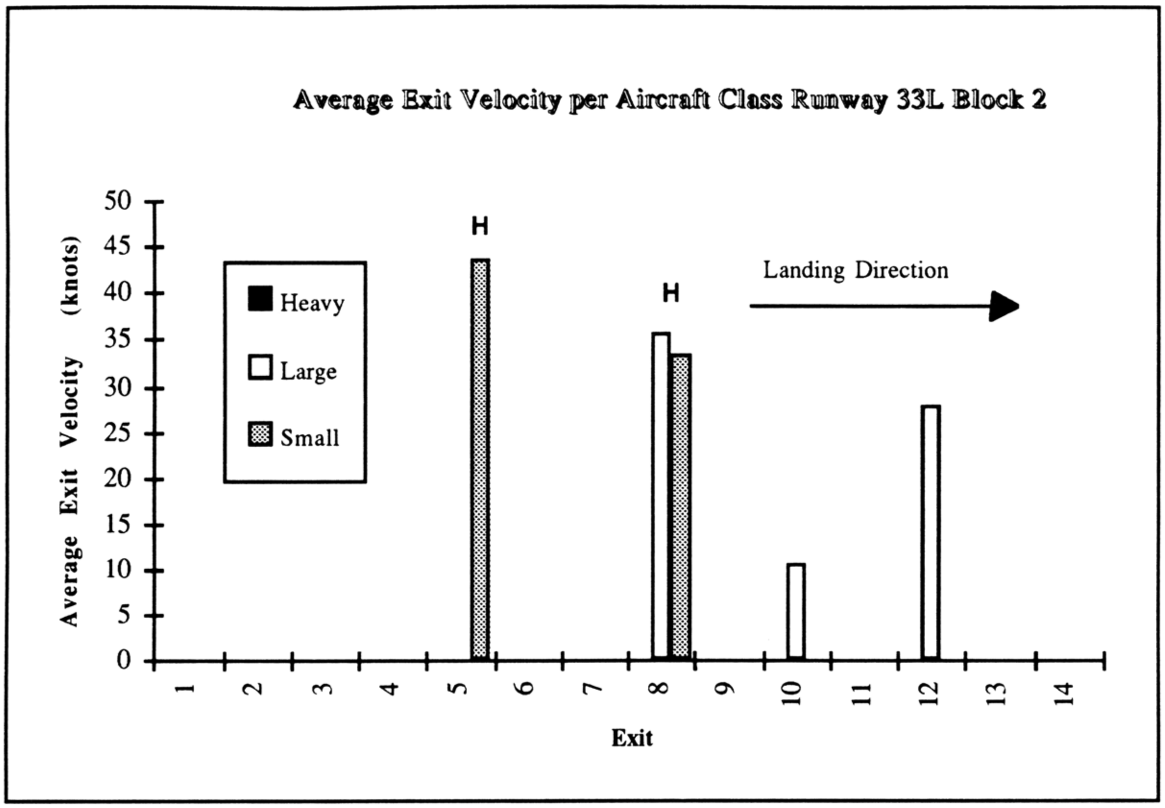
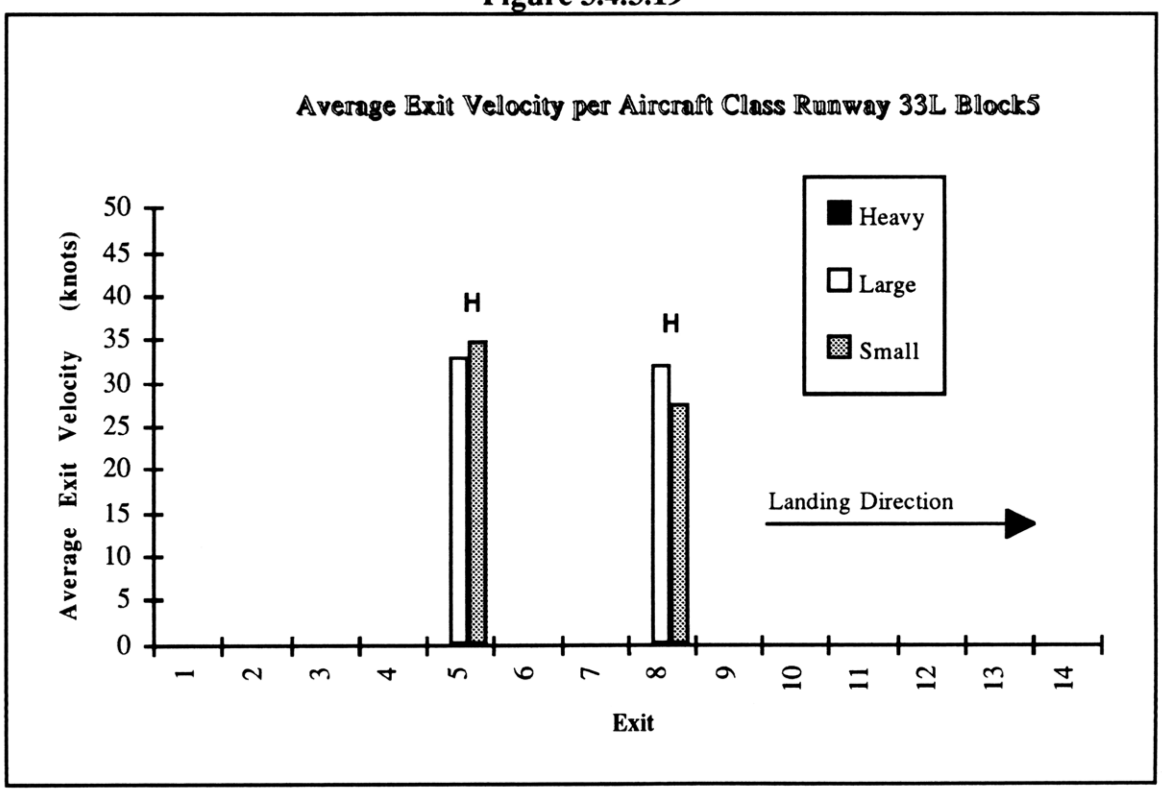


Figure 3.4.3.19



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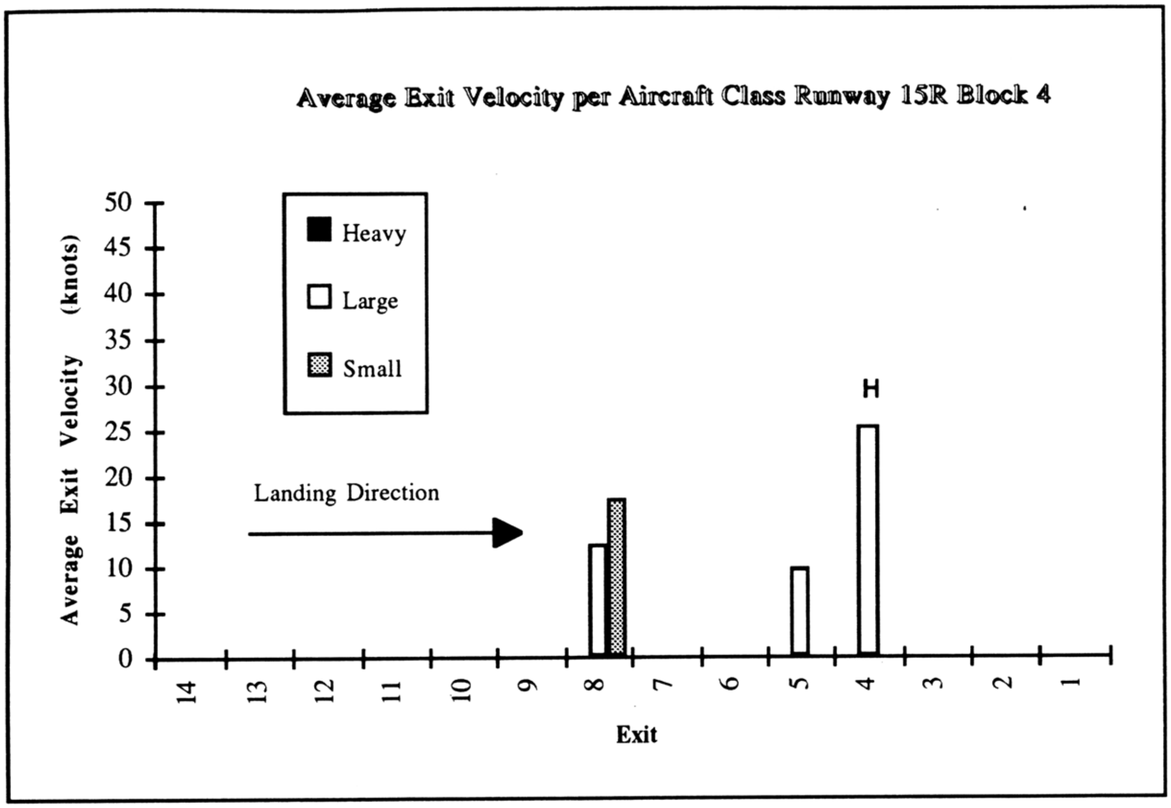


Figure 3.4.3.21

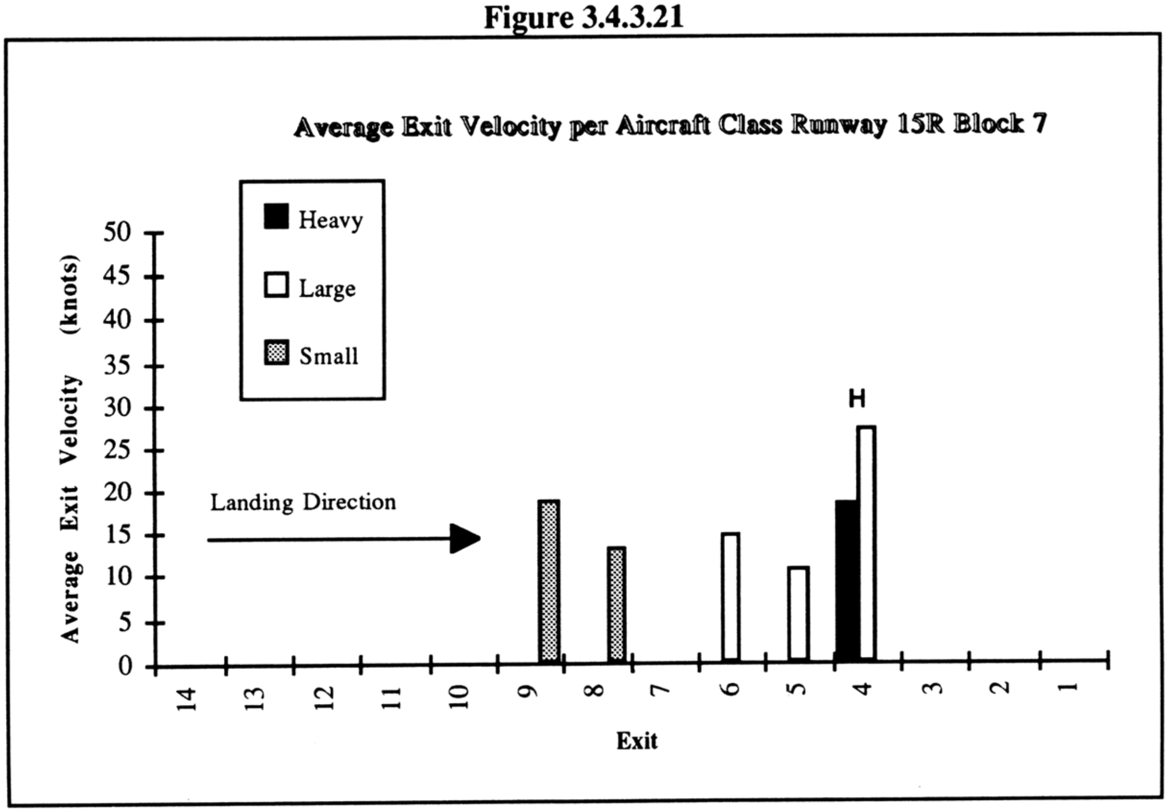


Figure 3.4.3.22

3.4.4 Velocity Profiles

3.4.4.1 Landing Velocity Profiles

Figures 3.4.4.1.1 through 3.4.4.1.13 show the landing profiles of all aircraft that landed in each runway. The aircraft that used a particular exit are grouped together. We can observe the different exit velocities and the higher or lower deceleration that occur, depending on the angle and the location of each exit. We must note the fact that some aircraft actually speed up after the runway threshold.

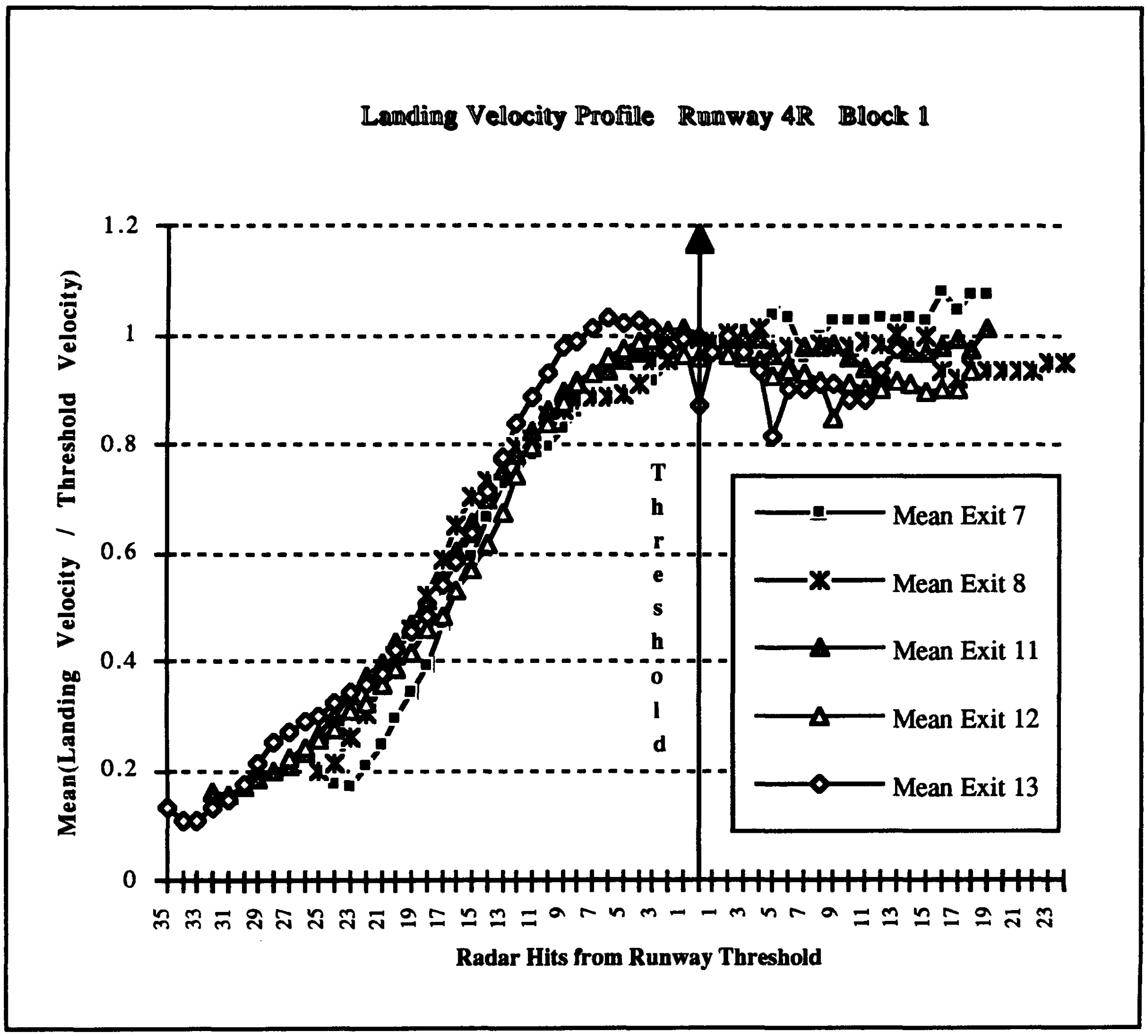
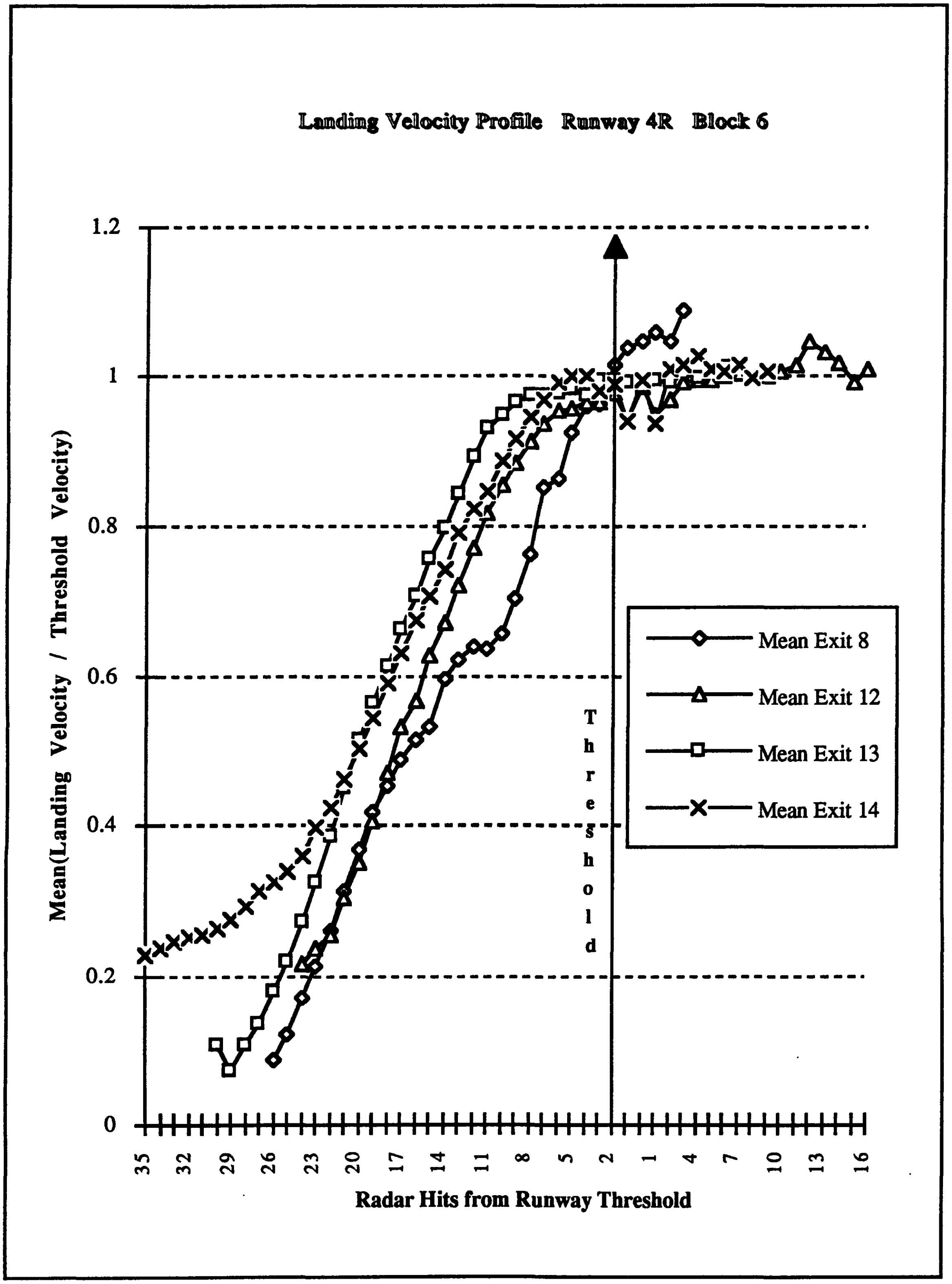


Figure 3.4.4.1.1



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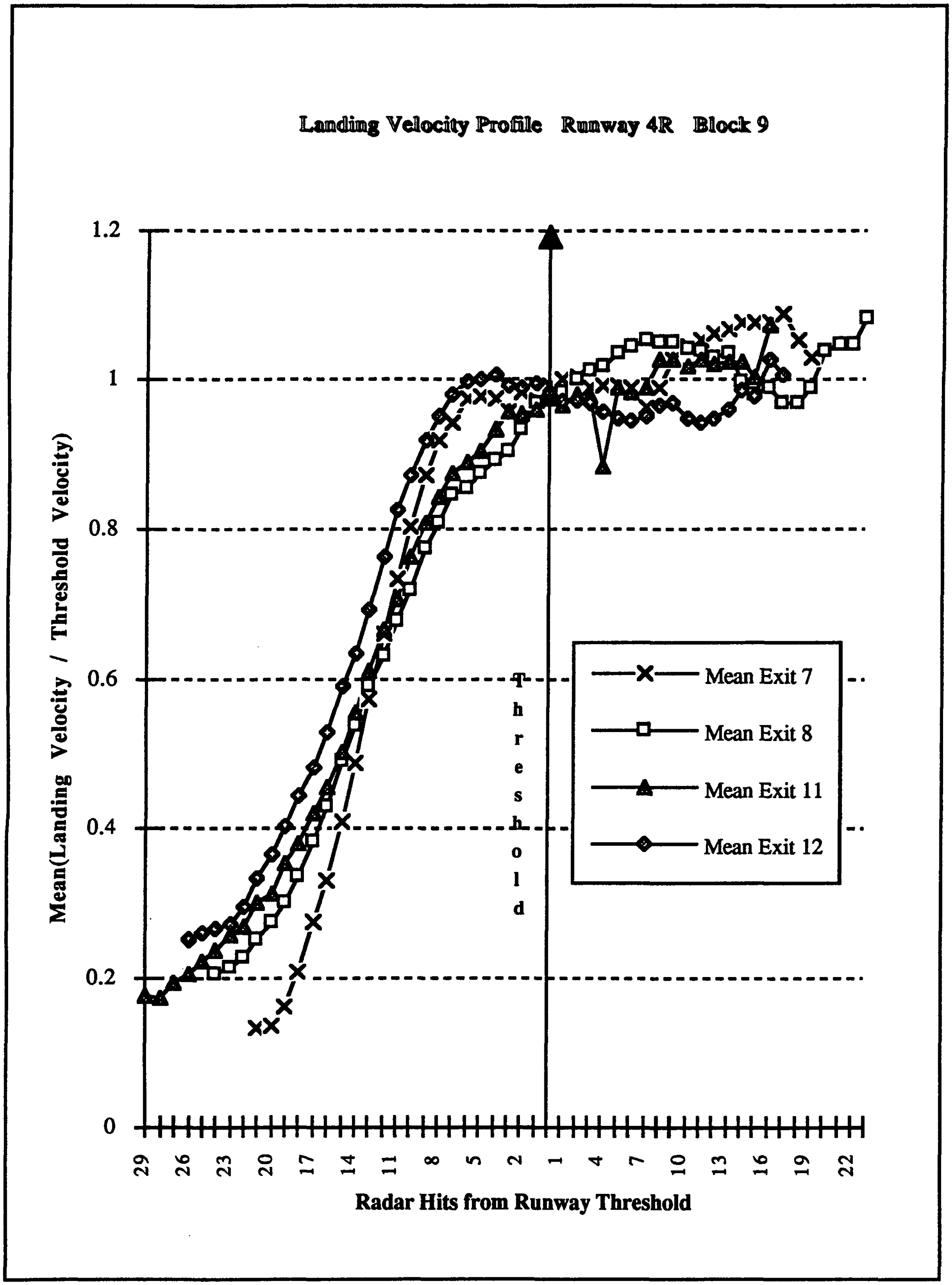


Figure 3.4.4.1.3

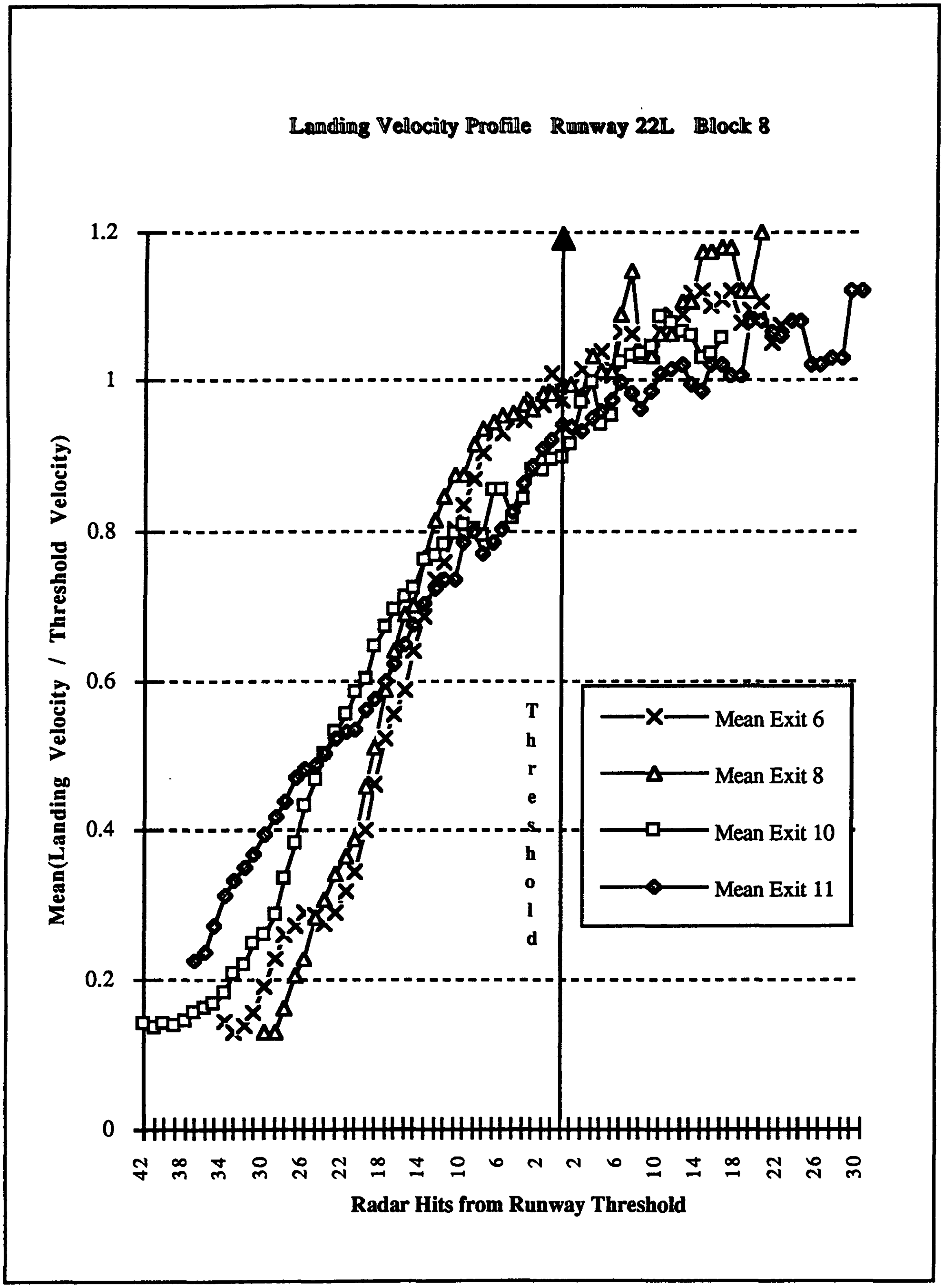


Figure 3.4.4.1.4

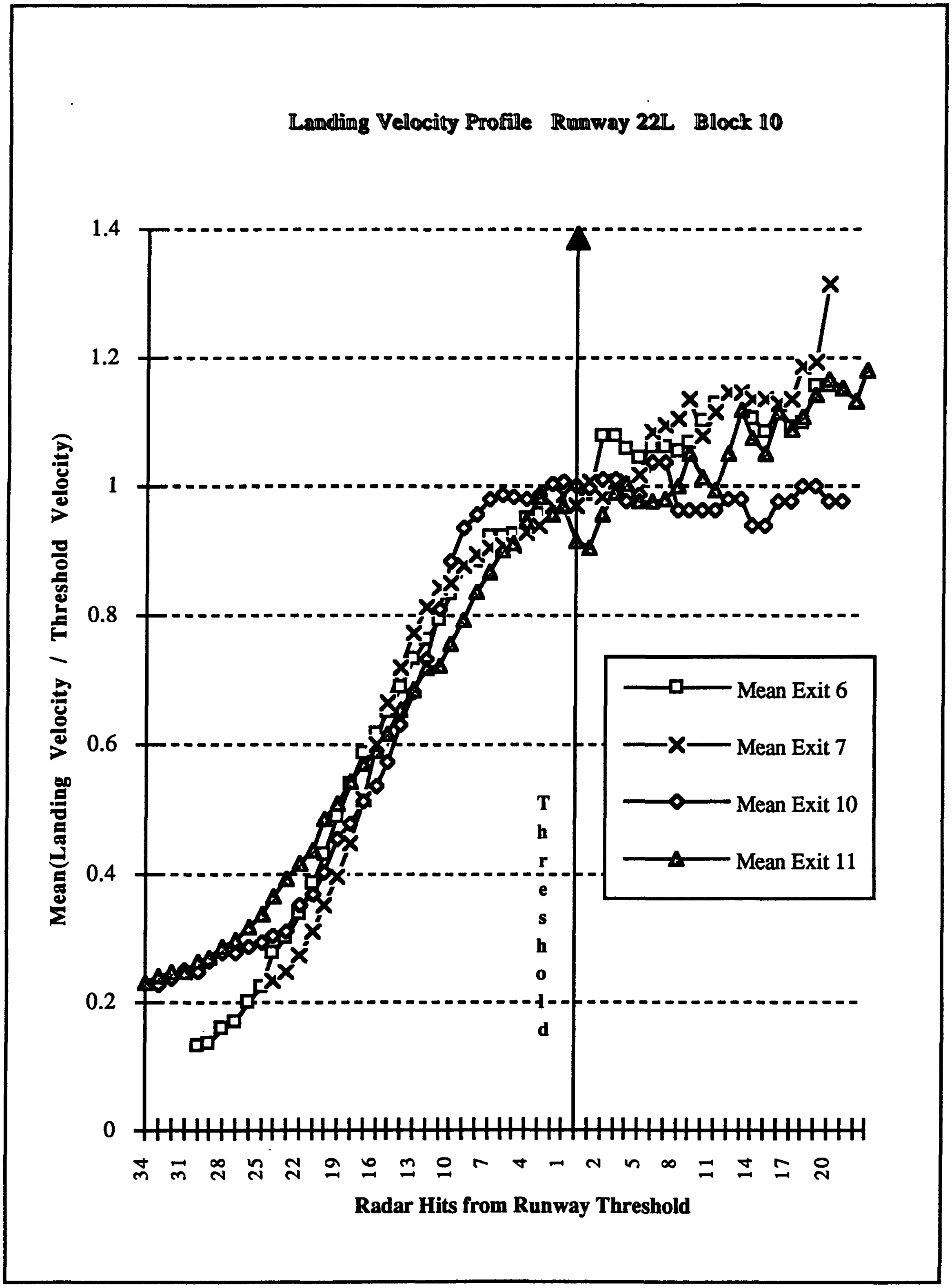


Figure 3.4.4.1.5

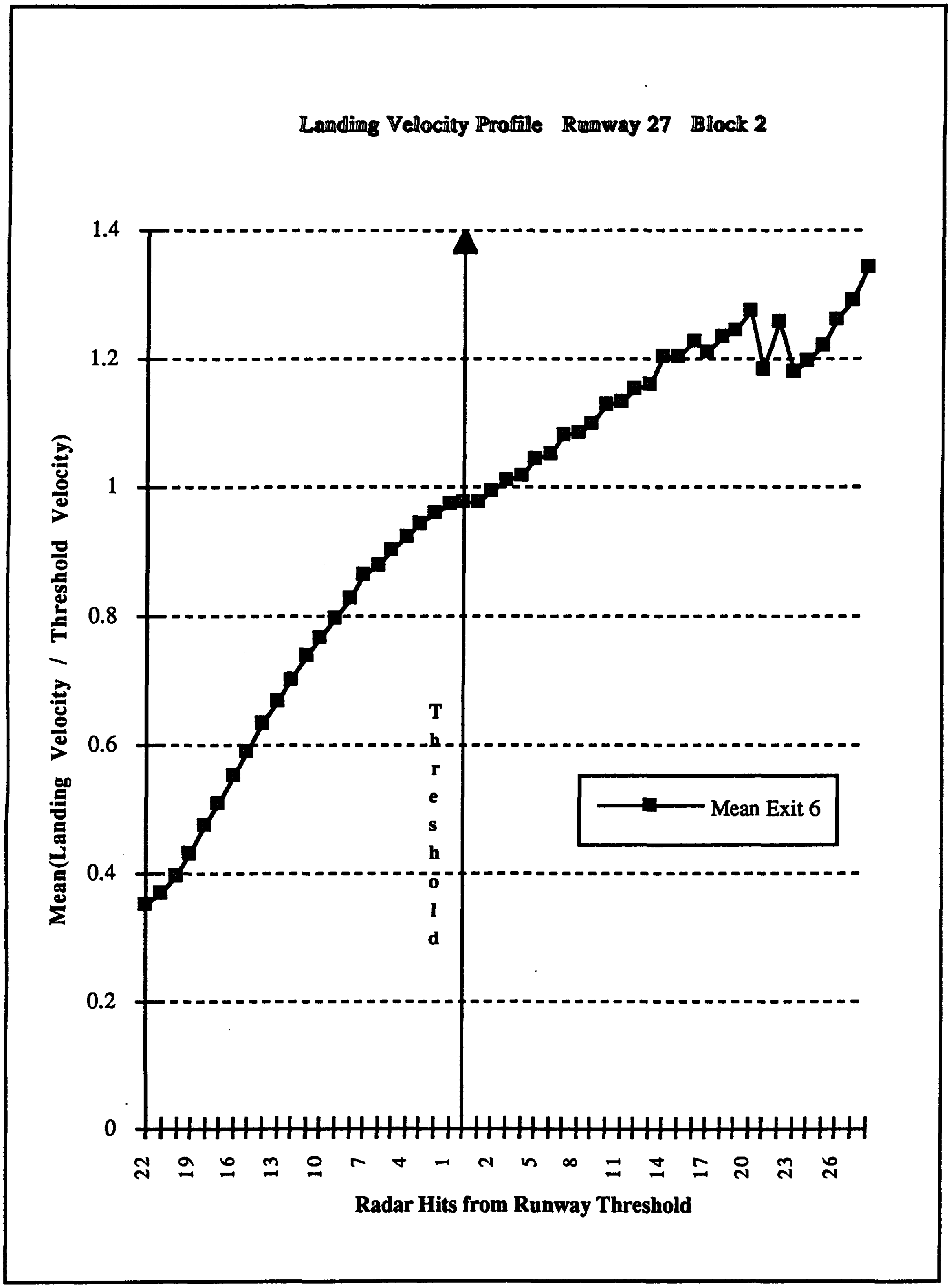


Figure 3.4.4.1.6

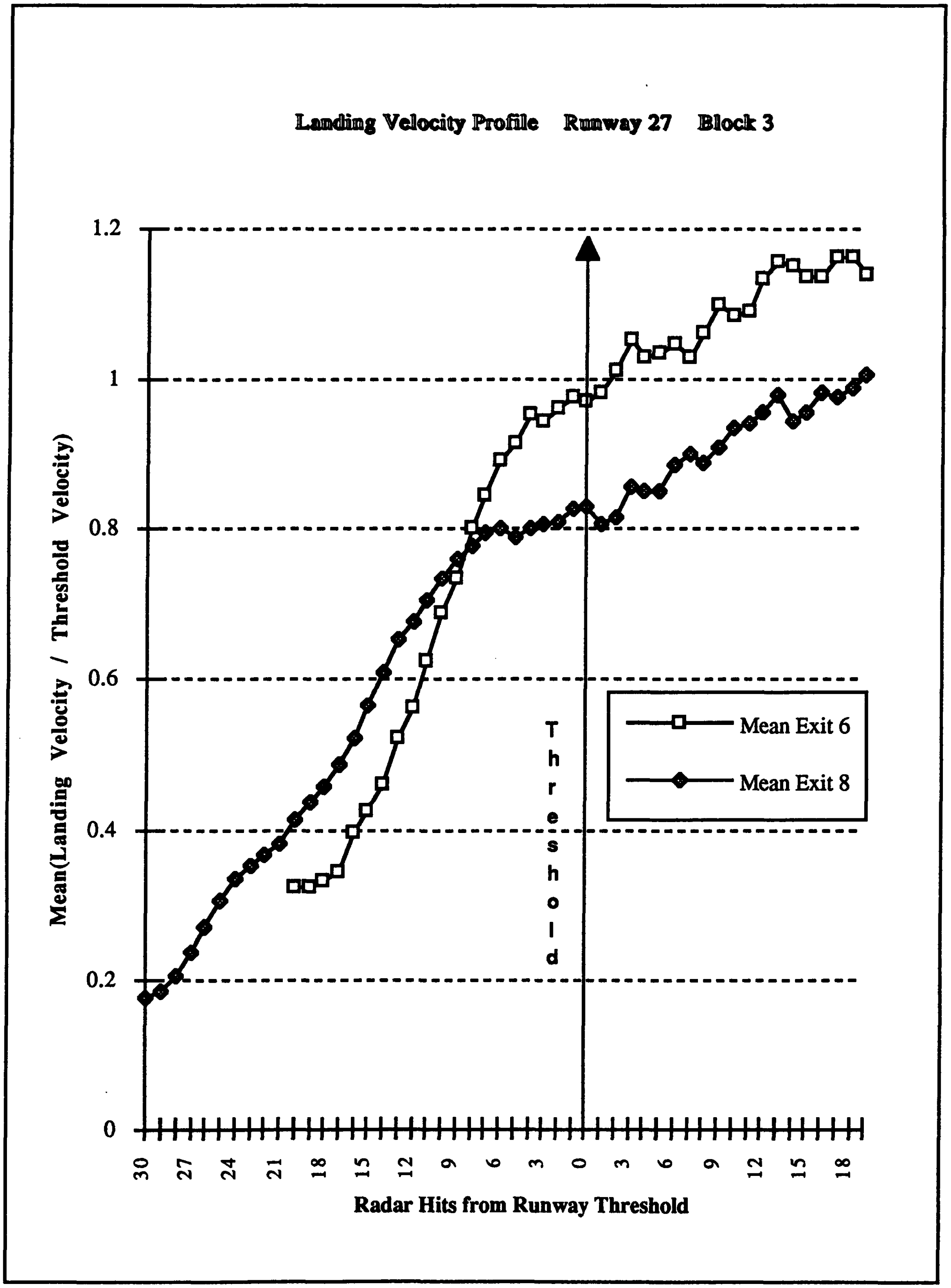


Figure 3.4.4.1.7

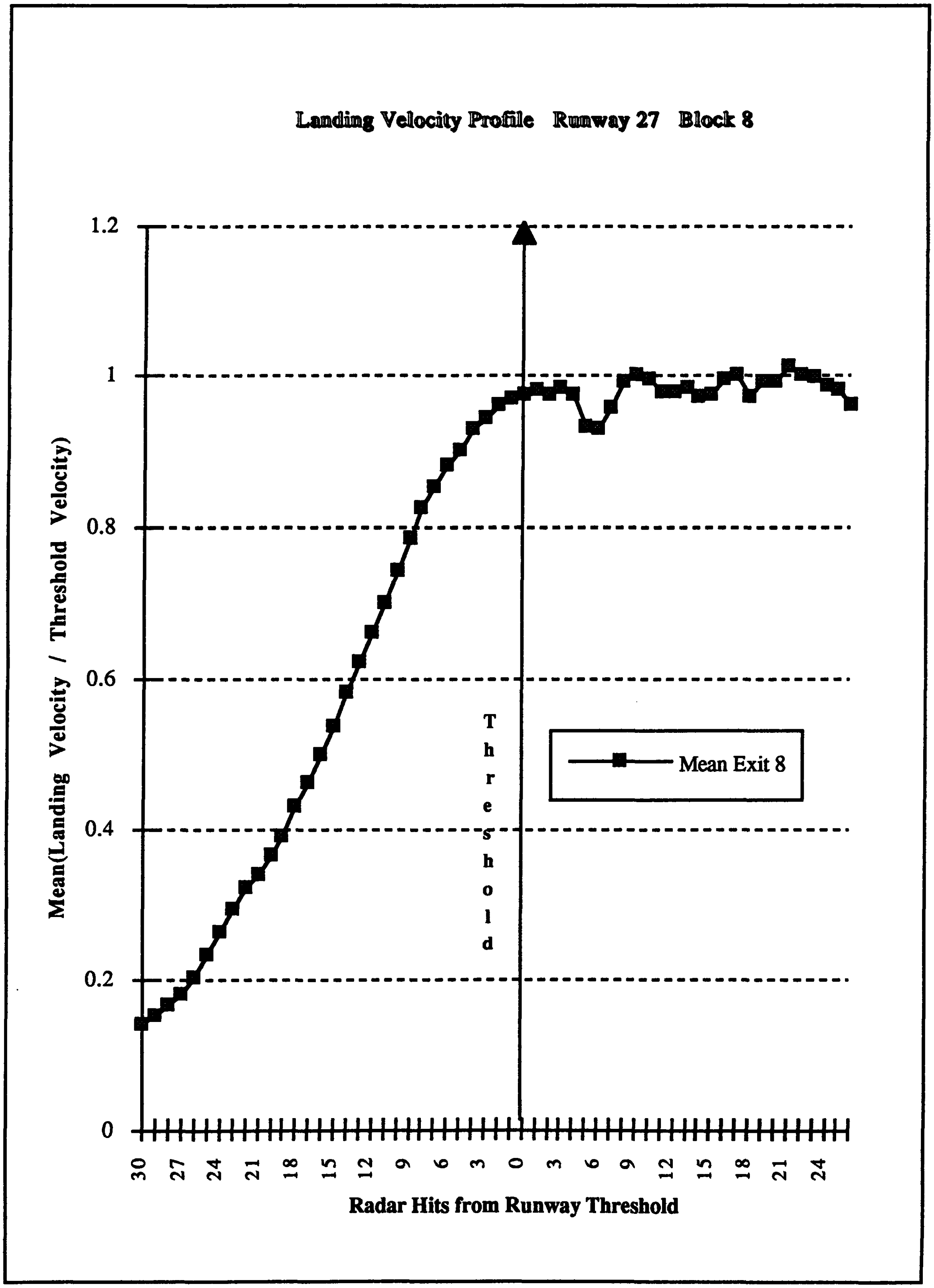


Figure 3.4.4.1.8

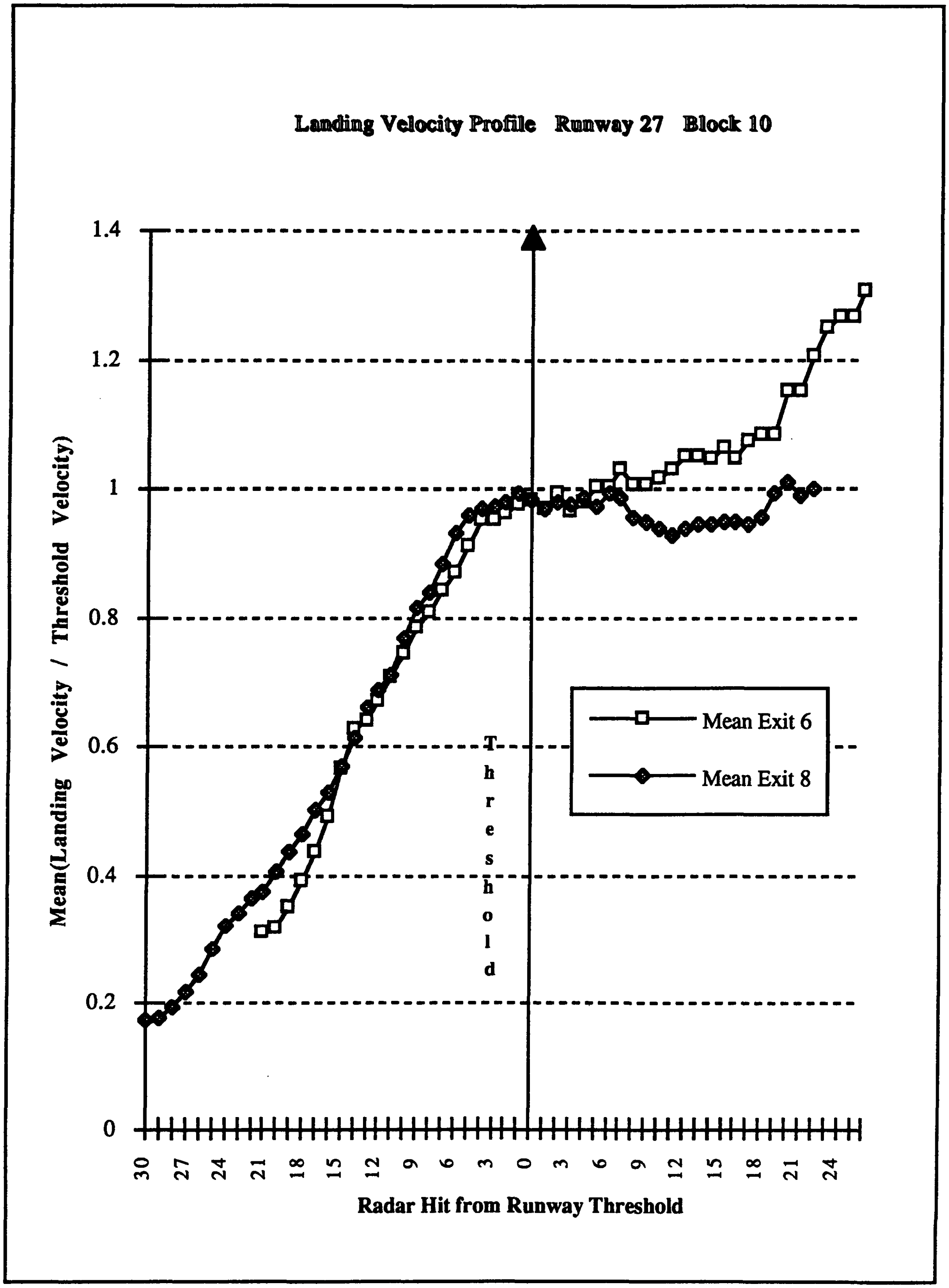


Figure 3.4.4.1.9

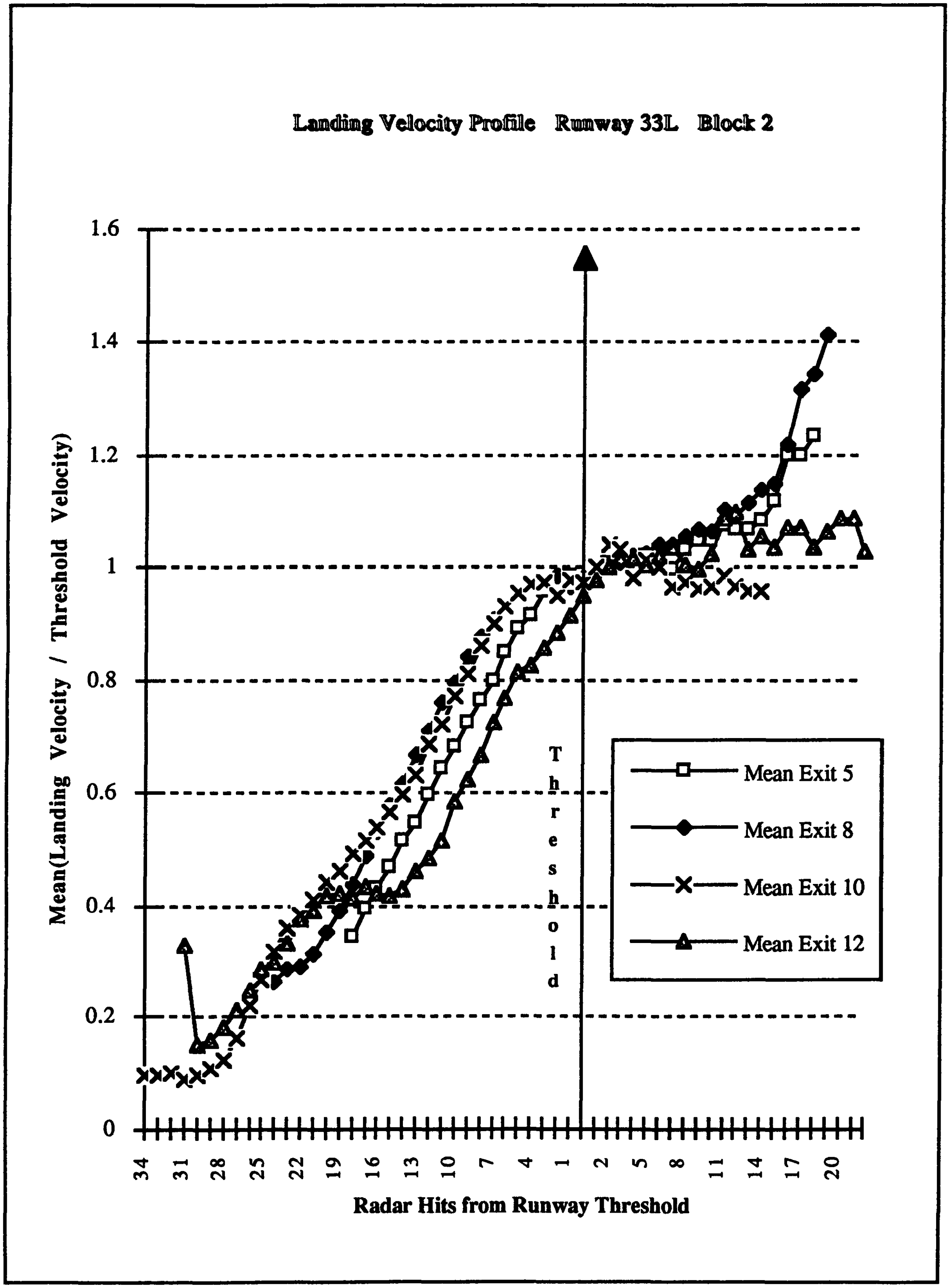


Figure 3.4.4.1.10

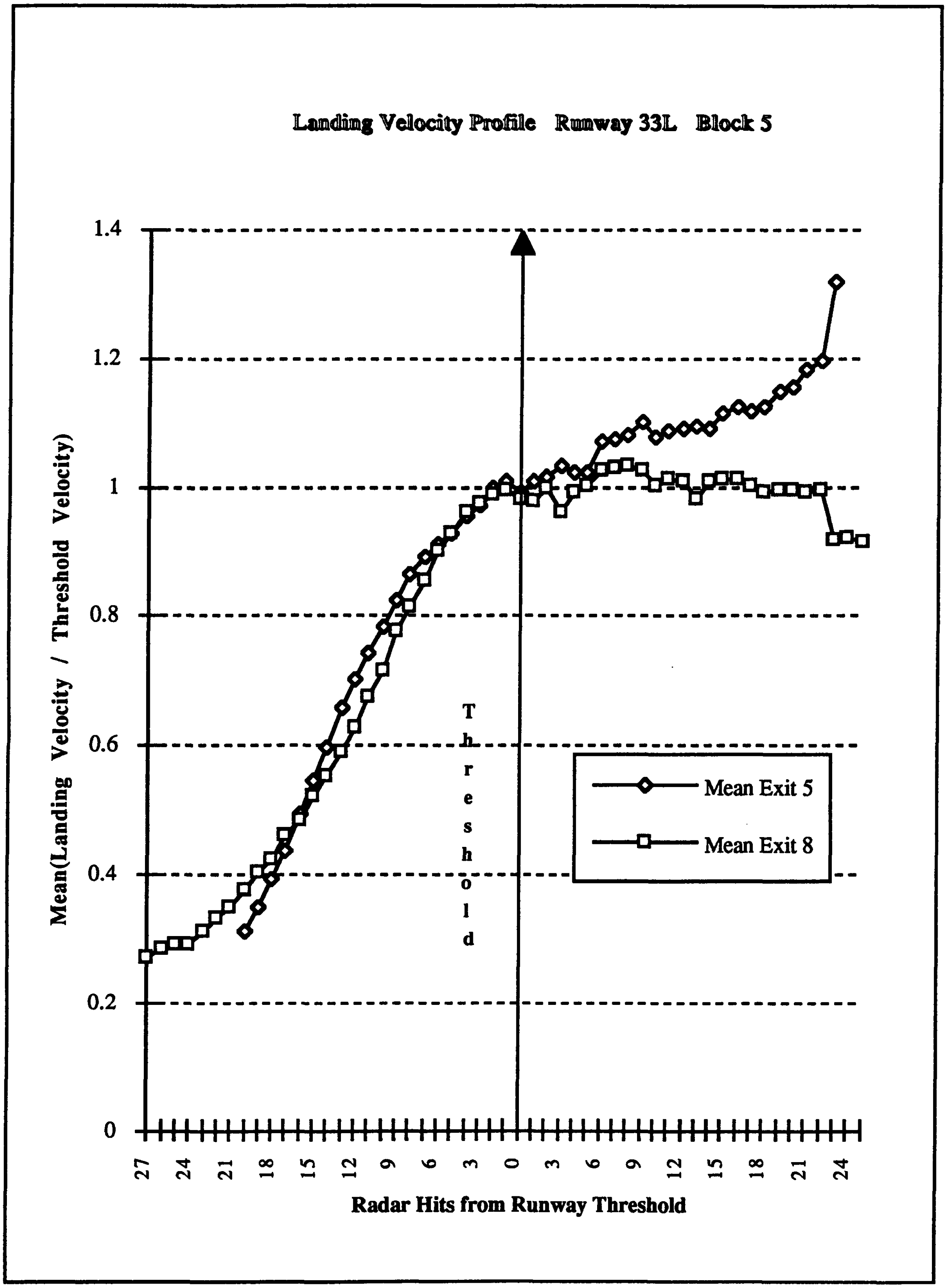


Figure 3.4.4.1.11

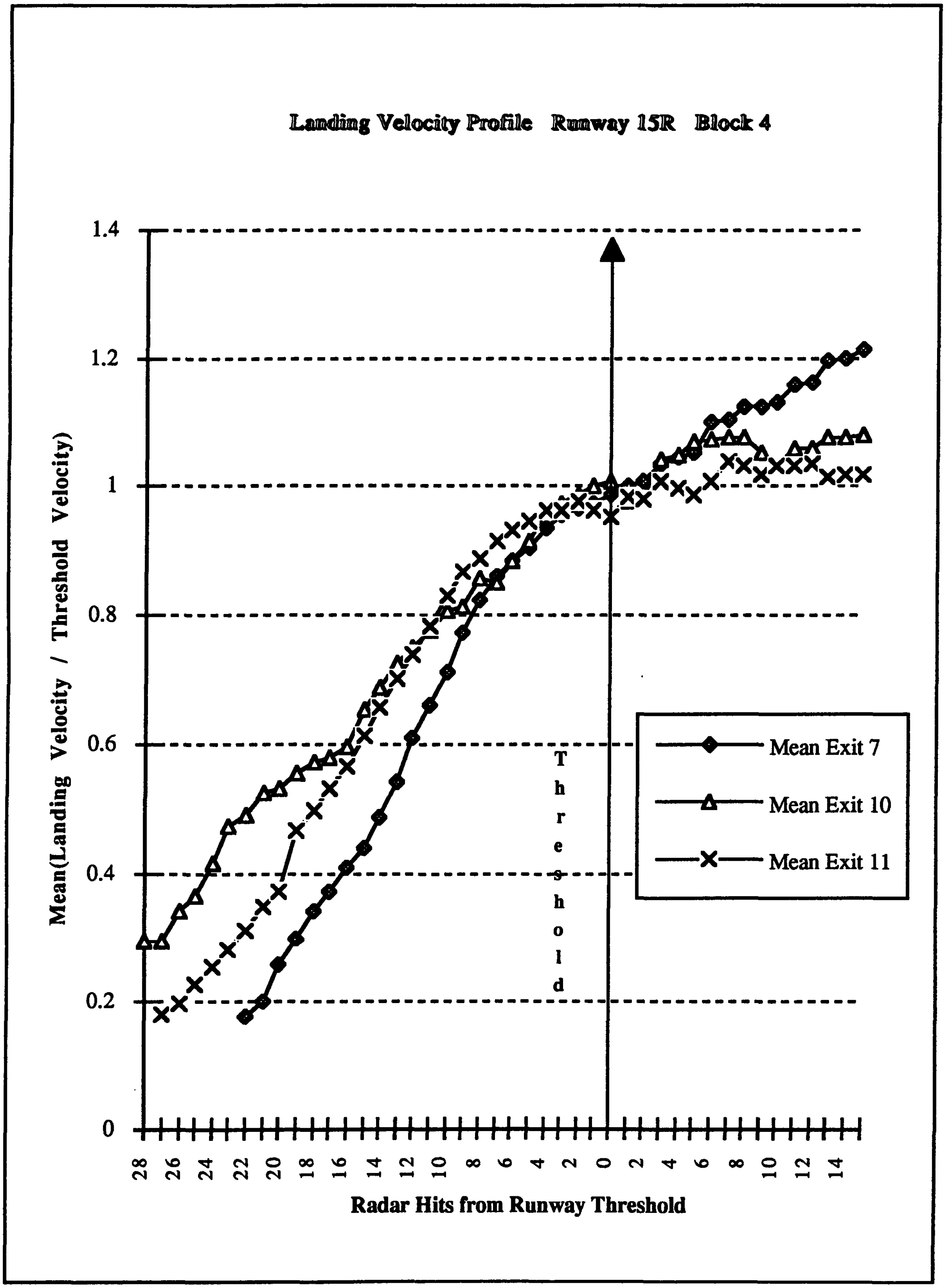


Figure 3.4.4.1.12

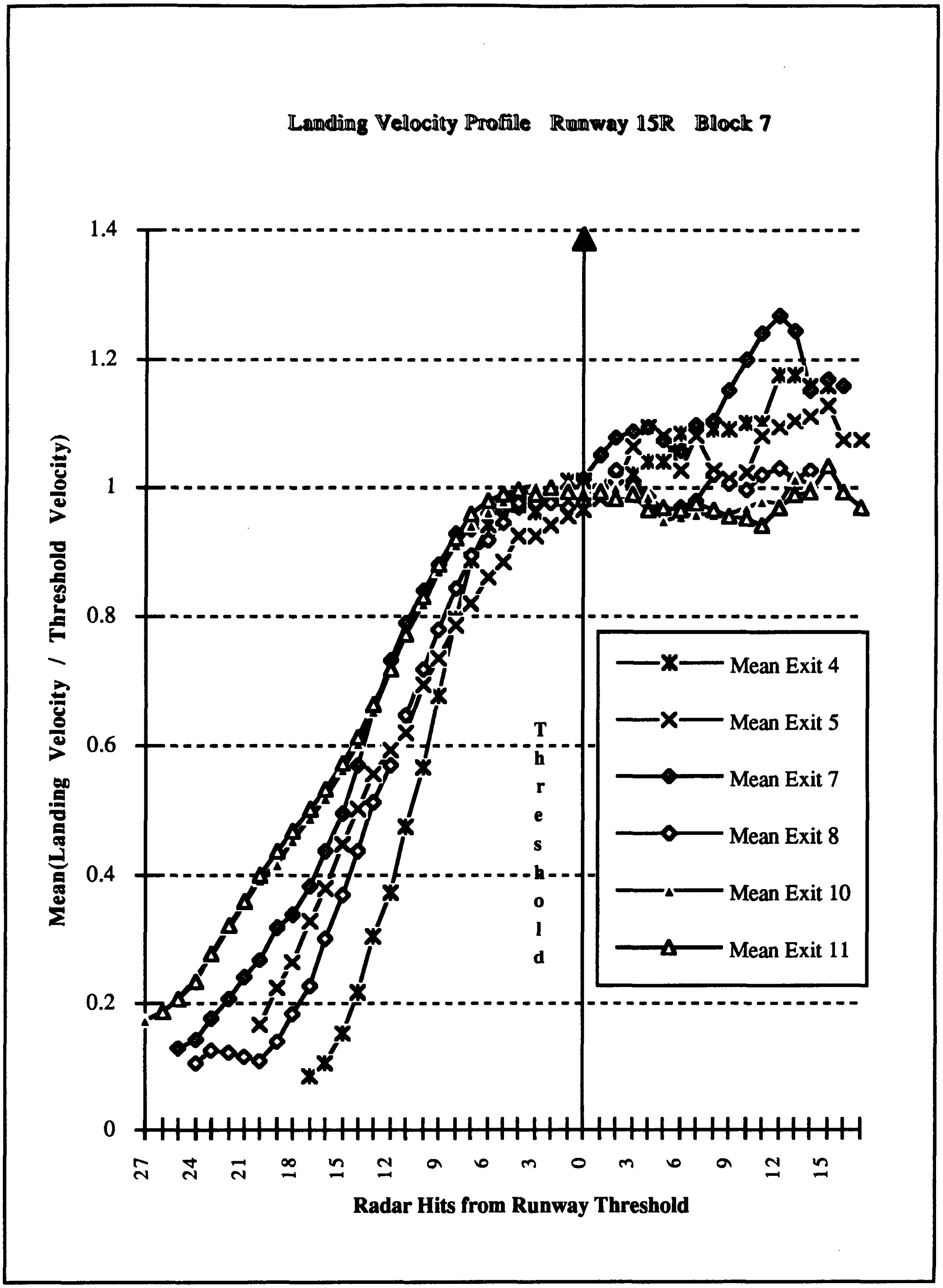


Figure 3.4.4.1.13

3.4.4.2 Final Approach Velocity Profiles

In the final approach velocity profile figures (3.4.4.2.1 through 3.4.4.2.13) we observe that in most runways, there is a small deceleration during the final approach. In some runways, 27 in particular, this deceleration is quite significant (Figure 3.4.4.2.6). In the same runway, during night operations (Figure 3.4.4.2.8) we see much more smooth final approach velocity. In runway 15 R, we note that even under different weather conditions, aircraft seem to accelerate before the runway threshold.

Overall, the standard deviations of the landing velocities fall between a value of 0.2 for a period of approximately 10 radar hits before the threshold and from then on it increases significantly. This could be due to the changing size of the available number of data points (radar hits), as further away from the threshold some aircraft target are not picked up by the surface radar.

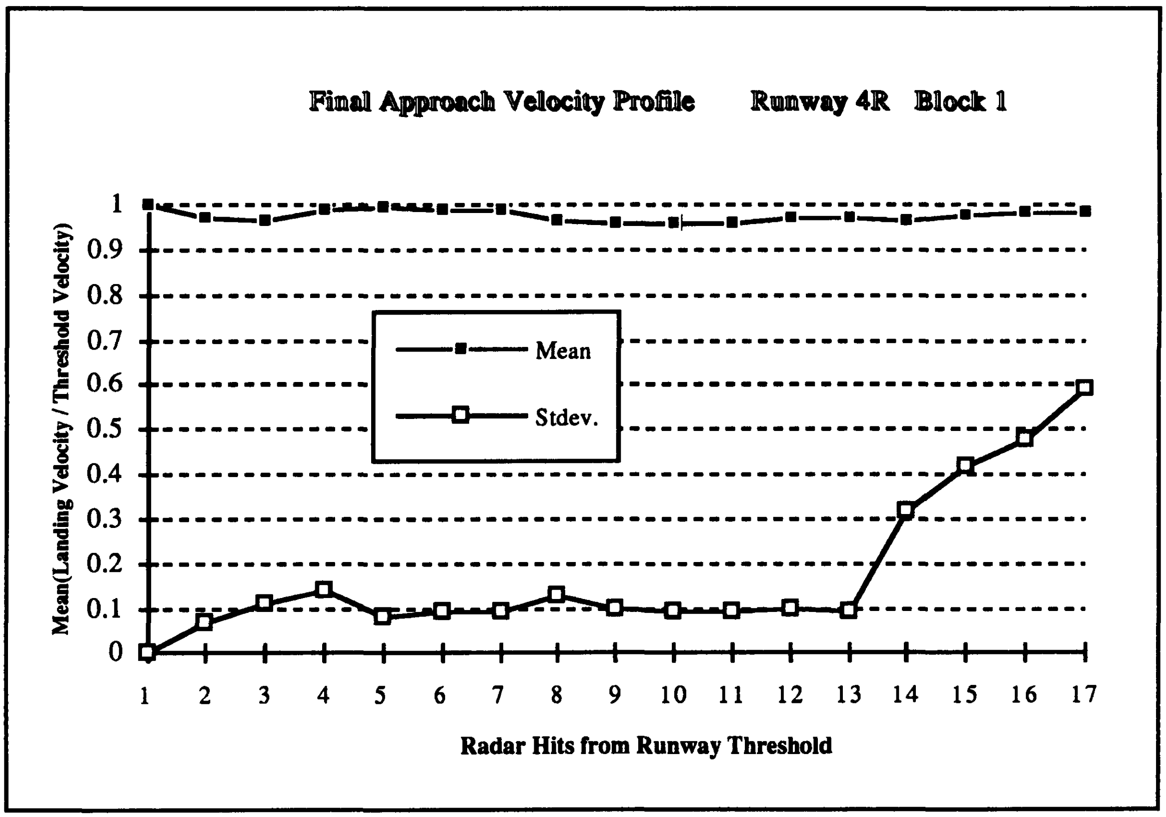


Figure 3.4.4.2.1

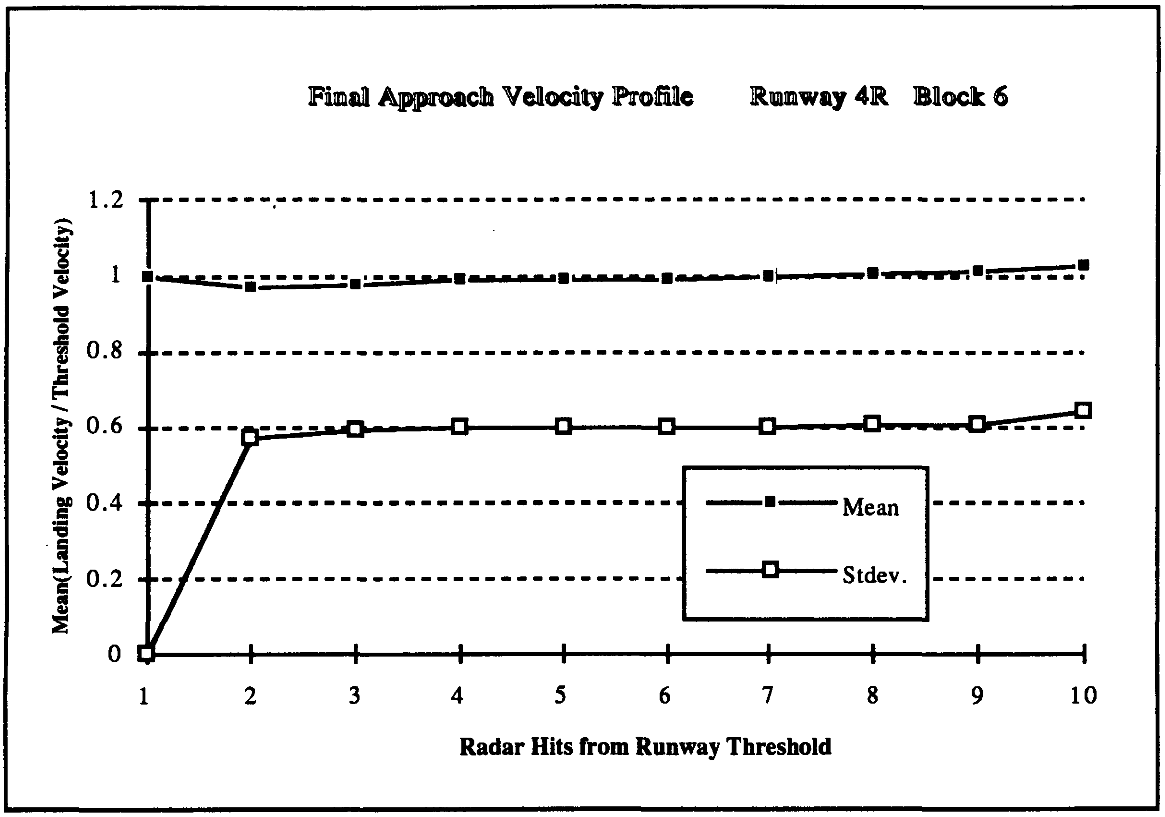


Figure 3.4.4.2.2

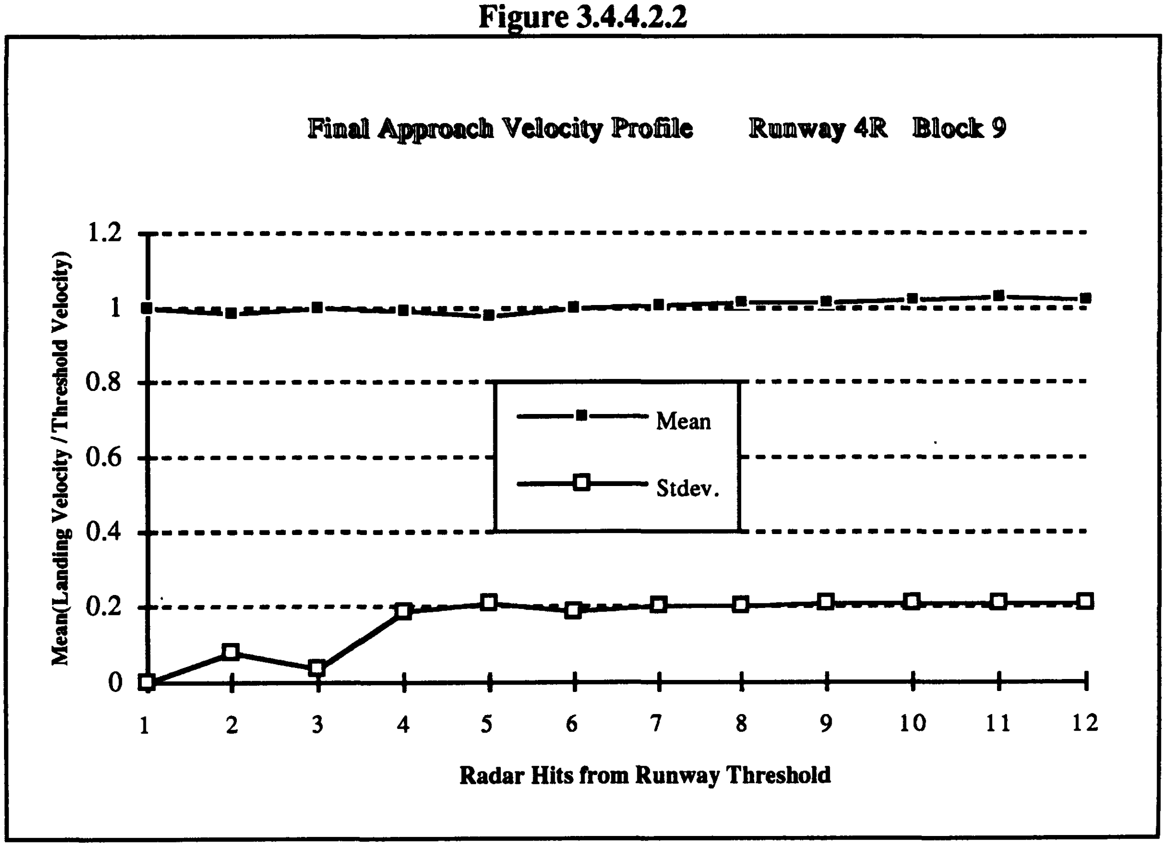


Figure 3.4.4.2.3

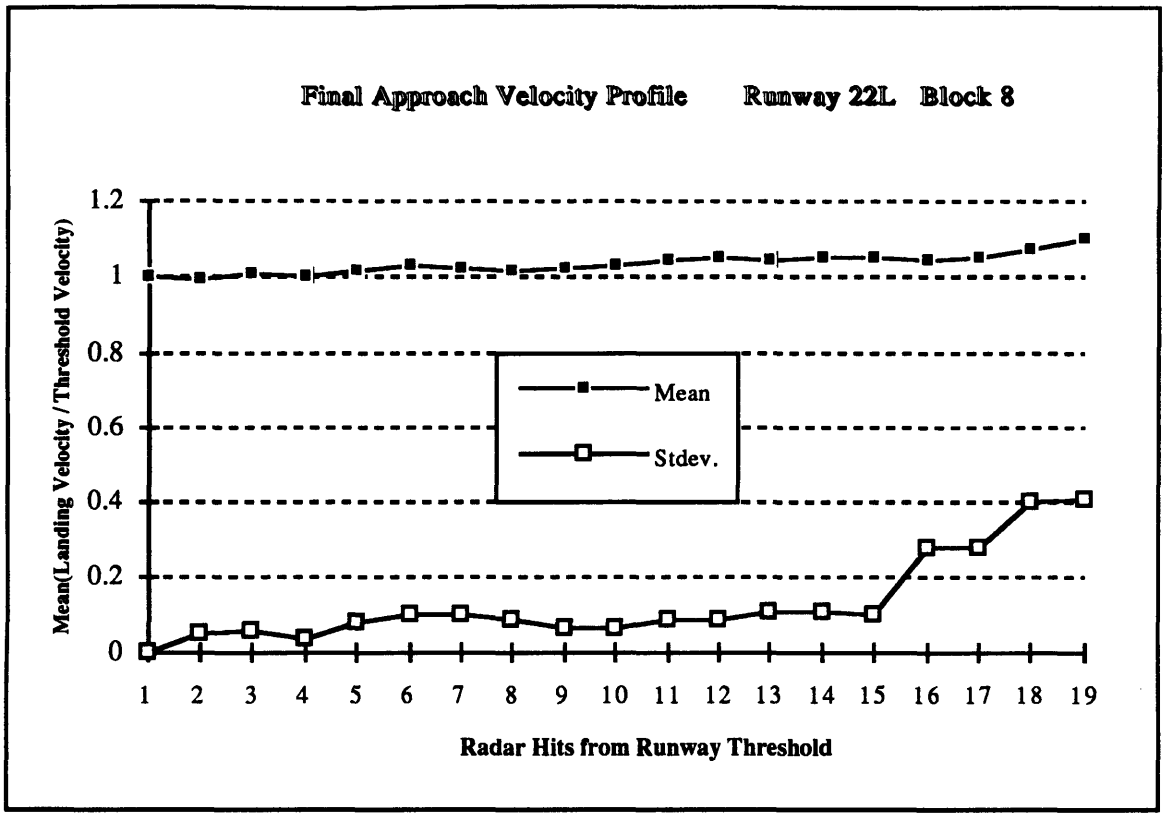


Figure 3.4.4.2.4

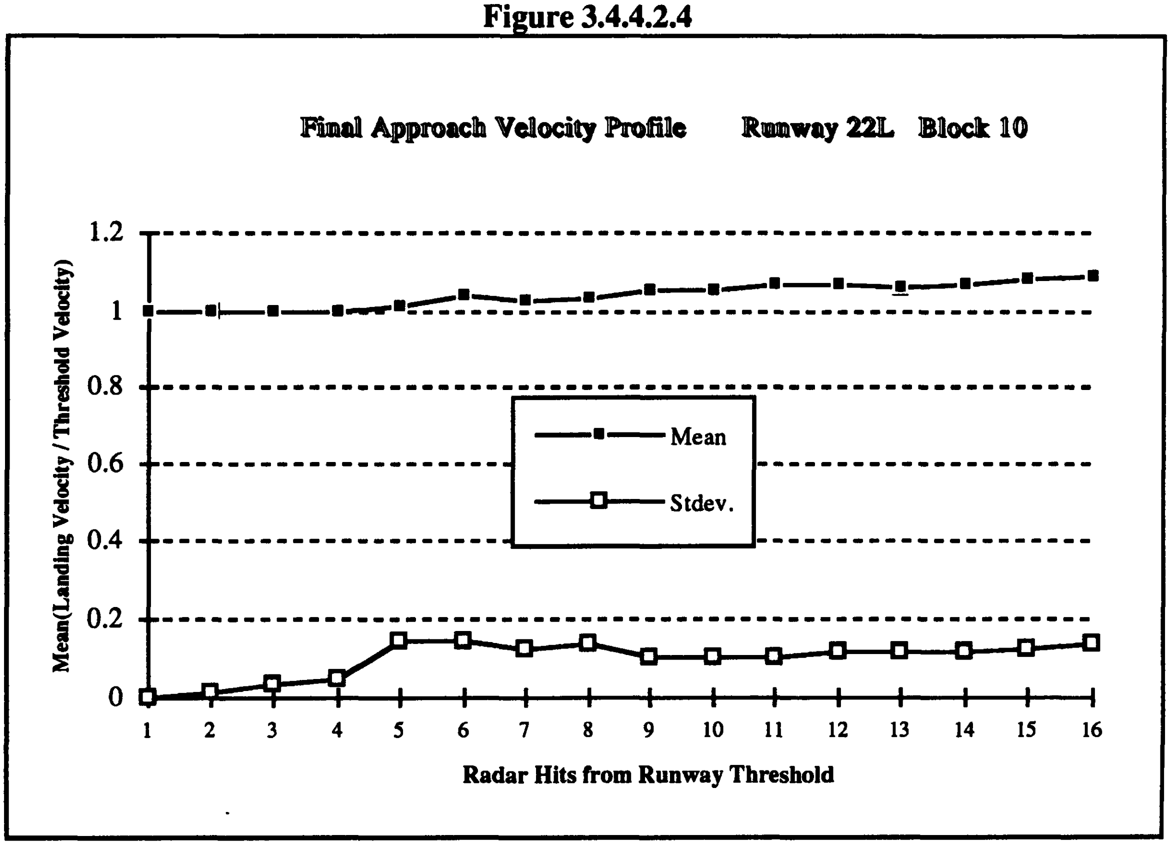
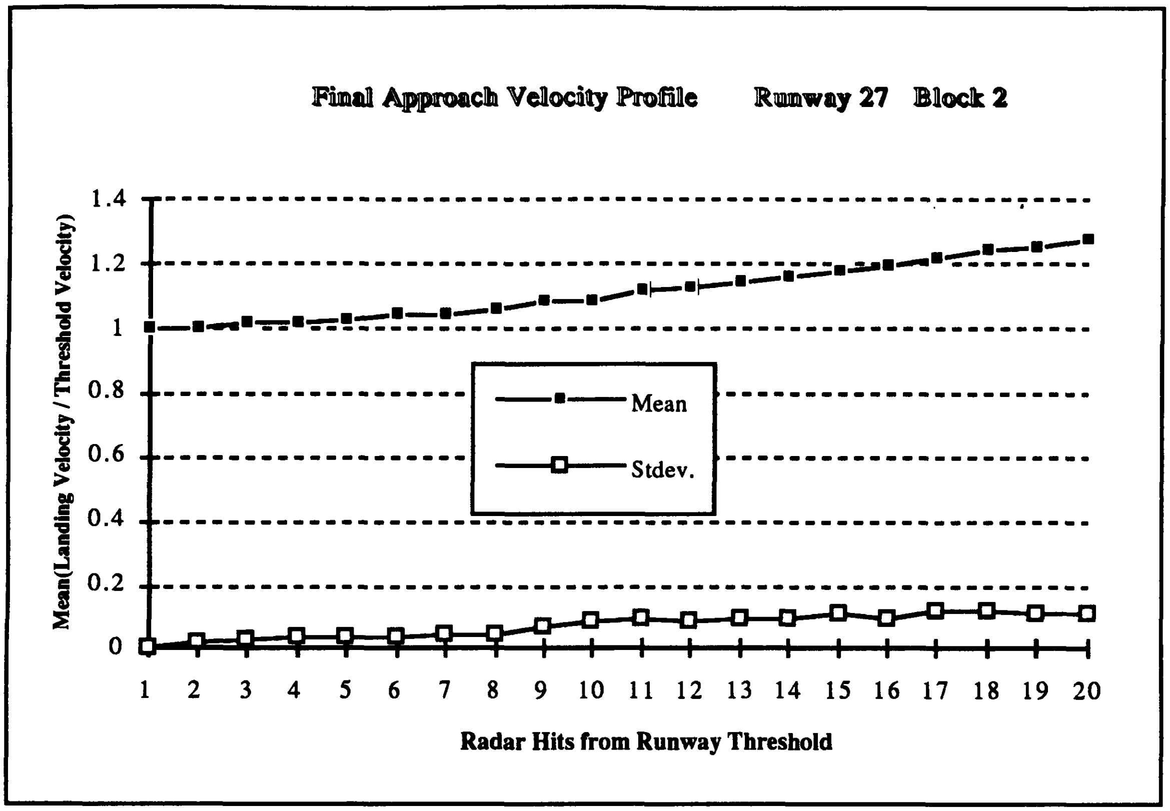


Figure 3.4.4.2.5



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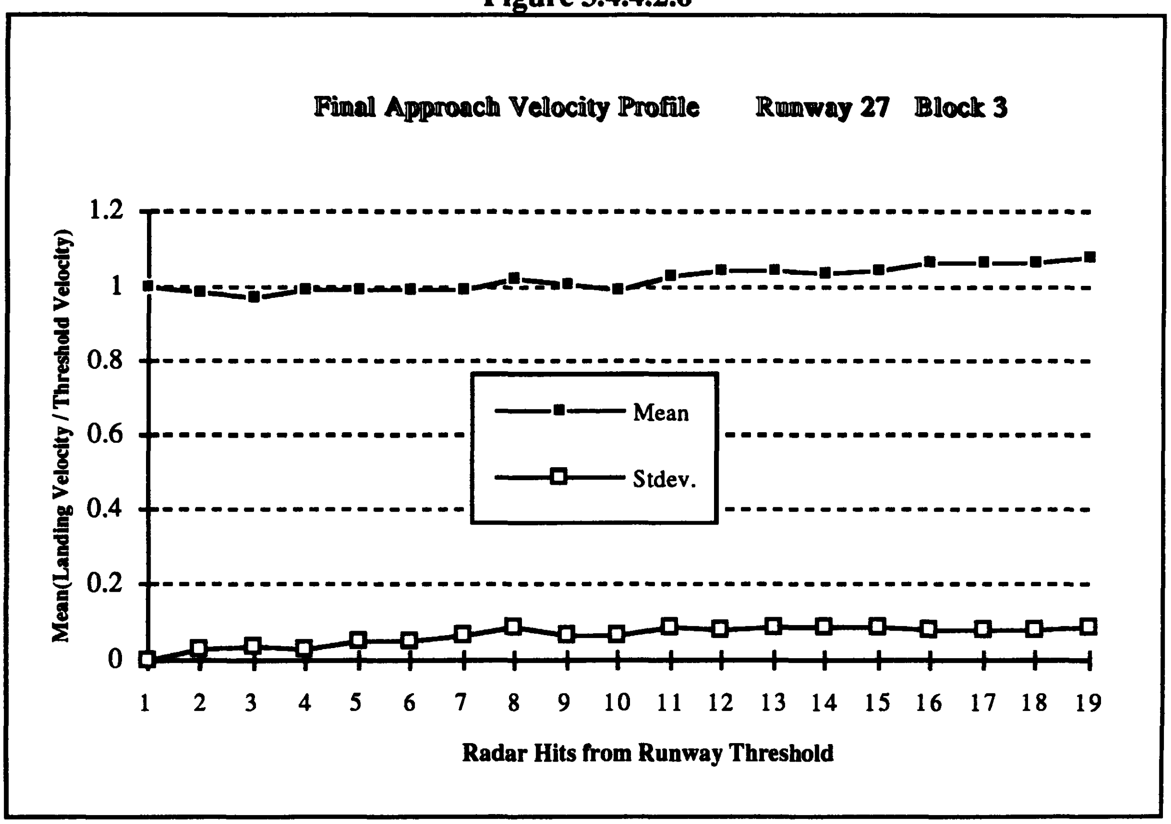
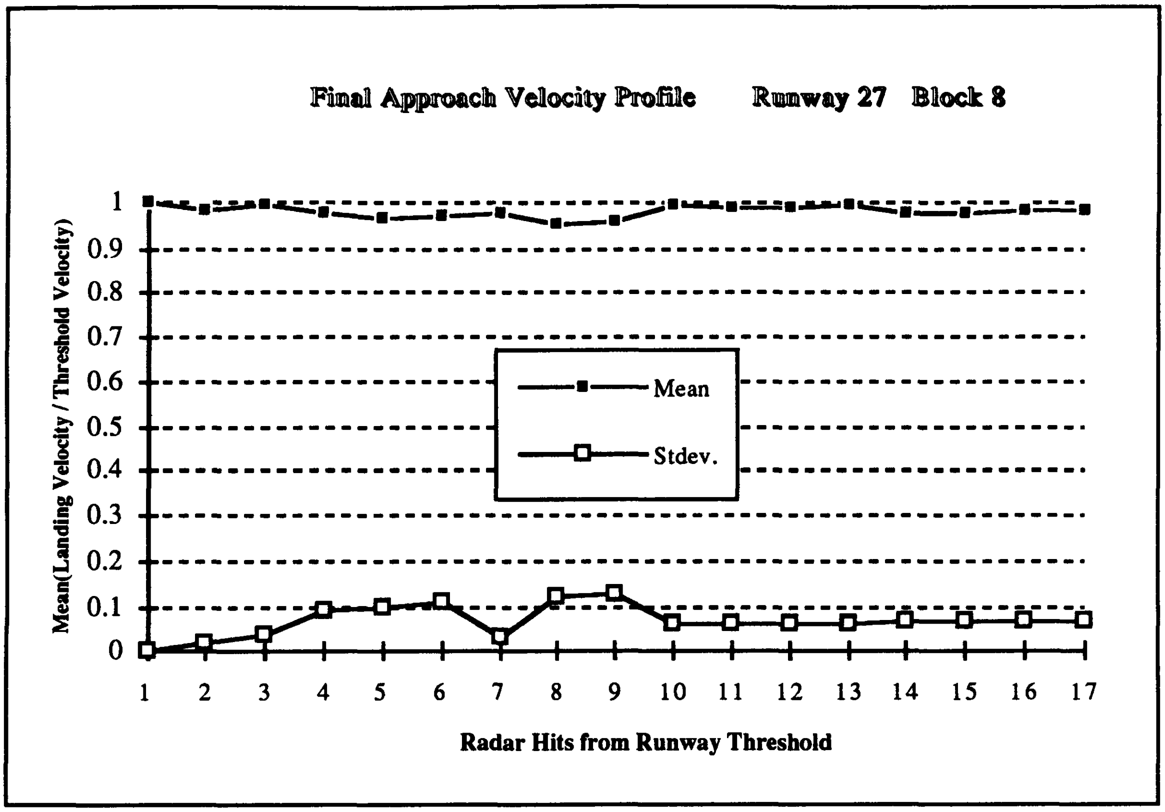


Figure 3.4.4.2.7



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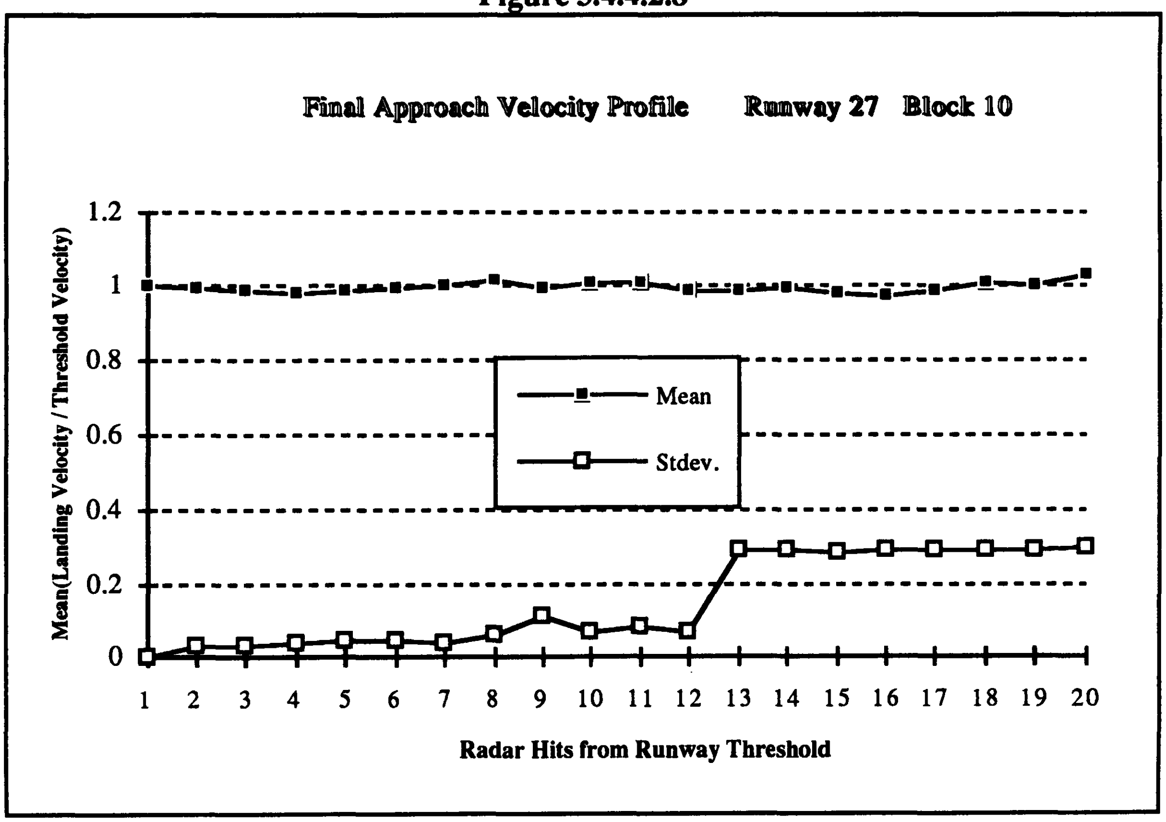

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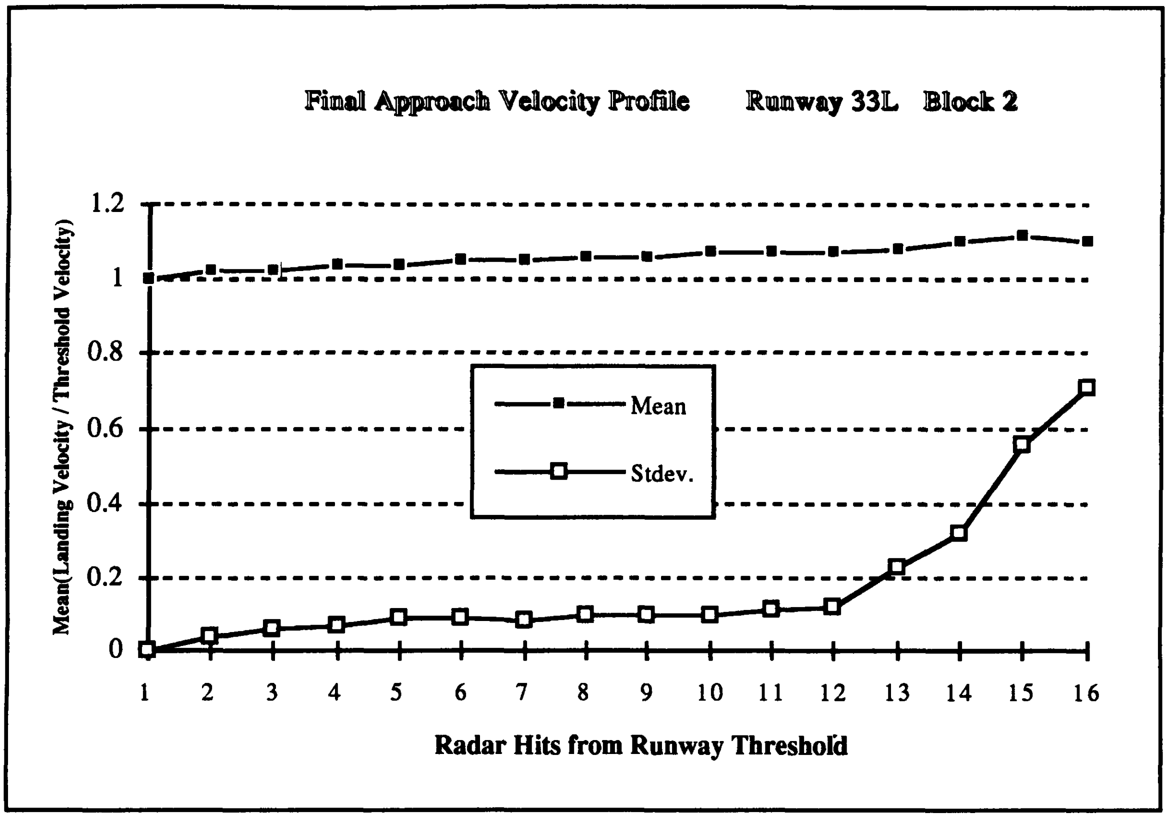

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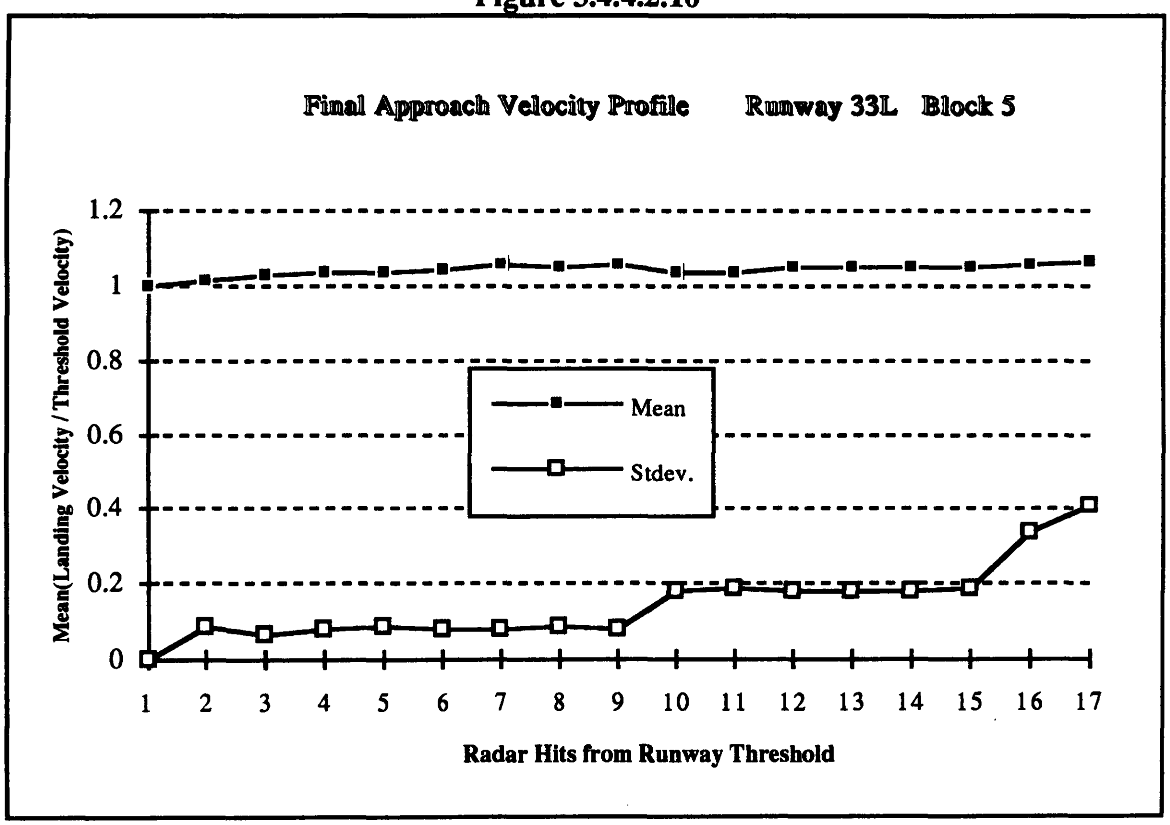


Figure 3.4.4.2.11

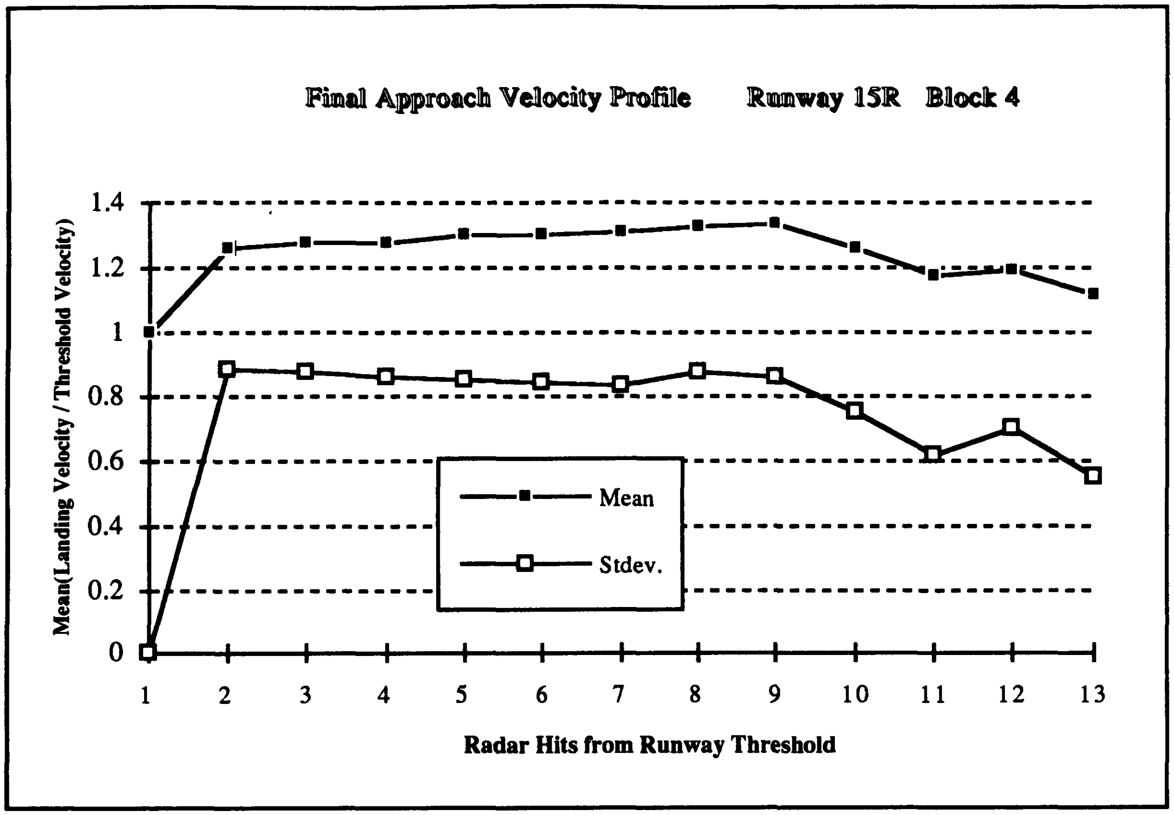


Figure 3.4.4.2.12

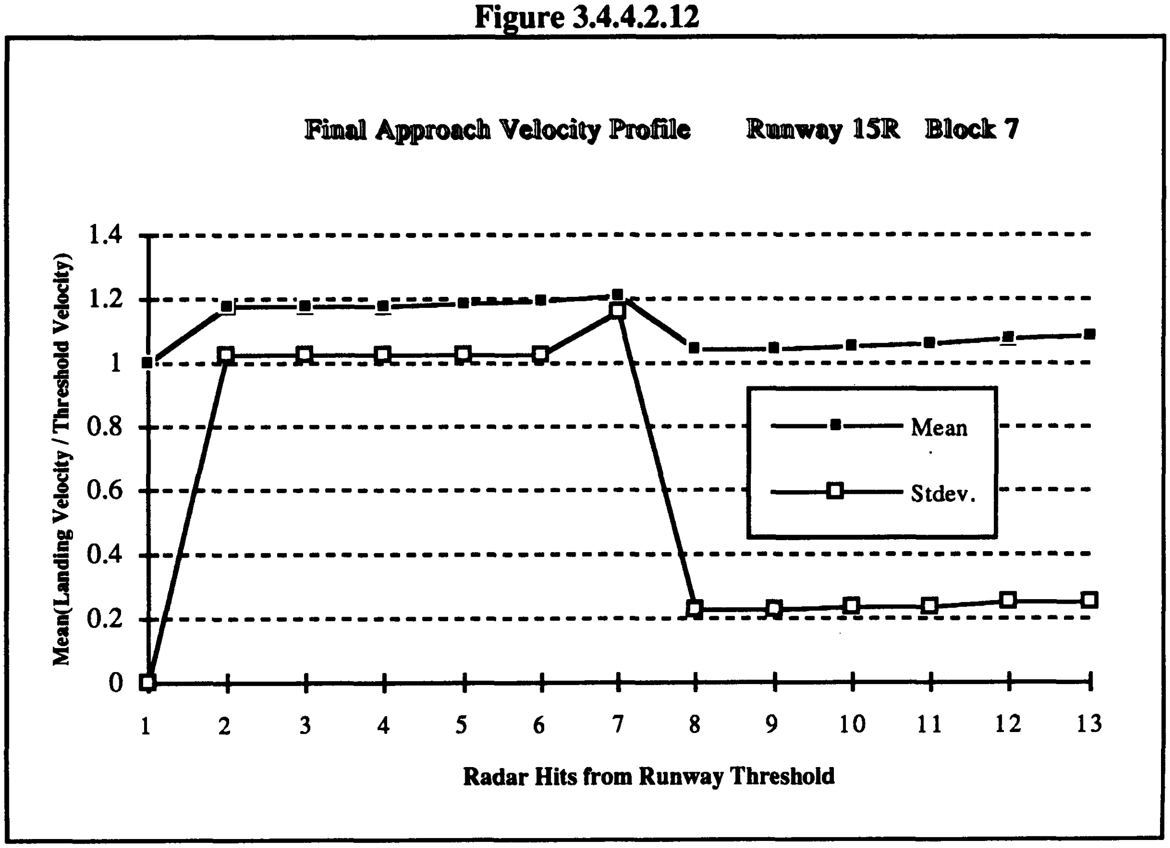


Figure 3.4.4.2.13

3.5 Intersection Analysis

3.5.1 Intersection Crossing Times

When an aircraft approaches an intersection it is either cleared to cross it by the ground controller, or it is instructed to stop or slow down to allow another aircraft to cross in front of it. Occasionally, in periods of heavy traffic a pilot will have to wait in a queue to cross a particular intersection or possibly wait for a queue of aircraft to pass through an intersection.

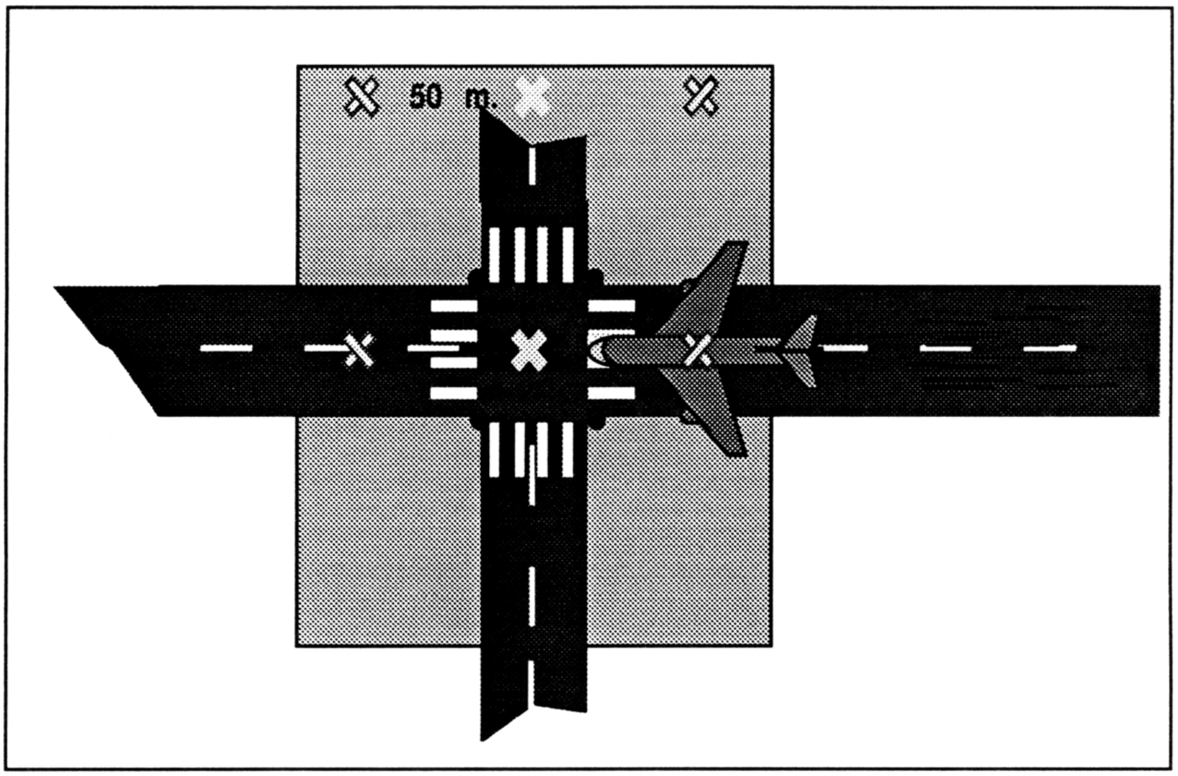


Figure 3.5.1.1: Typical Intersection

Due to the complexity of the runway and taxiway system at Logan airport, a departing or arriving aircraft has to cross a significant number of intersections in its way to the gate or departing runway. In order to measure the intersection crossing time as

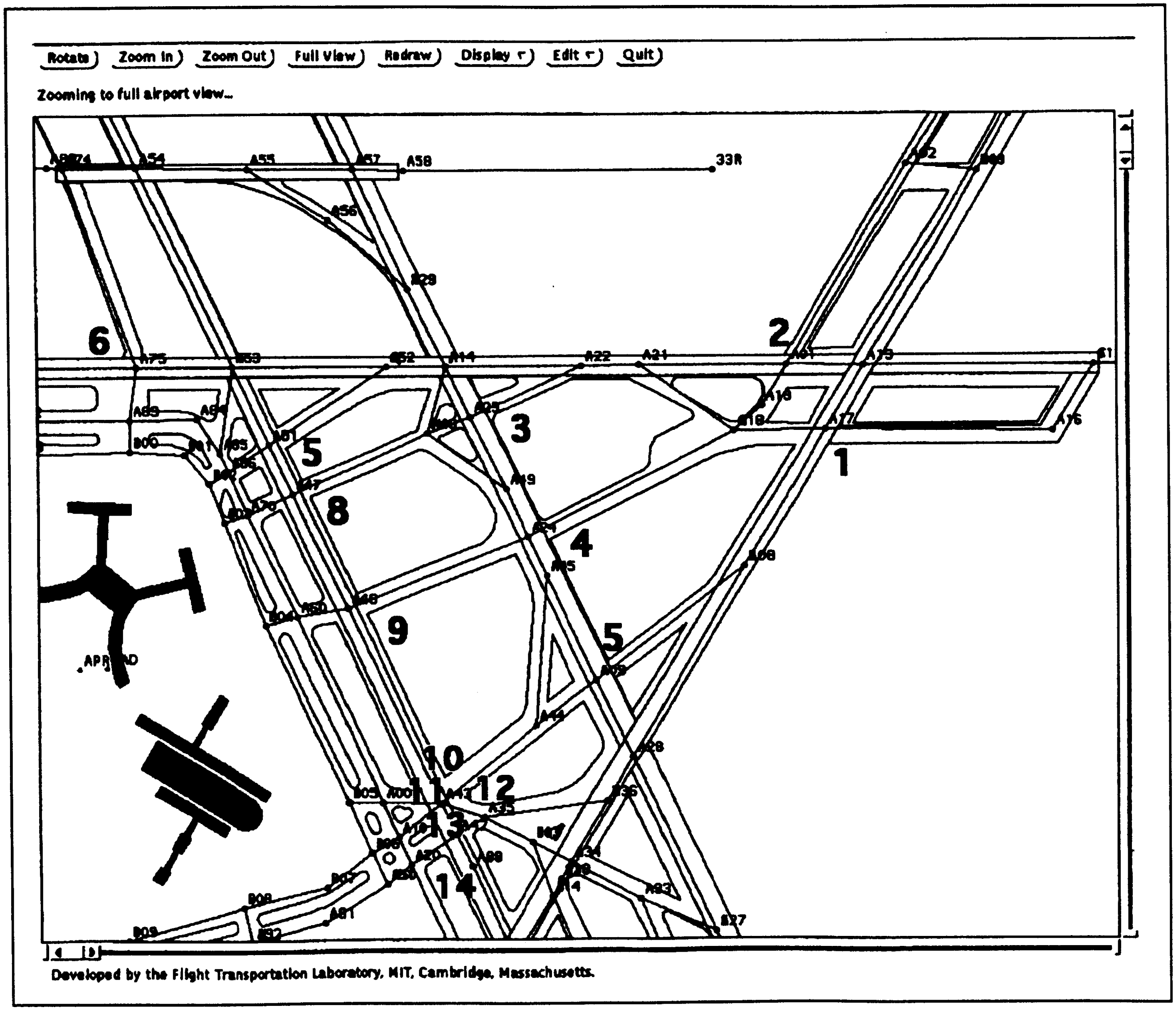

Rotate
Zoom In
Zoom Out
Full View
Redraw
Display
Edit
Quit
Zooming to full airport view...
A54
A55
A57
A58
33R
A56
A29
6
A75
A52
A14
A22
A21
2
A19
A17
A16
3
1
5
8
4
9
5
10
11
12
13
14
A28
A36
A27
A33
Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.

Figure 3.5.1.2

accurately as possible a distance of fifty meters before and after the intersecting runway or taxiway centerline was chosen. Since the radar hits are skin returns from the center of the aircraft' s fuselage, such a distance would ensure that the calculated crossing time would include the initial crossing of the front part of the aircraft and will end after its tail has cleared the crossing runway or taxiway (Figure 3.5.1.1).

The calculated crossing time was split in two segments. The first (time 1) being the time from the start until the aircraft crosses the intersecting centerline and the second segment (time 2) from the centerline until the aircraft clears the runway or taxiway. The following table lists the series of airport links corresponding to each intersection number.

Intersection	Series of Links
1	A16 A17 A18
2	A02 A01 A19
3	A22 A23 A48
4	A18 A24 A46
5	A08 A09 A44
6	A74 A75 A83
7	A52 A51 A86
8	A48 A47 A70
9	A24 A46 A60
10	A44 A43 A00
11	A44 A43 A10
12	A35 A43 A00
13	A35 A43 A10
14	A35 A42 A20

Table 3.5.1

Figures 3.5.1.3 through 3.5.1.12 show the average crossing times along with the standard deviations for every intersection in the ten blocks of collected data. As figures

3.5.1.13 and 14 show there is a significant difference in average crossing time depending in the runway configuration and thus in the direction of use of some intersections. For example, when intersections 10, 11, 12, 13 and 14 are used in the inbound direction (towards the terminal area), usually after arrivals in runway 27, the crossing times seem to be much smaller compared to those of departing aircraft which use the same intersections but in the opposite direction (outbound), and often have to form a queue while waiting to depart from runway 9 and thus cross these intersections very slowly. Similarly in intersection 6 the inbound direction of crossing is much quicker (aircraft landing on runway 4R) that the outbound one (aircraft waiting to depart from 22L and 22R).

Comparing the crossing times of the two different segments of each intersection (time 1 and time 2), we observe that usually when an intersection is used in the inbound direction time 2 is larger than time 1 and when it used in the outbound time 1 is larger. This could be possibly due to the fact that when a pilot is on his way to the gate, after crossing the intersection it has to slow down since the connecting taxiway segments A75-A83, A51-A86, A47-A70 etc. are short as they intersect with the circuferential outer taxi lane which is often congested. On the other hand, in the outbound direction usually time 2 is smaller than time 1 probably because the connecting taxiways that lead away from the terminal area are longer and therefore the pilot accelerates faster.

Figures --- through --- show the average crossing times per aircraft class (size) for intersections where ten or more aircraft crossed them. Larger aircraft are heavier and logically should have longer crossing times but the graphs show this is the case only in few blocks of data (block 1).

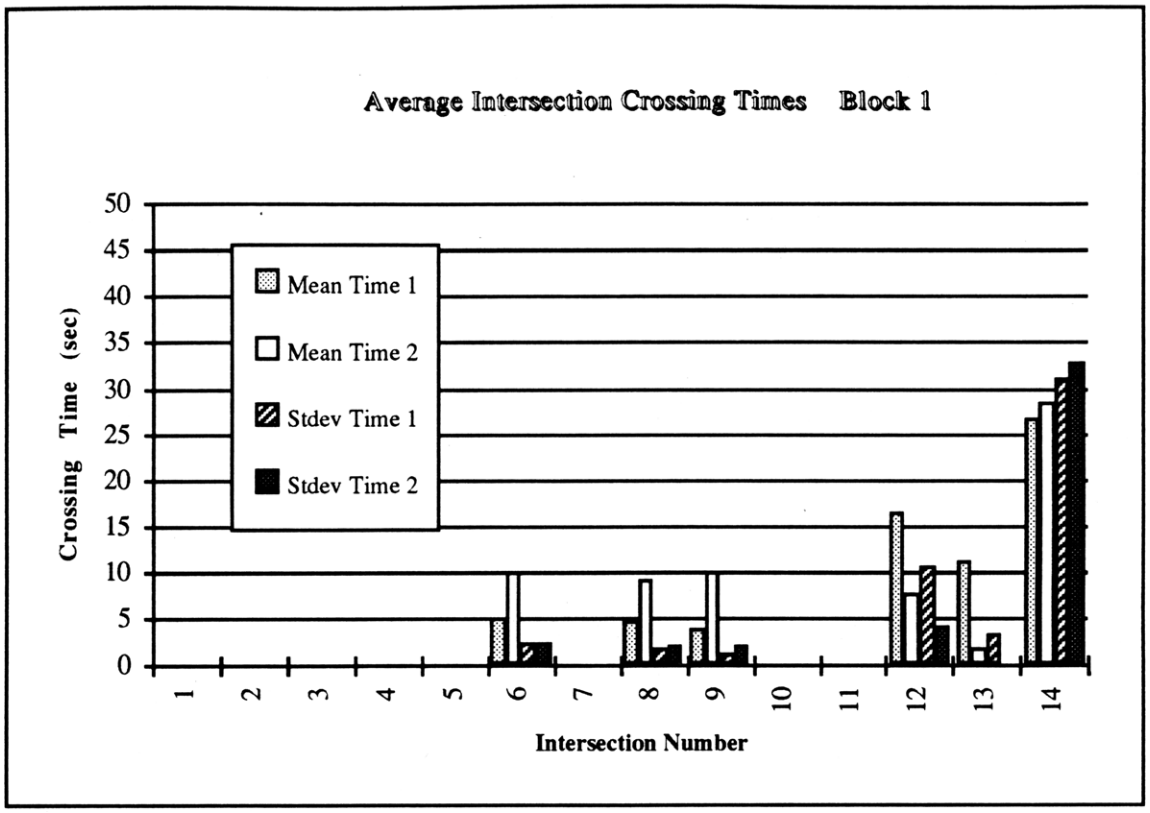


Figure 3.5.1.3

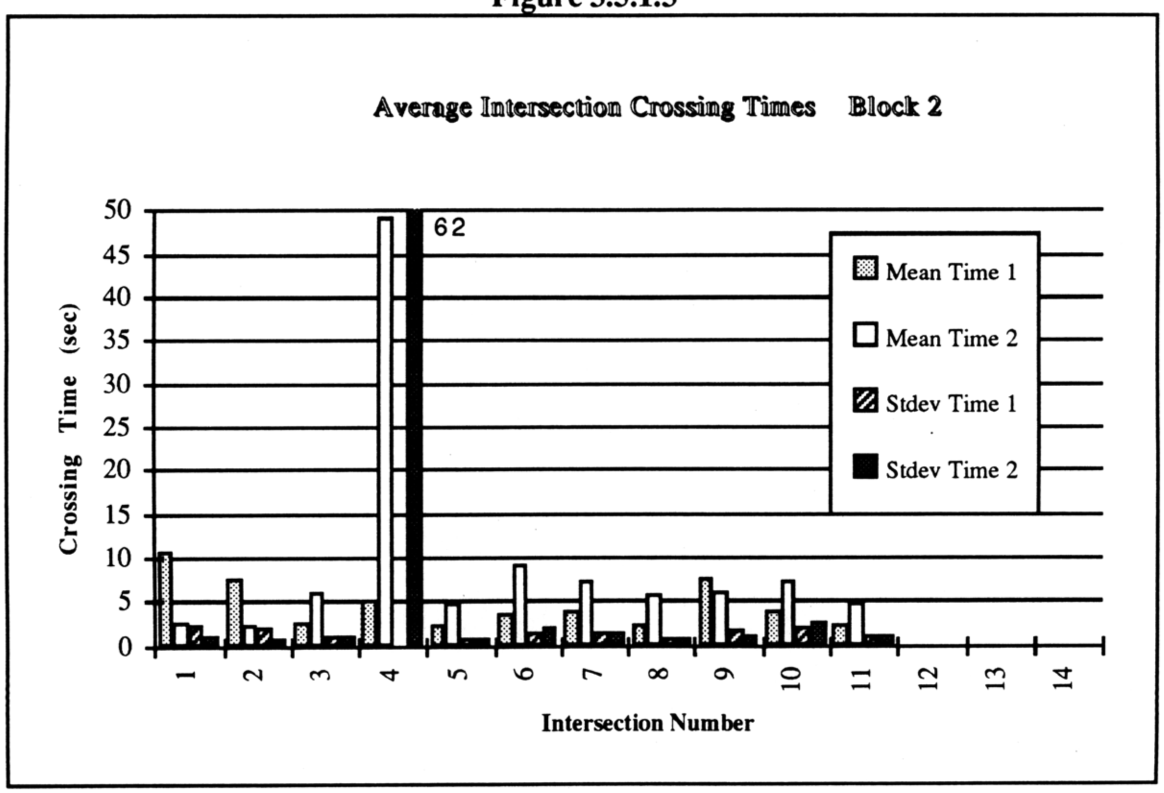


Figure 3.5.1.4

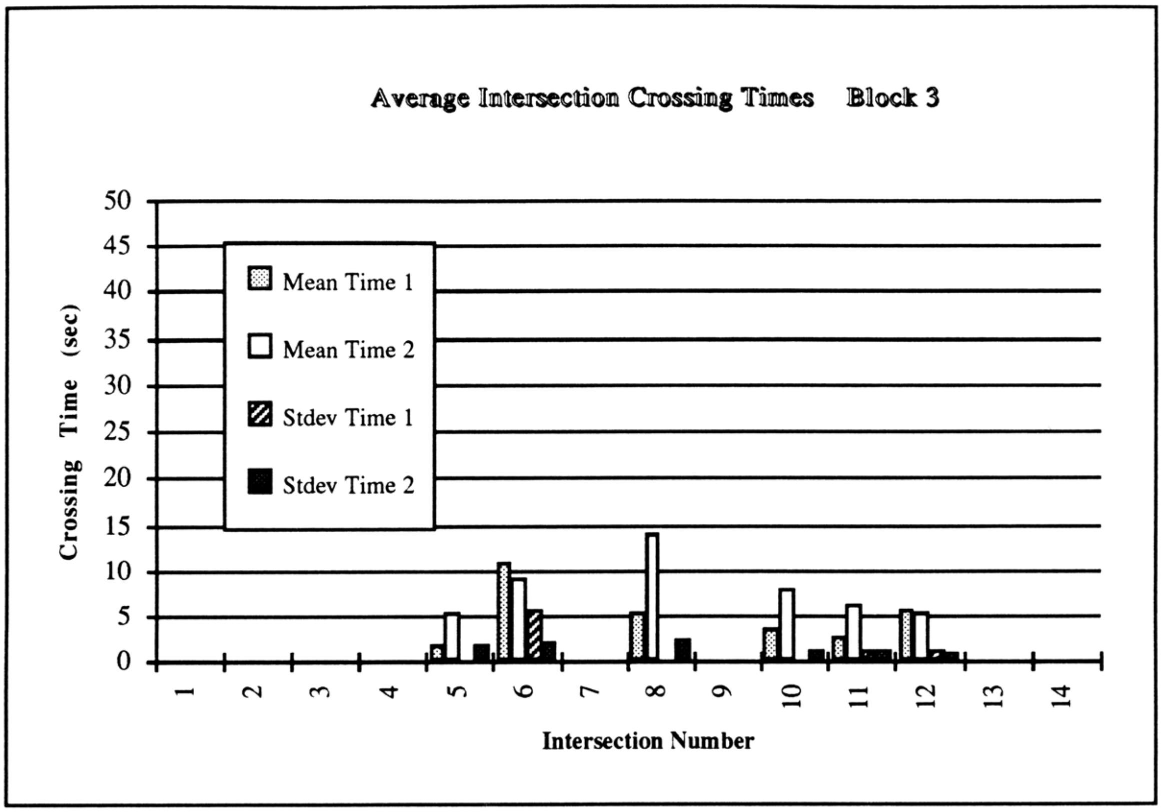


Figure 3.5.1.5

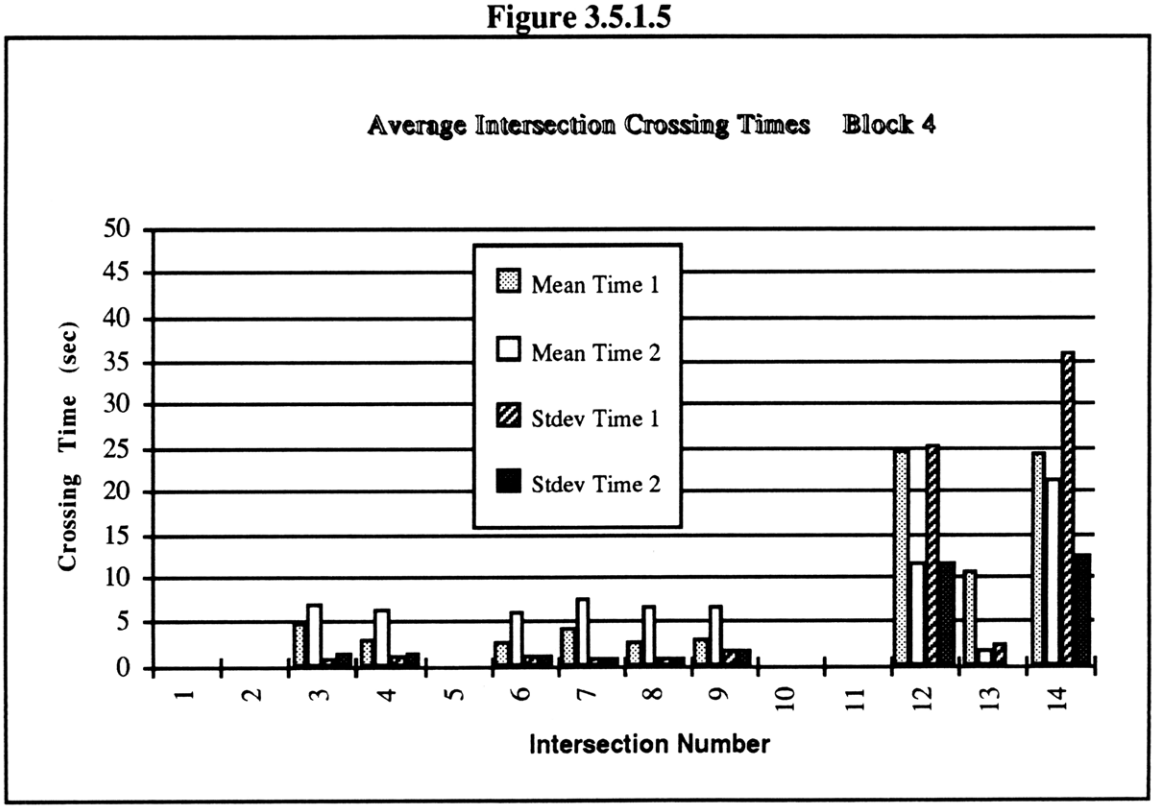


Figure 3.5.1.6

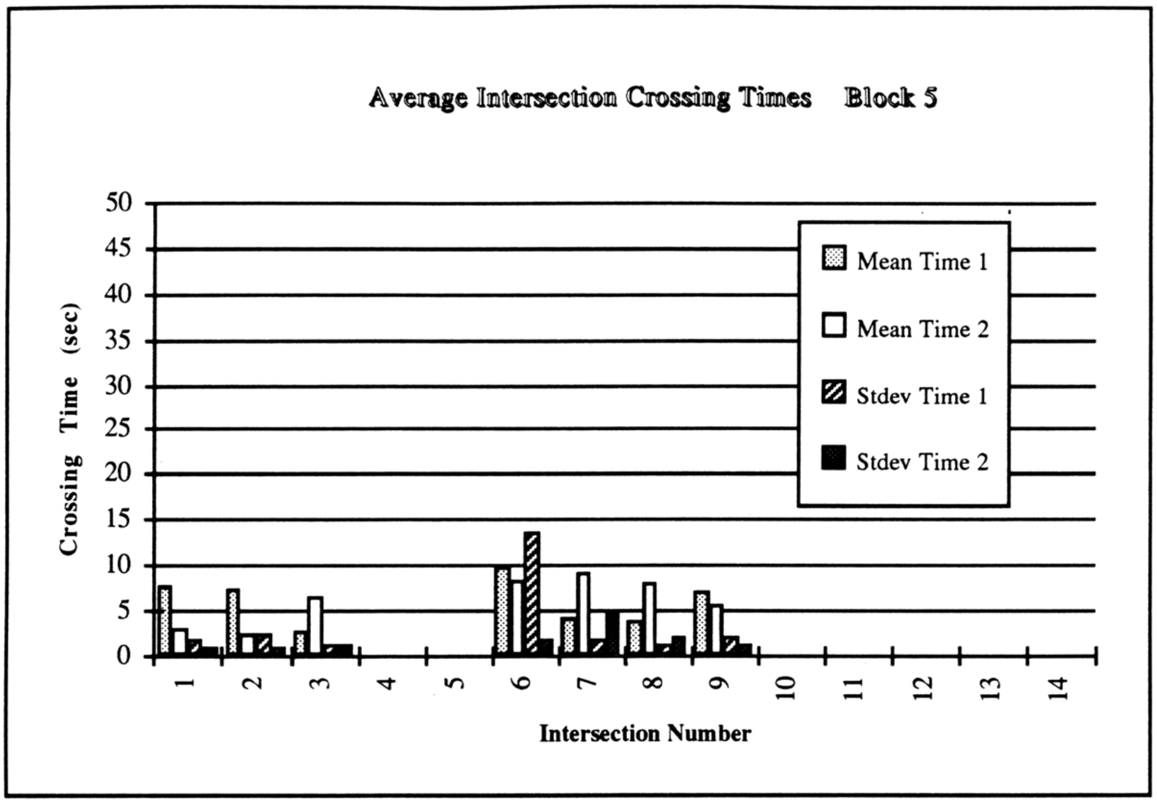


Figure 3.5.1.7

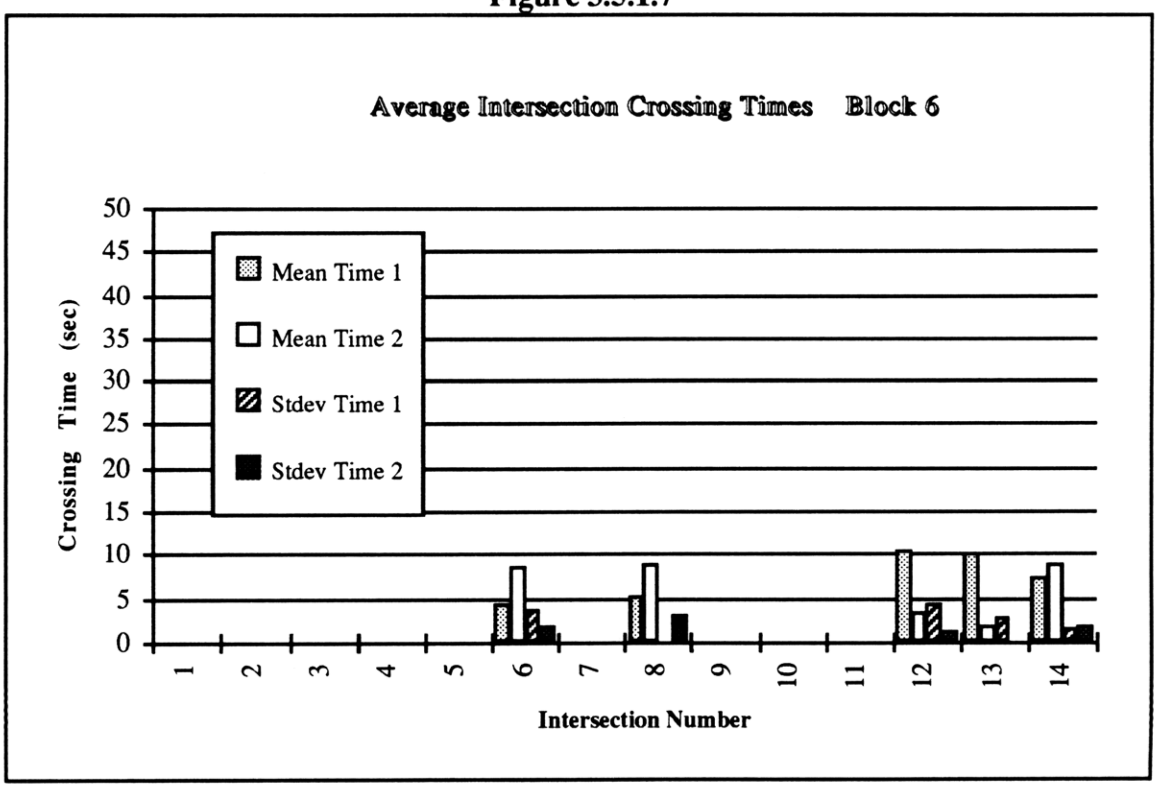


Figure 3.5.1.8

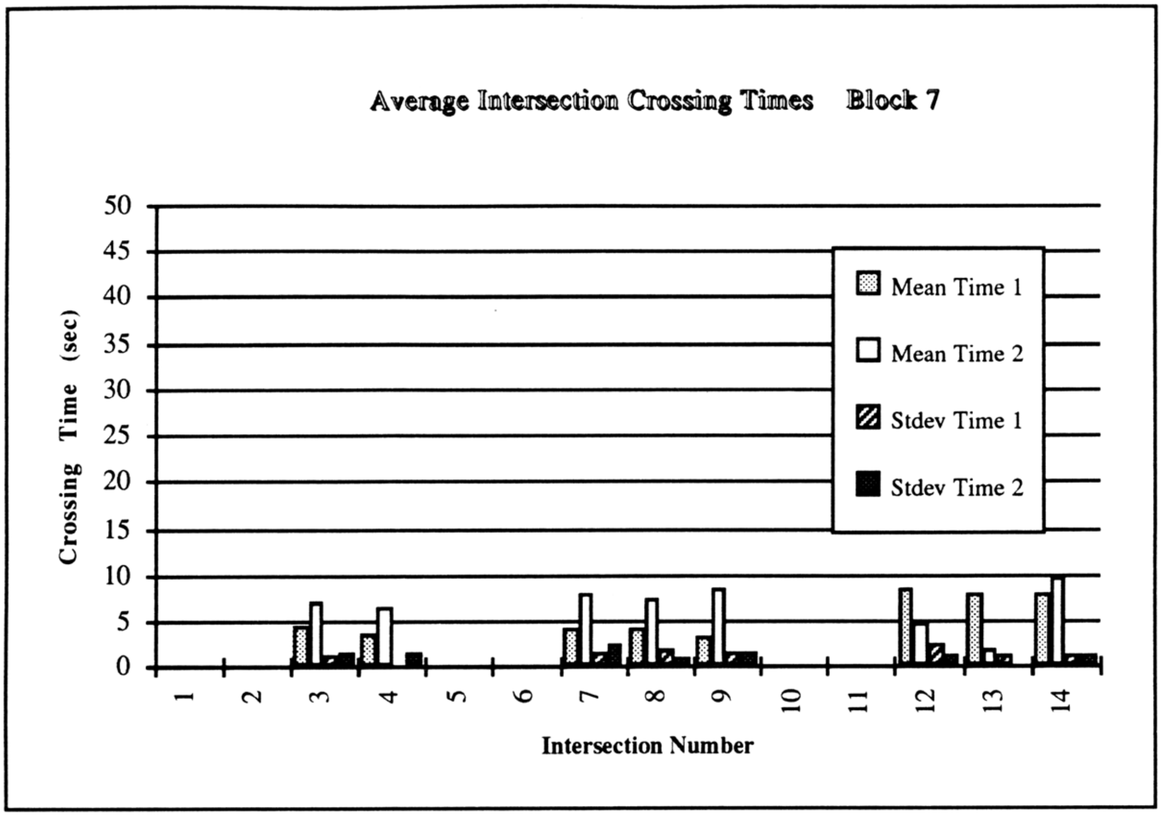


Figure 3.5.1.9

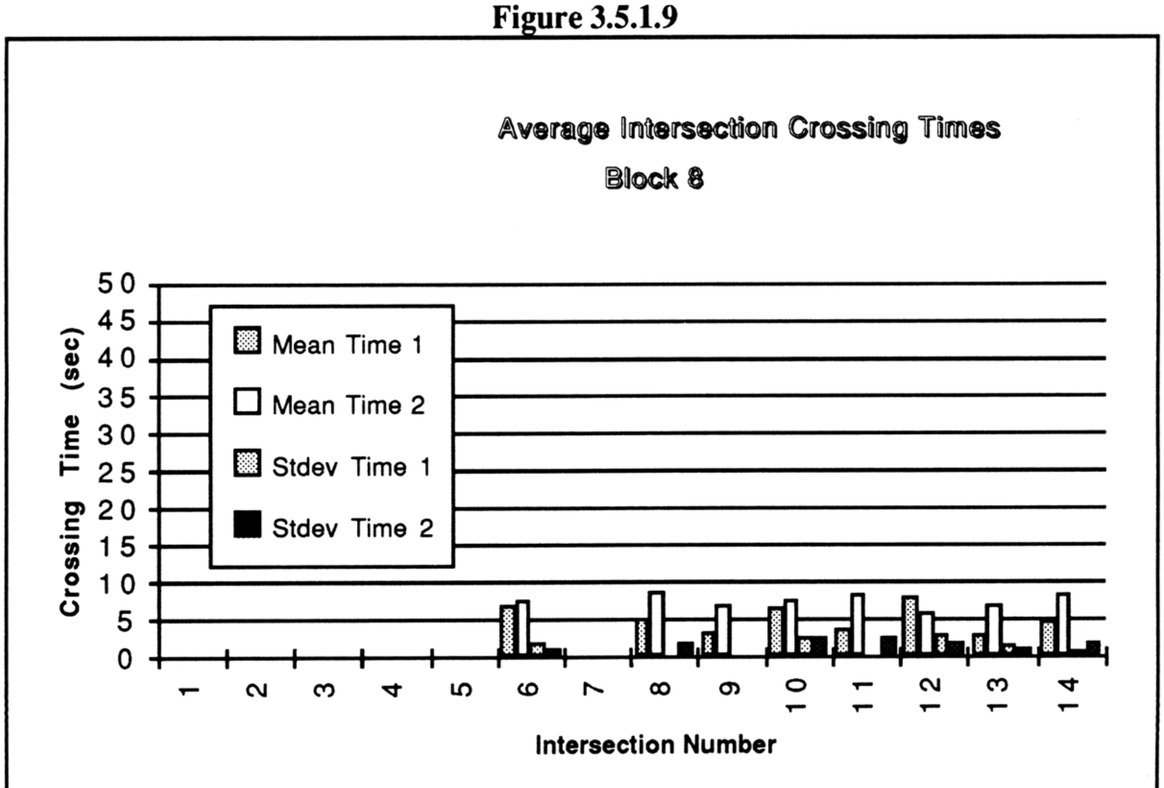


Figure 3.5.1.10

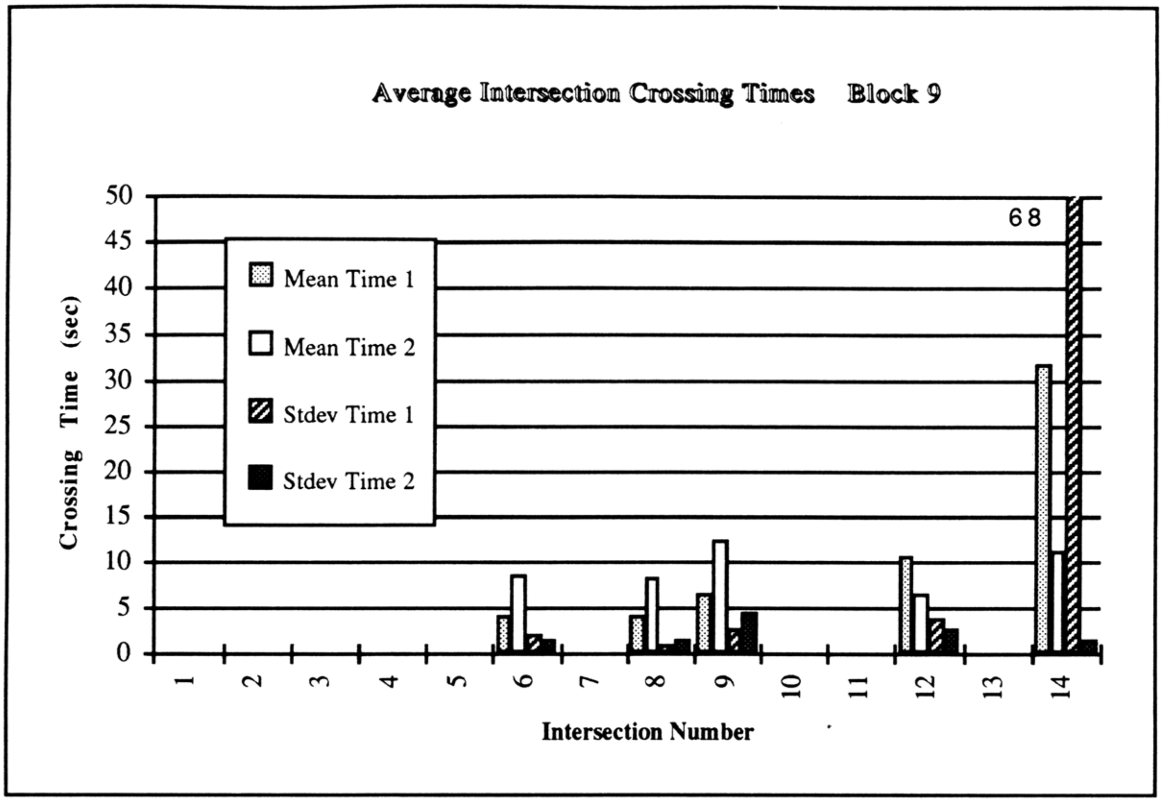


Figure 3.5.1.11

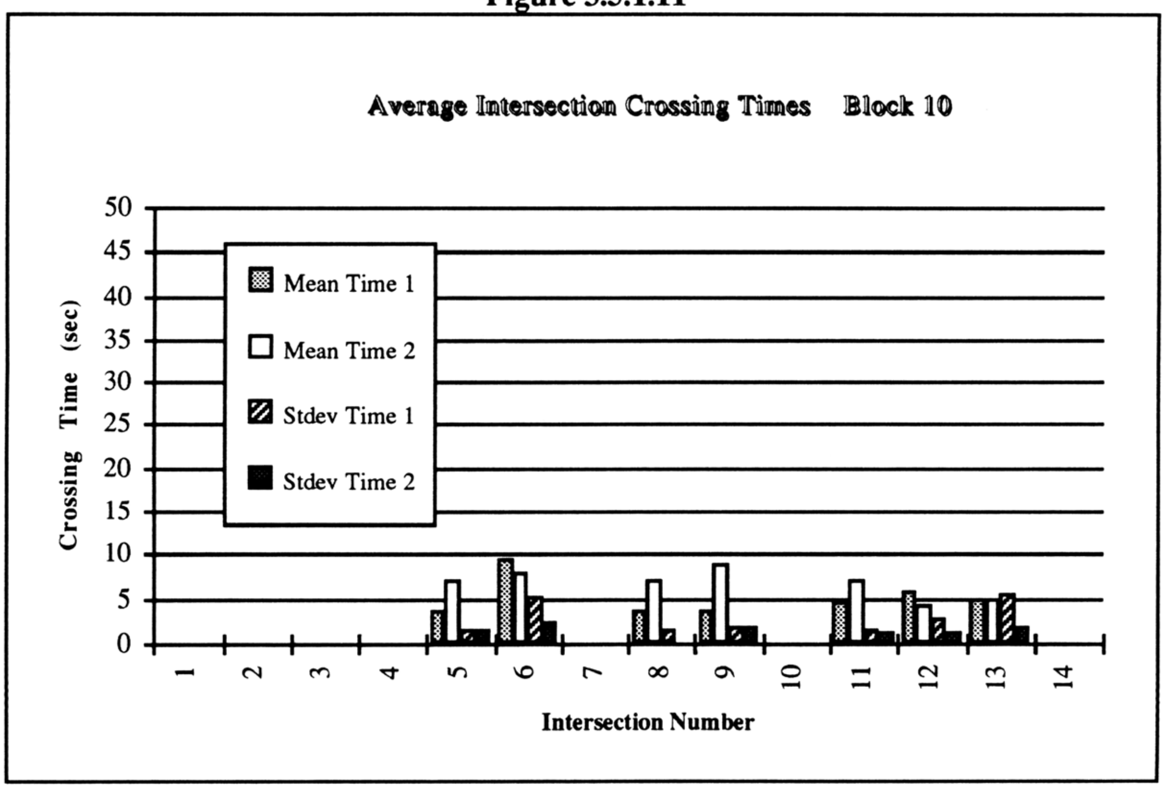


Figure 3.5.1.12

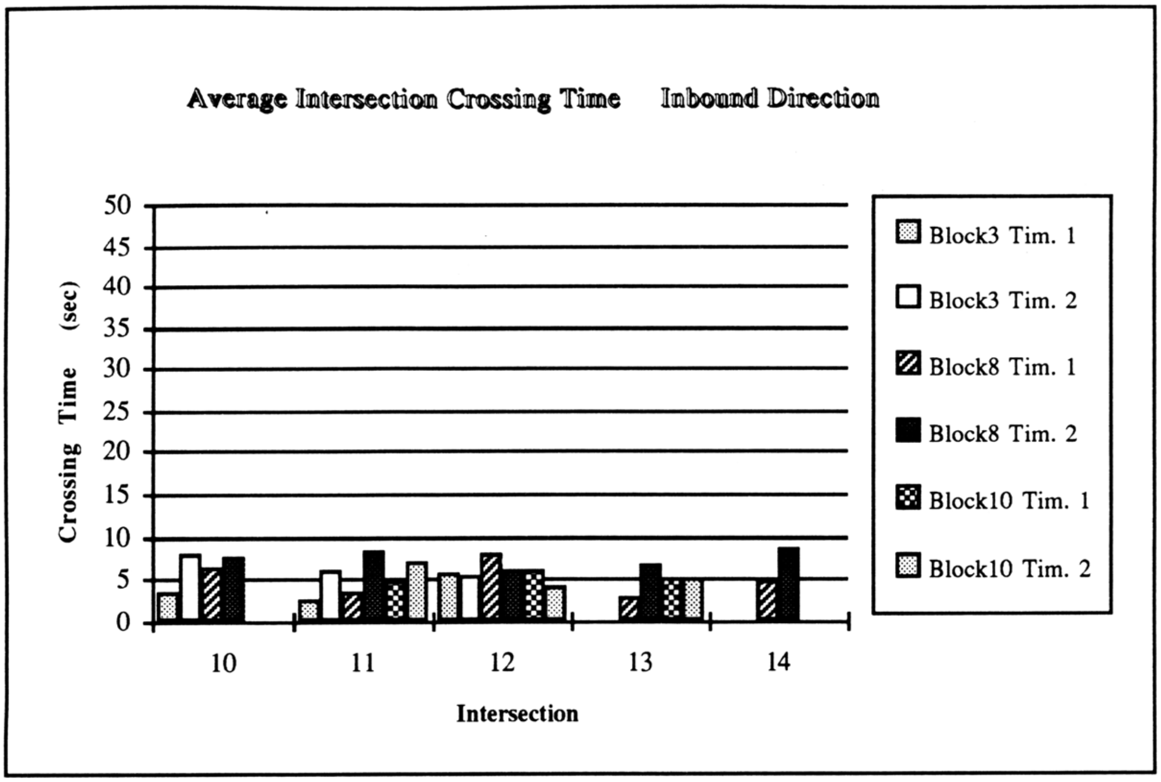


Figure 3.5.1.13

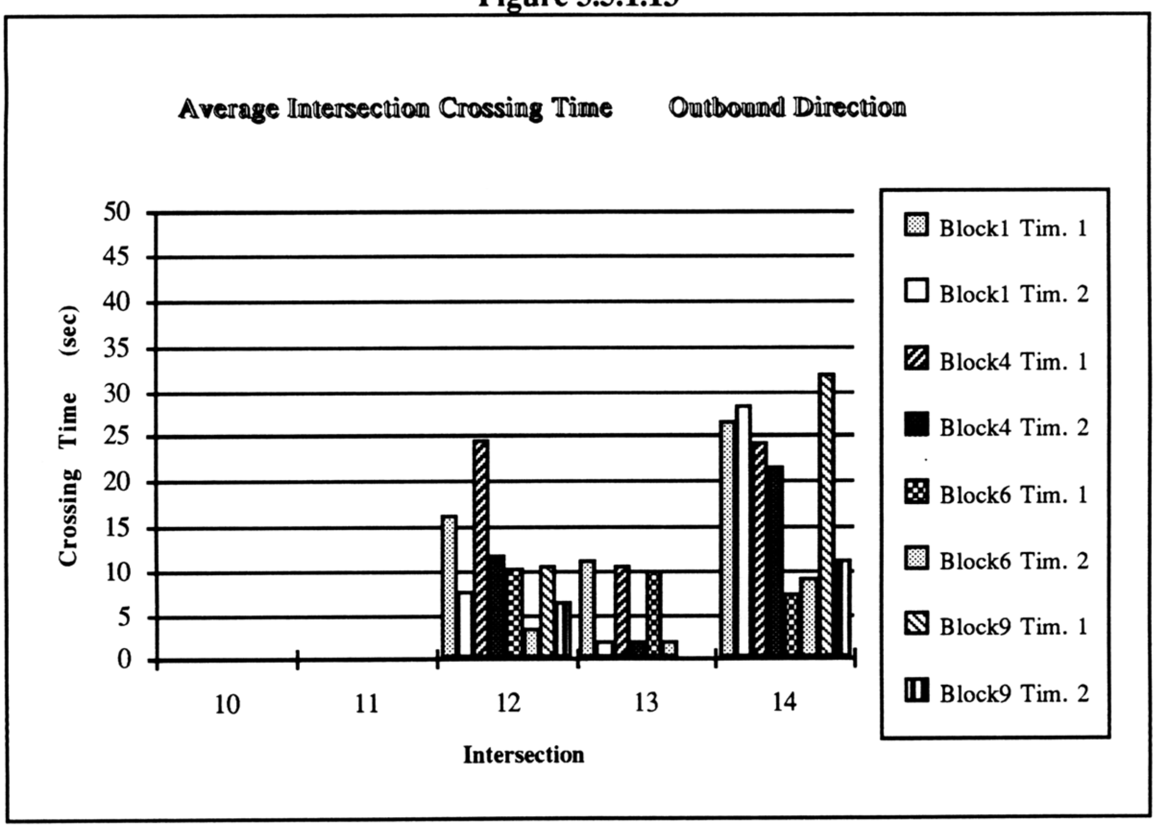


Figure 3.5.1.14

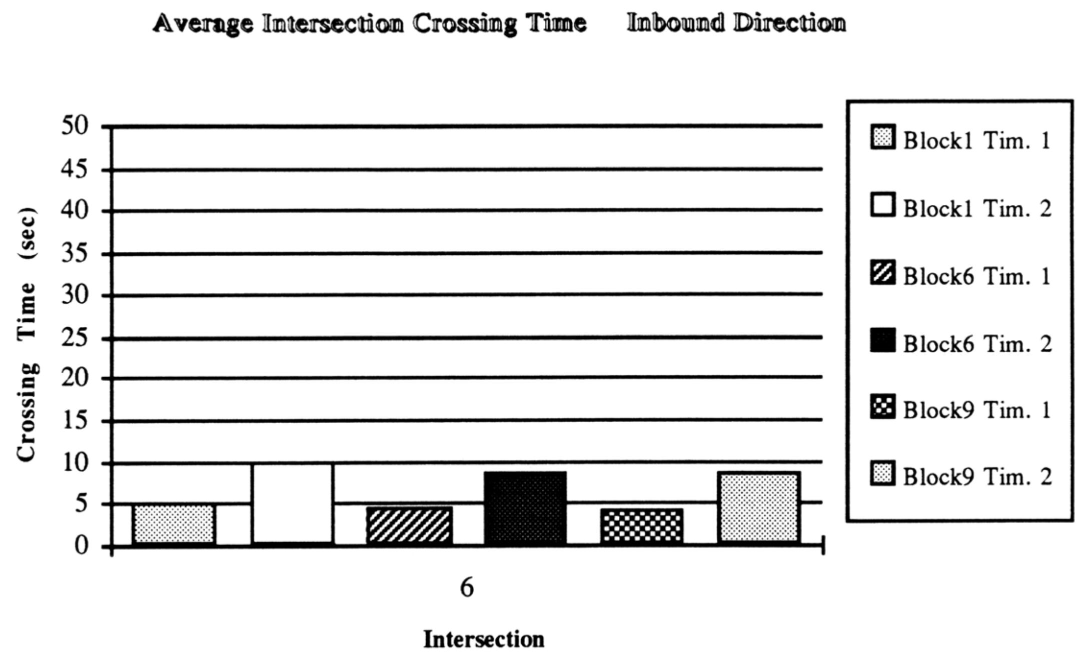


Figure 3.5.1.15

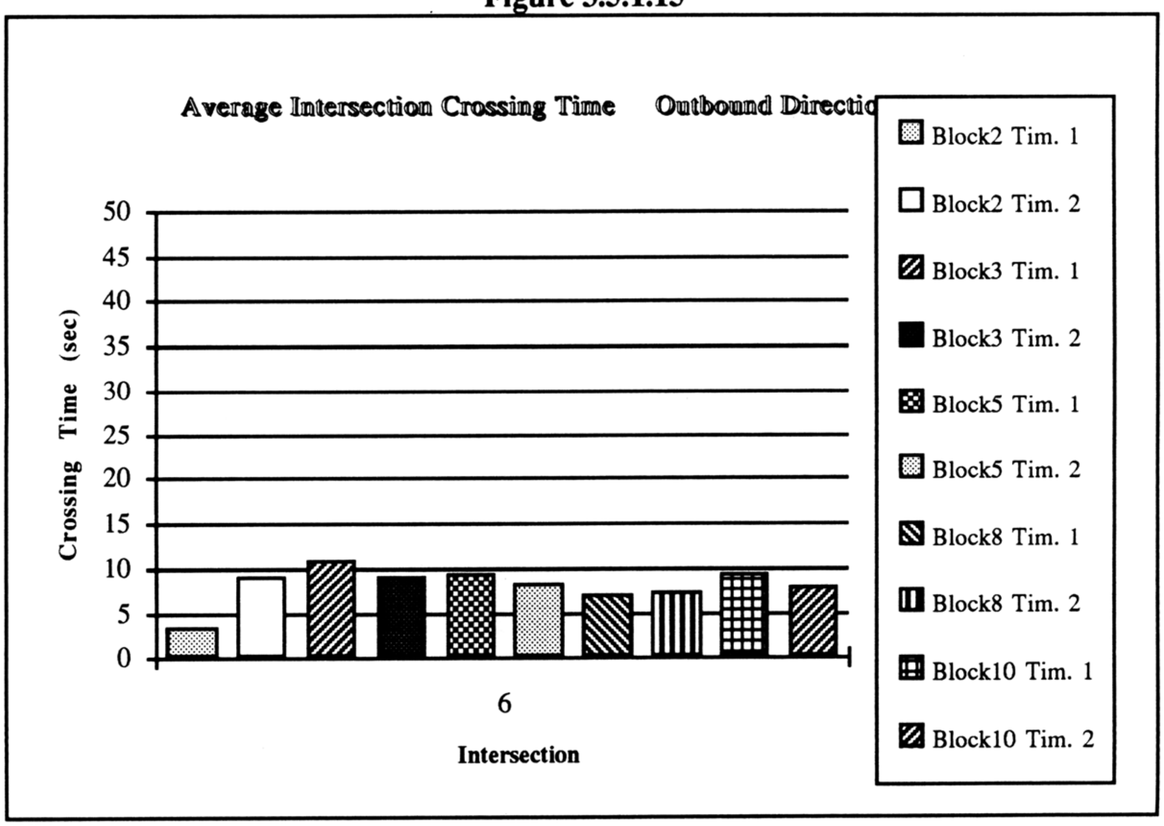
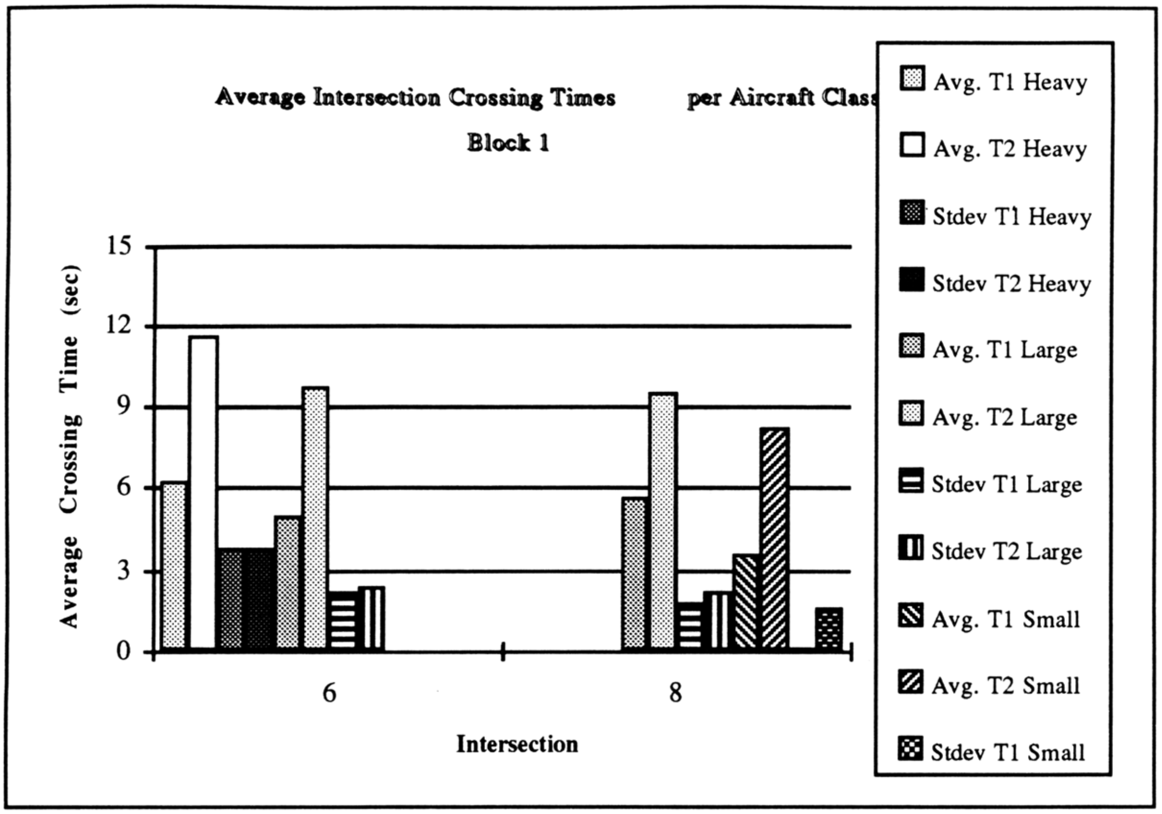


Figure 3.5.1.16



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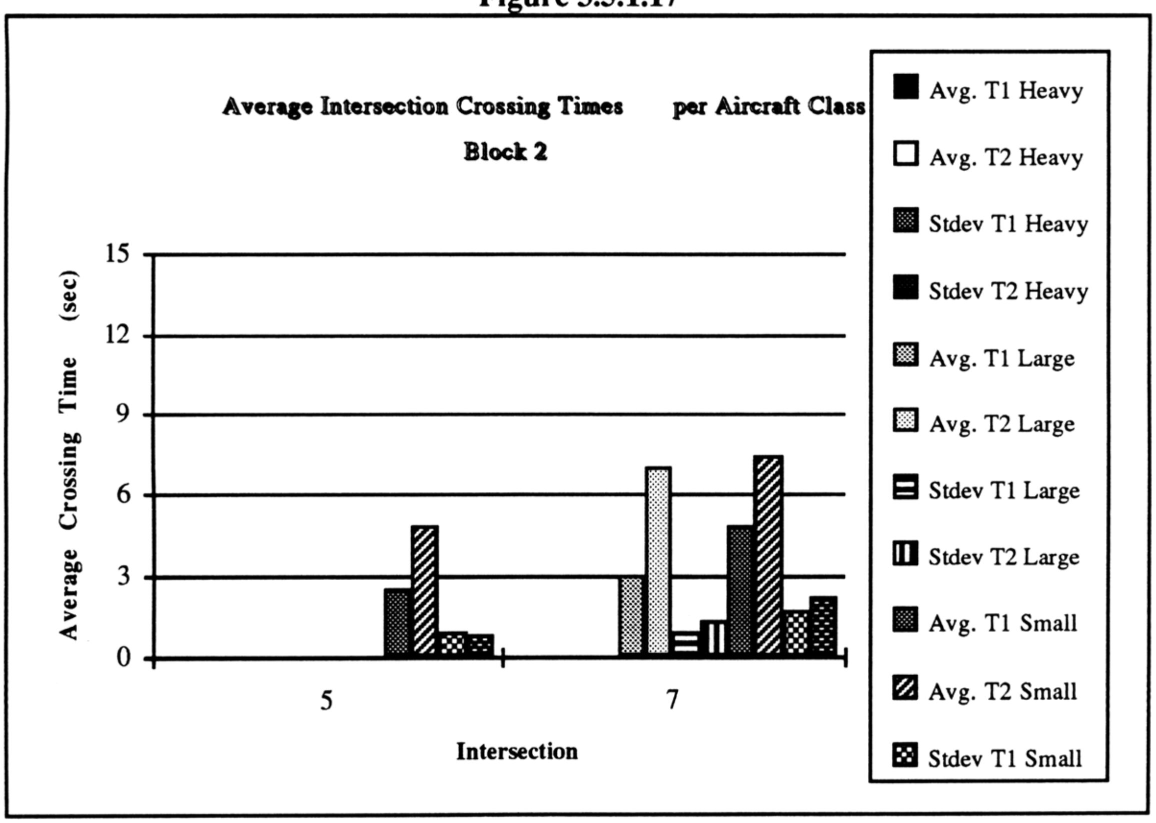


Figure 3.5.1.18

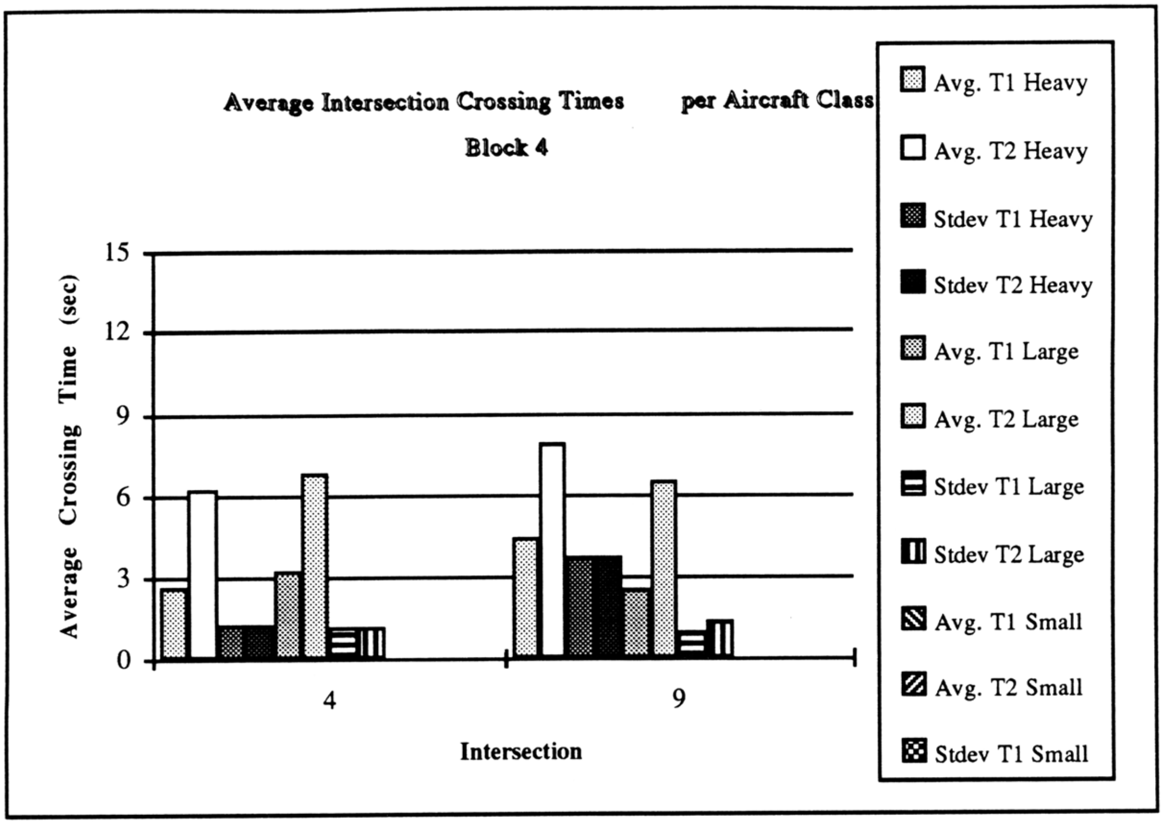


Figure 3.5.1.19

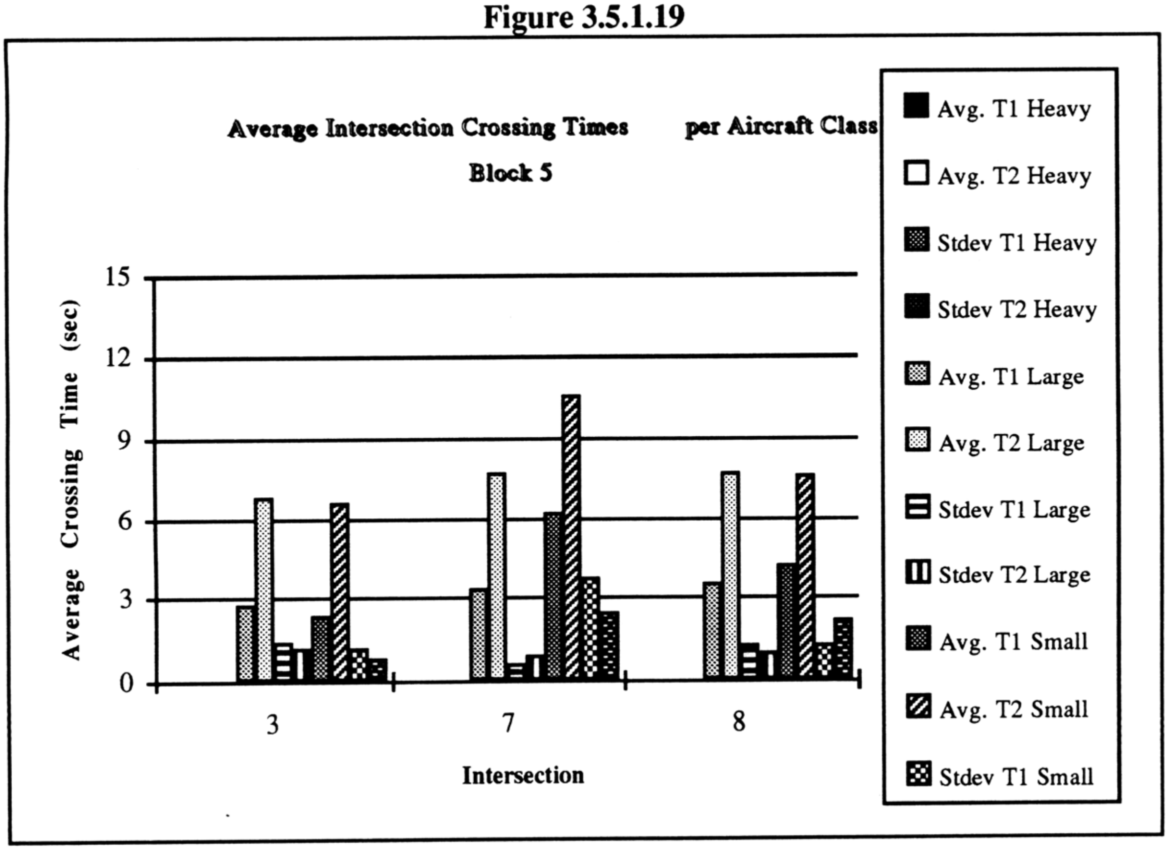


Figure 3.5.1.20

3.5.2 Intersection Use

The following table provides information about the number of aircraft that used each intersection. Figures 3.5.2.1 through 3.5.2.4 show the intersection use under the four most popular runway configurations at Logan airport. As we can see, the use of a specific exit is closely related to the operating runway configuration.

Number of Aircraft Using Each Intersection

Intersection	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9	Block 10
1	0	2	0	0	6	0	0	0	1	0
2	0	15	0	0	23	0	0	0	0	0
3	0	5	0	4	21	0	7	0	0	0
4	0	2	0	12	1	0	9	0	0	0
5	0	13	3	0	1	0	0	1	0	4
6	13	4	25	2	7	26	0	36	6	45
7	0	18	0	7	16	1	6	1	1	1
8	11	6	3	5	20	3	11	3	11	4
9	8	30	0	11	50	0	11	2	6	3
10	0	9	2	0	1	0	0	3	0	1
11	0	3	2	0	0	0	1	4	0	5
12	11	0	6	25	0	9	7	8	9	3
13	4	0	1	4	1	3	2	7	1	6
14	11	1	1	11	0	10	3	5	8	0

Table 3.5.2

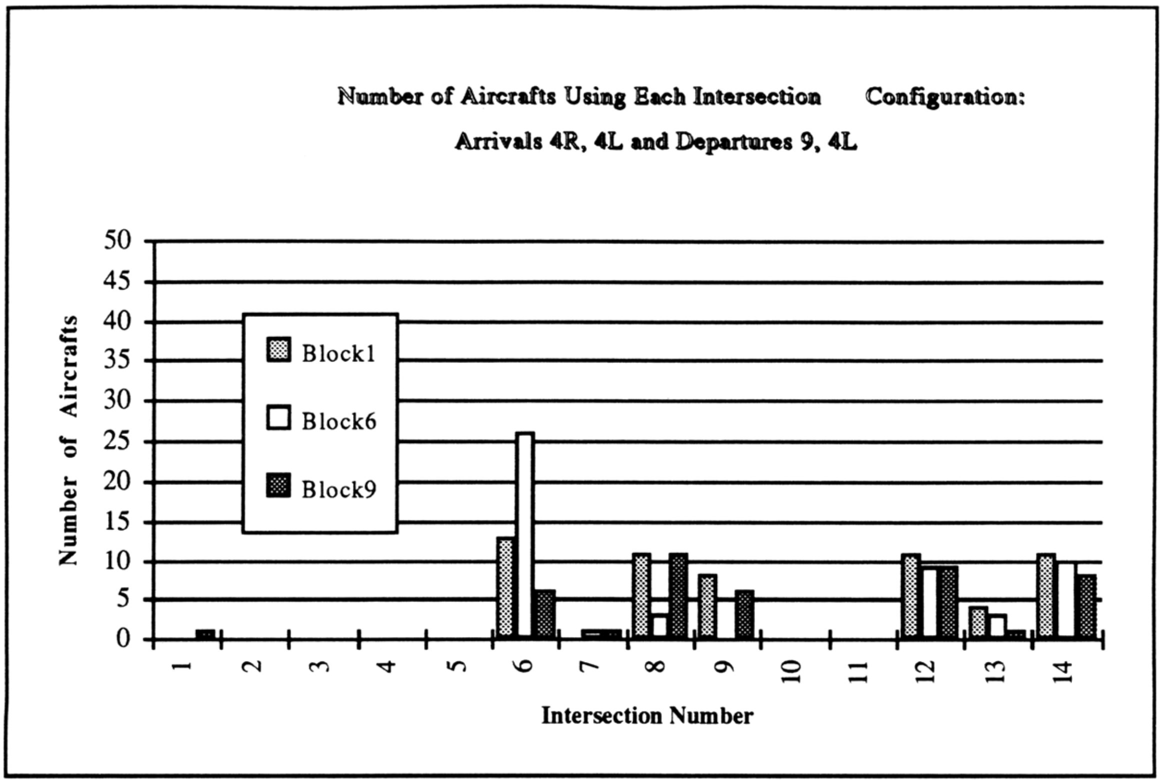


Figure 3.5.2.1

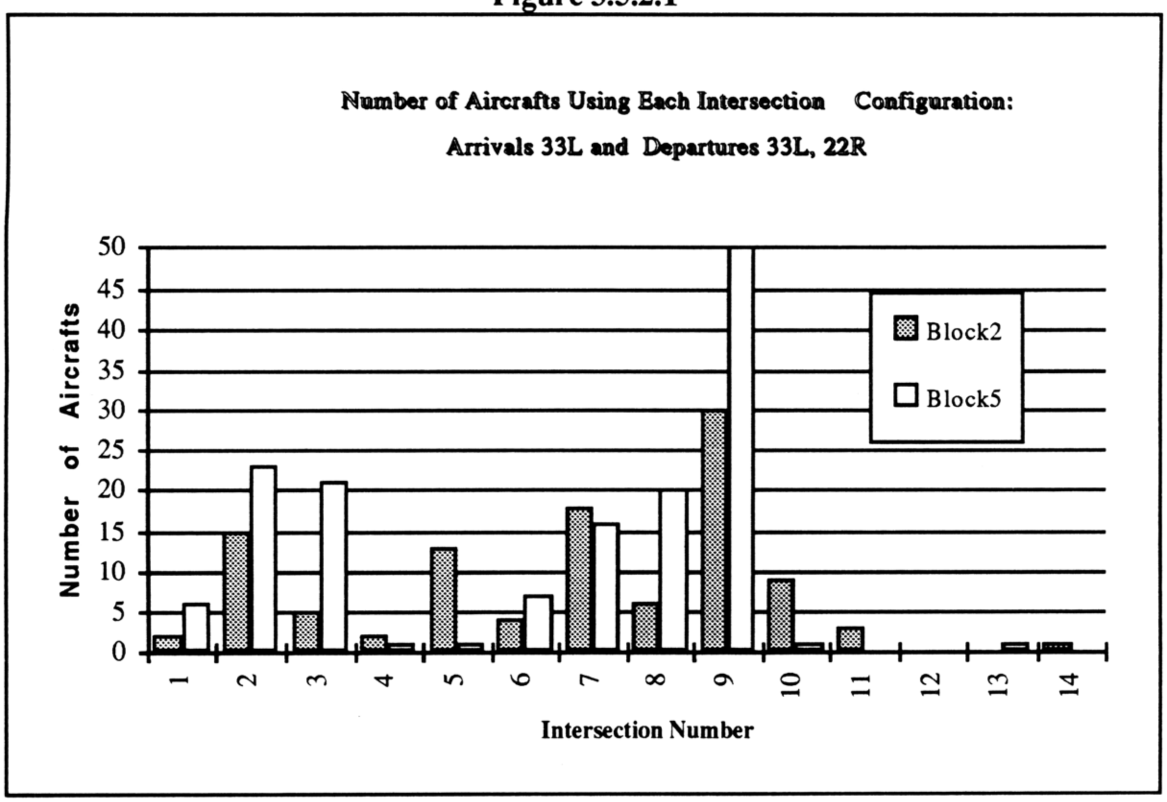


Figure 3.5.2.2

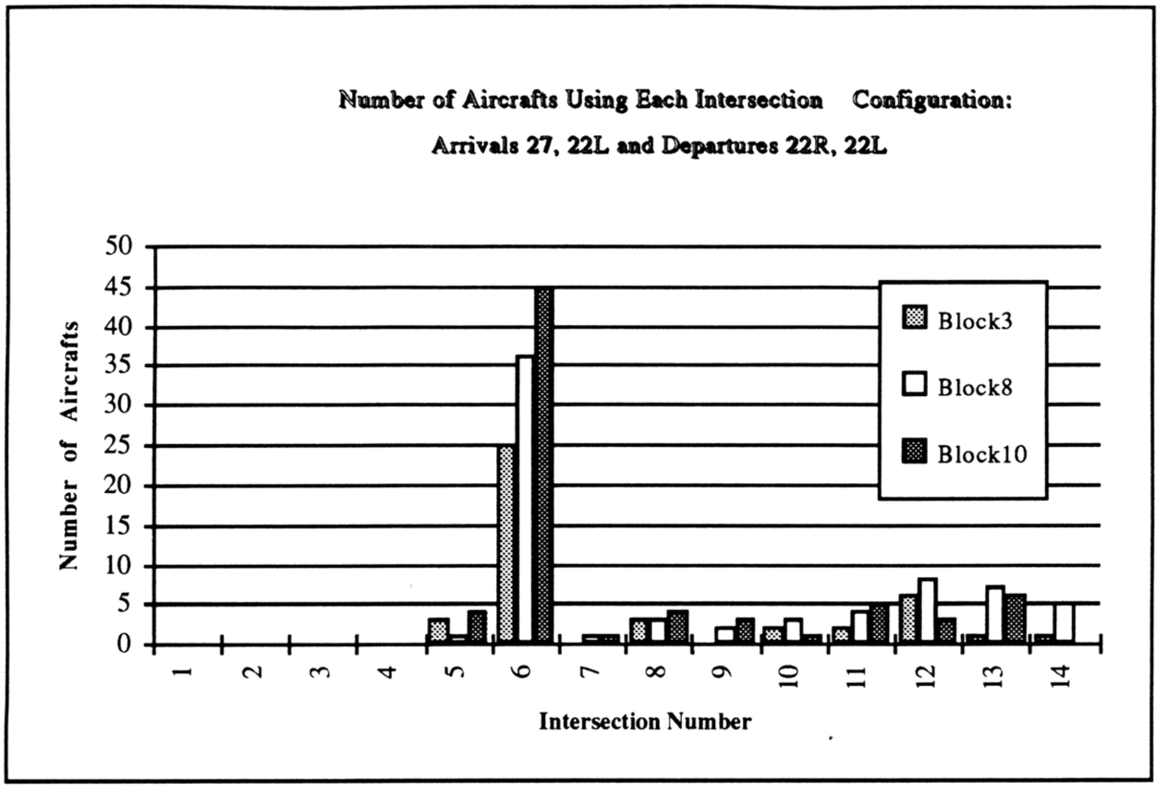


Figure 3.5.2.3

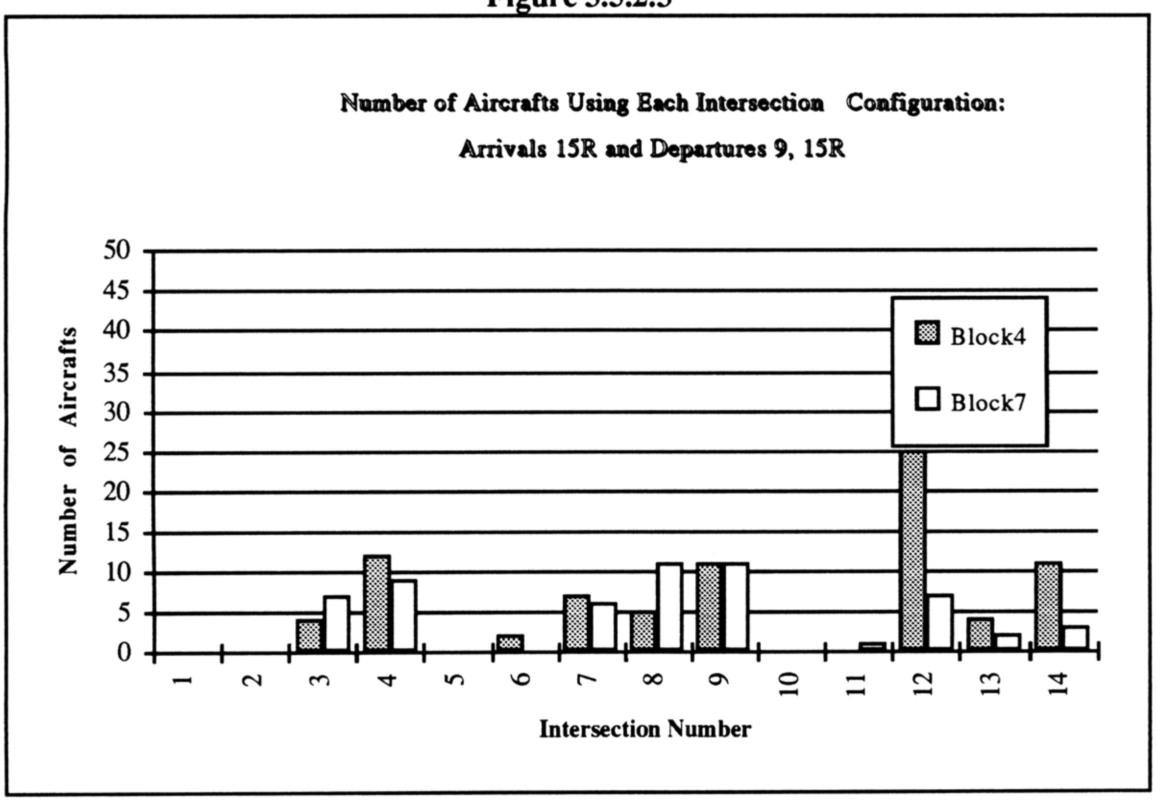


Figure 3.5.2.4

3.6 Taxiway Analysis

3.6.1 Taxiway Average Velocity

The average velocity of an aircraft moving on an airport taxiway system depends on many factors. Before the analysis of the collected data, we expected that the distance of the taxiing segment would be a significant determinant of this velocity. Usually when pilots are moving on a short segment, prefer to taxi slowly since they expect soon to arrive at an intersection and might be instructed by the controller to stop for crossing traffic. On the other hand when a pilot sees that he has a long stretch in front of him with no imminent intersection, he taxies at higher speeds.

The location of the taxiway segment should also play an important role. Taxiways far away from the terminal area are more likely to exhibit higher average velocities since they tend to be less congested and their surrounding areas are usually free of obstacles. Other variables that affect the taxiway velocities, are the complexity of the taxiway system at the particular airport and the level of familiarity that each pilot, who operates there, has with the system. The first variable usually remains constant while the second one can vary, and cannot be very easily quantified.

Trying to test if the taxiway length and location relates to the average taxiway velocity, we categorized each taxiway link that did not belong to a runway or was not an exit link, into two groups. Those links that were shorter than 500 meters were assigned a letter **S** and those that were longer a letter **L**. Each taxiway was also assigned either a letter **C** (close) if it was located inside the outer taxilane, or a letter **F** (far) otherwise.

Figure 3.6.1.1 shows the average velocity of all taxiways for each data block independent of segment length or location. The velocities range between 7 and 16 knots. However, standard deviations vary from 6 to 22 knots. Data block 3 exhibits the lowest average velocity for its taxiways (7 knots), possibly due to the heavy traffic of that time period. To traffic congestion can be also attributed the low velocities that we observe in data block 4. Bad weather conditions (thunderstorms and fog) are the probable reasons for low velocities in blocks 1 and 9.

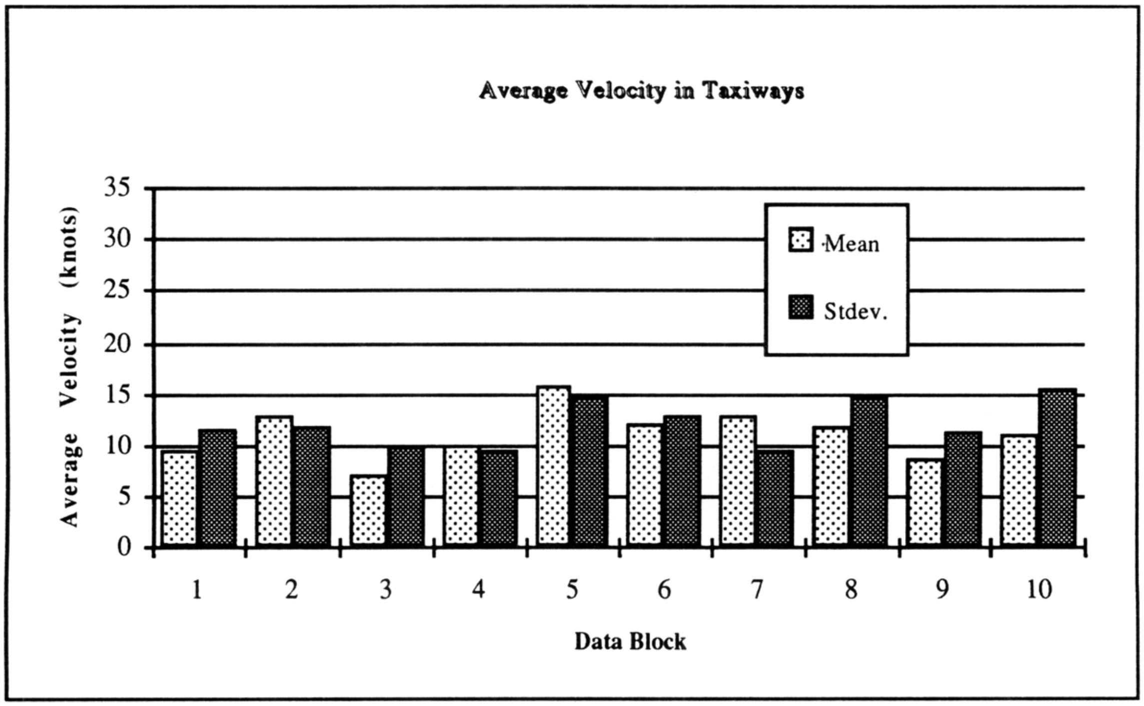


Figure 3.6.1.1

The results of the previous taxiway categorization can be seen in figures 3.6.1.2 and 3.6.1.3. Longer segments almost always display higher average velocities than the shorter ones. We must note though that in periods of heavy traffic the differences in speed between longer and shorter taxiways become smaller. As figure 3.6.1.3 shows, taxiways that are located far from the terminal area, in data blocks 1, 6, 9, 4 and 7, have higher average velocities while in the other blocks lower. It is interesting to note that blocks that have higher velocities, the runway configuration is the same (block 1, 6, 9 arrivals in 4R departures from 9). The same pattern (same configuration for all blocks that exhibit similar velocity characteristics) occurs in the other blocks of data, where the combination (higher velocity - taxiway location) is opposite.

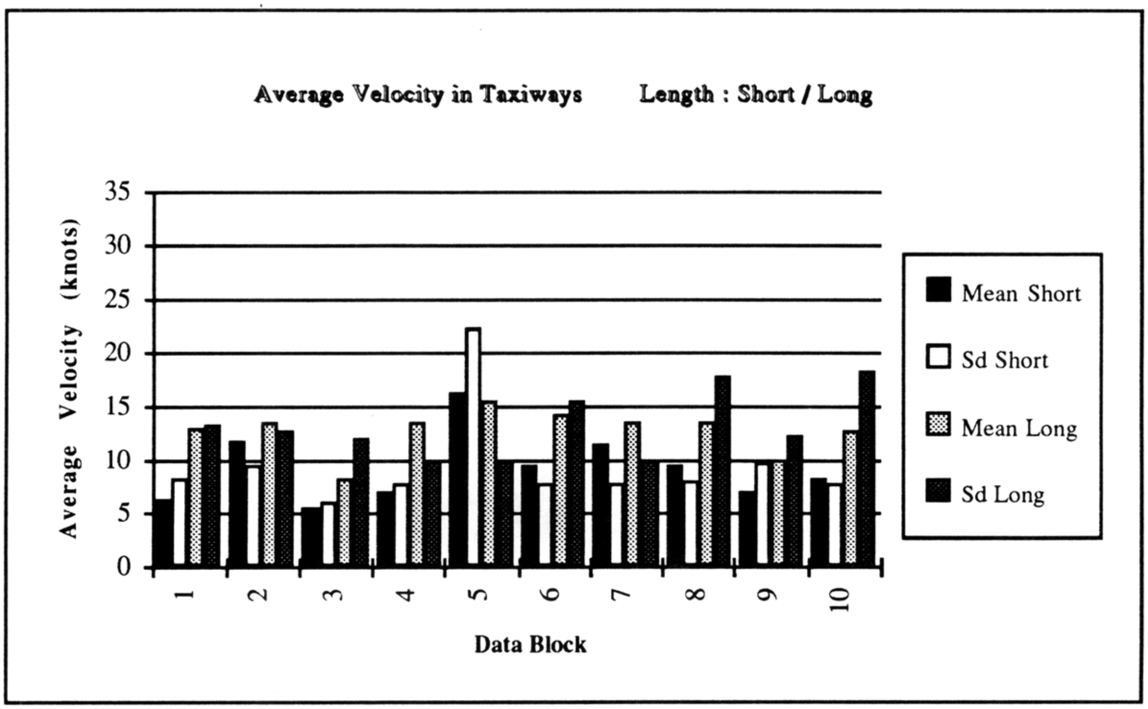


Figure 3.6.1.2

Figure 3.6.1.4 shows two groups of taxiways. In the first group, belong taxiways that are located close to the terminal area and are short in length, while in the second one the taxiways that are located further away and are longer. Here, the differences in velocities between the far and long and the close and short becomes even larger in favor of the longer and further away ones compared to the previous two figures. However, these differences, in the blocks where close and short taxiways have higher velocities, become smaller.

Overall, we can conclude that there exist a close relationship between the length of the taxiway and the taxiing velocity. The location of the taxiway segment seems to be also critical. We must also note that traffic congestion has a more deleterious effect on the average taxiing velocity than bad weather conditions.

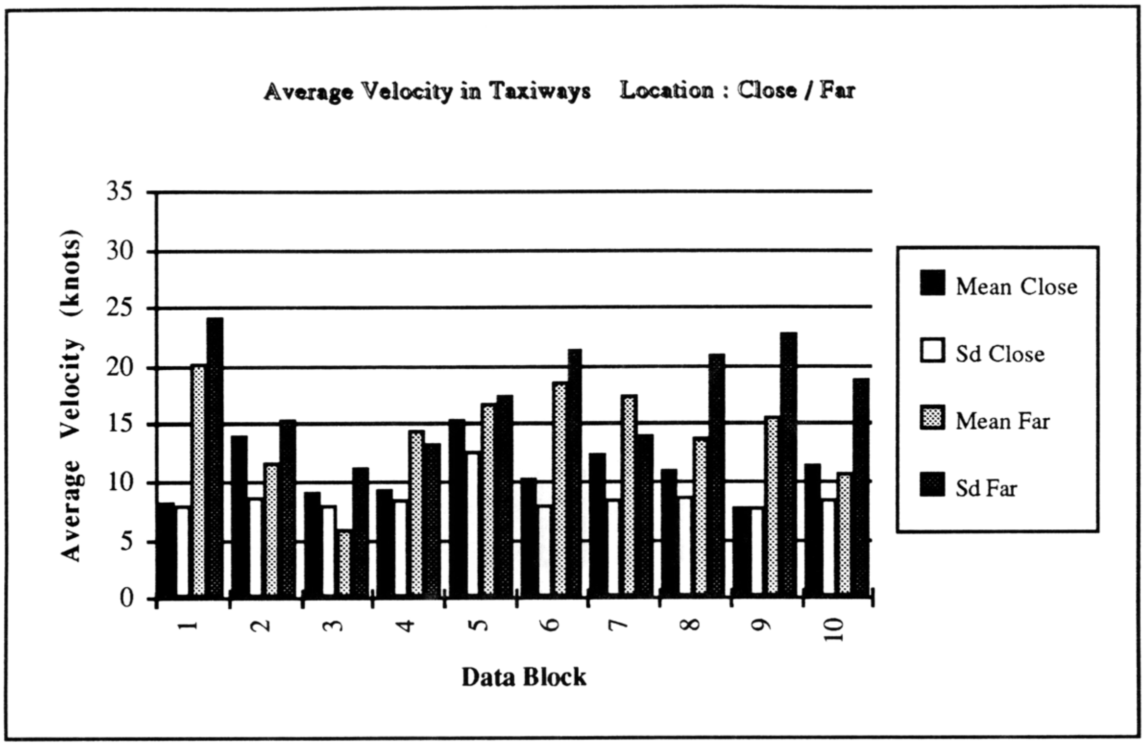


Figure 3.6.1.3

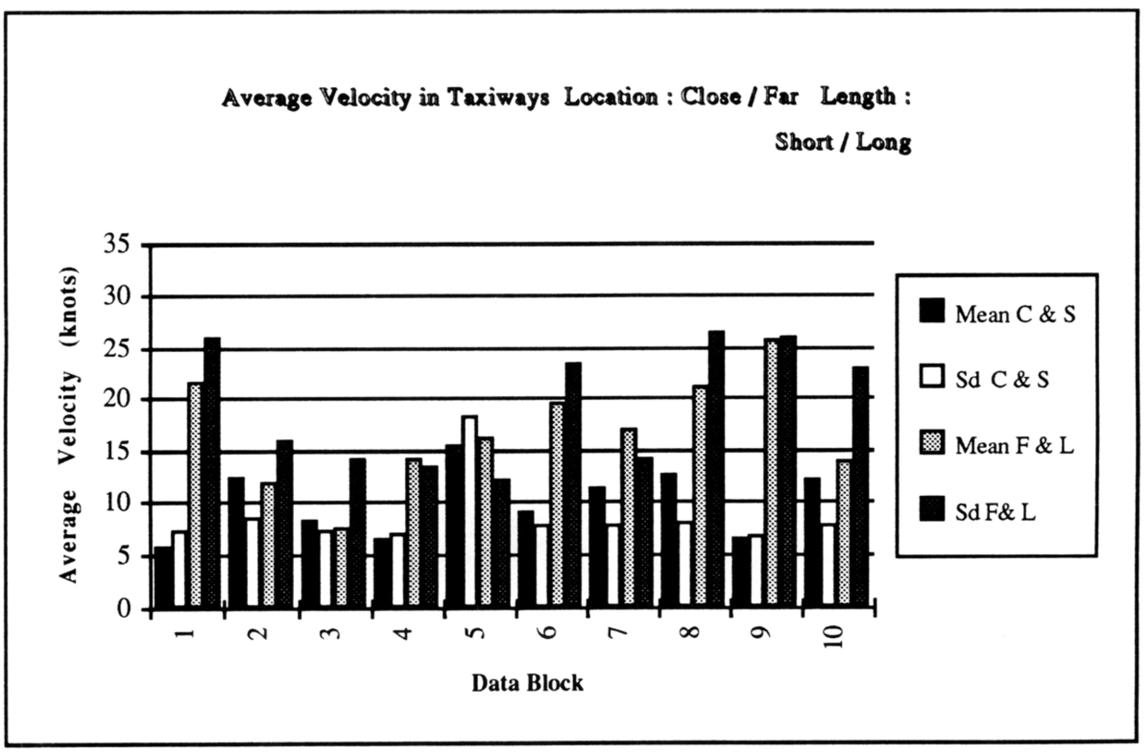


Figure 3.6.1.4

3.6.2 Taxiway Use

Figure 3.6.2.1 through 3.6.2.10 present the use of the taxiway segments that constitute the inner and outer taxilanes. All data blocks show an almost identical taxiway use no matter what is the runway configuration. The most often used taxiway links are B03-B04 and B04-B05 of the inner taxilane. Only block 3 demonstrates a higher percentage wise use of the outer taxilane, probably due to the heavy surface traffic of that day.

In figure 3.6.2.11 through 3.6.2.20 the use of the supporting taxiways is presented. As supporting taxiways are classified all the taxiway links that do not belong to either a runway or the inner and outer taxilanes, but feed traffic to the terminal and runway areas. A very strong relationship between the use of the these taxiway links and the particular runway configuration seem to exist, as figures of data blocks with the same configuration seem identical.

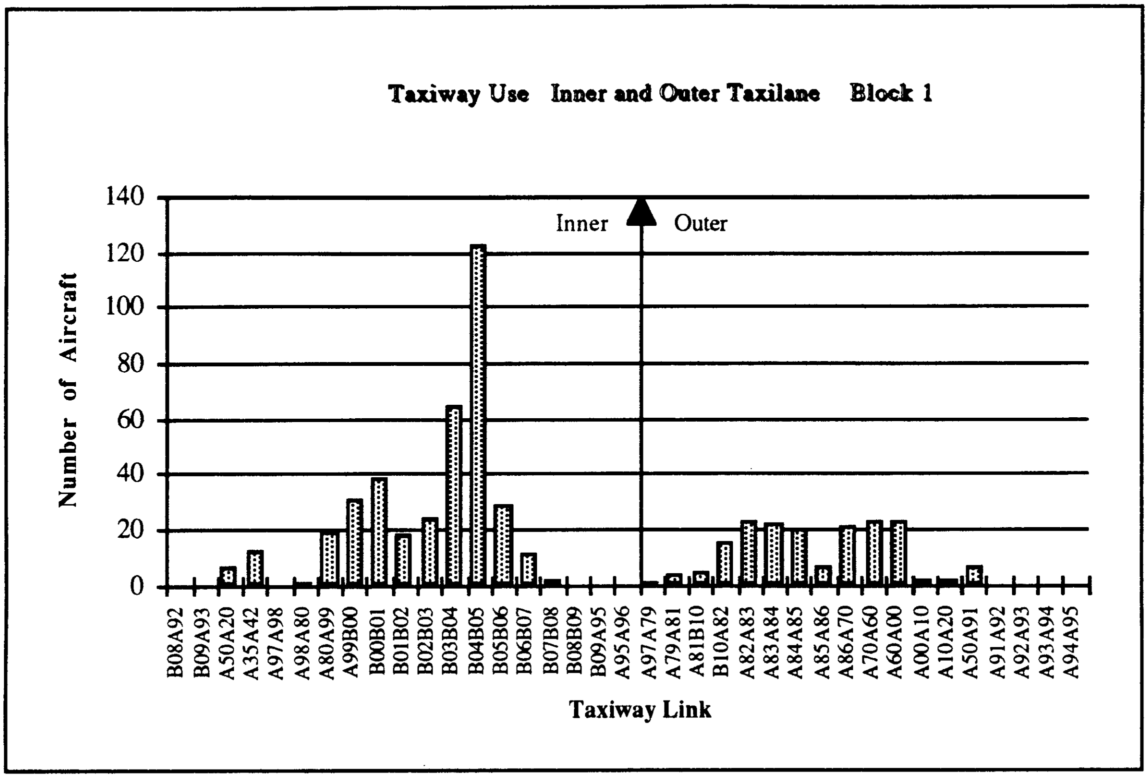


Figure 3.6.2.1

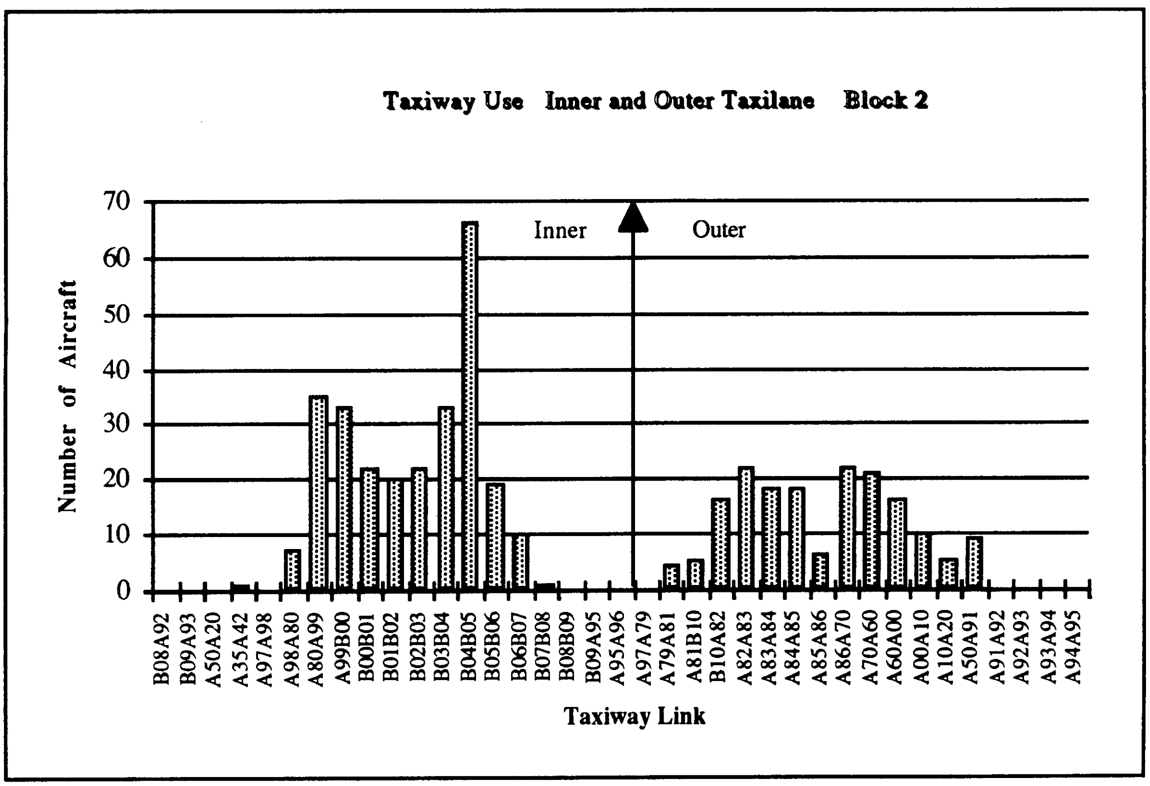
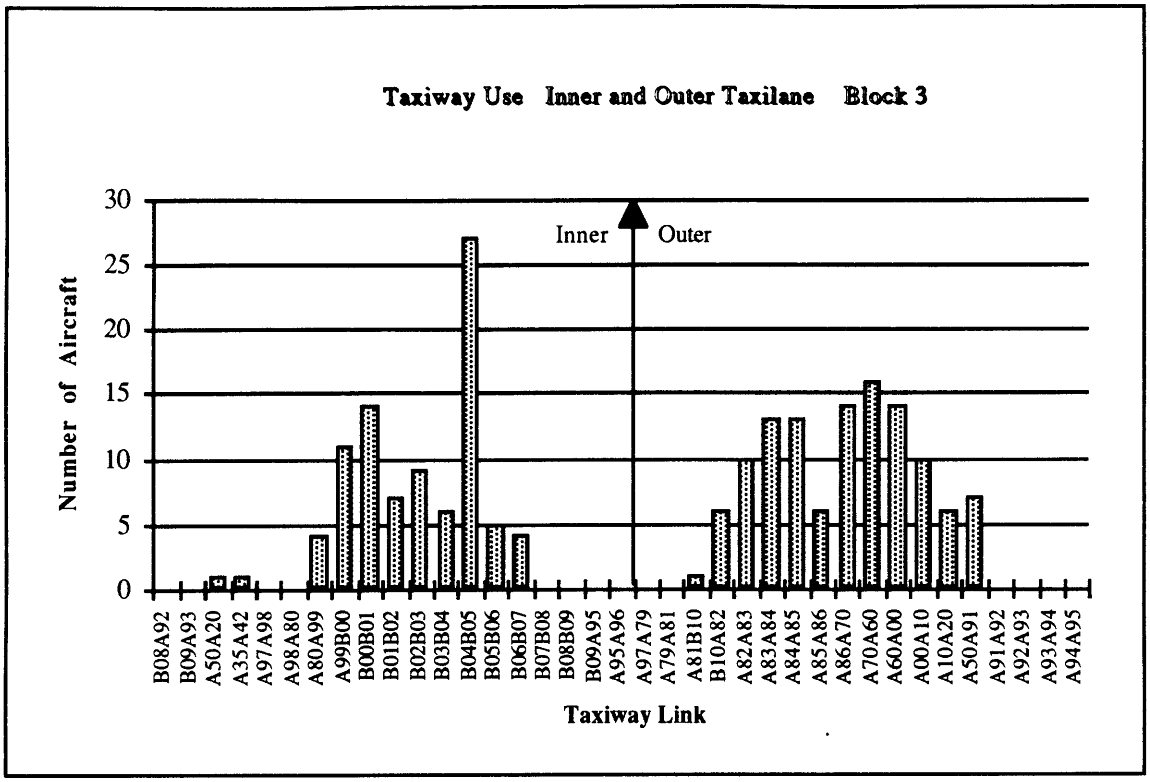


Figure 3.6.2.2



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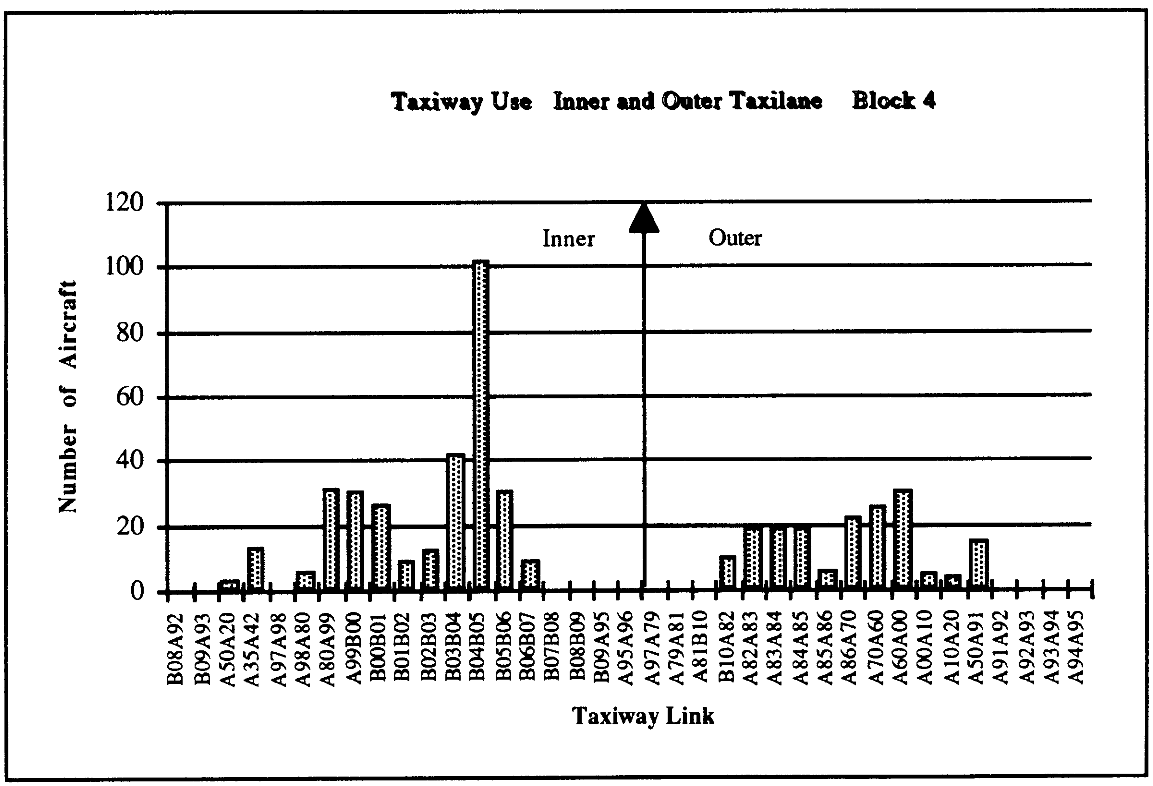


Figure 3.6.2.4

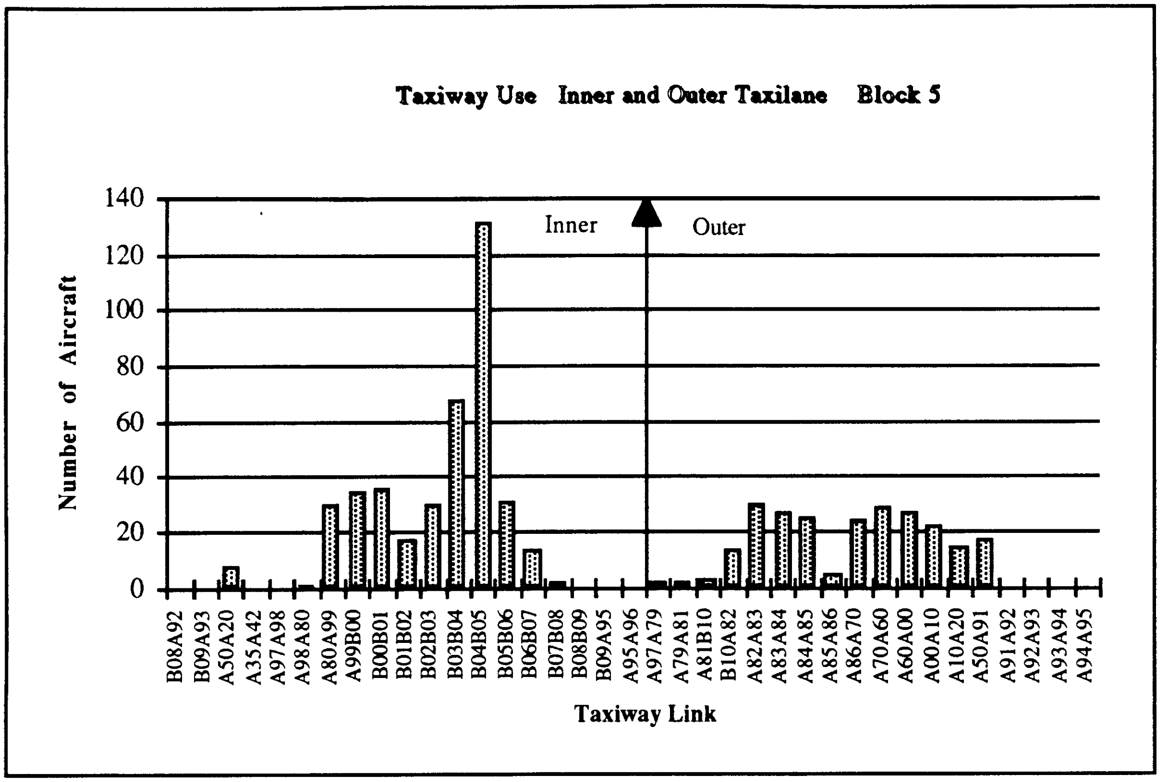


Figure 3.6.2.5

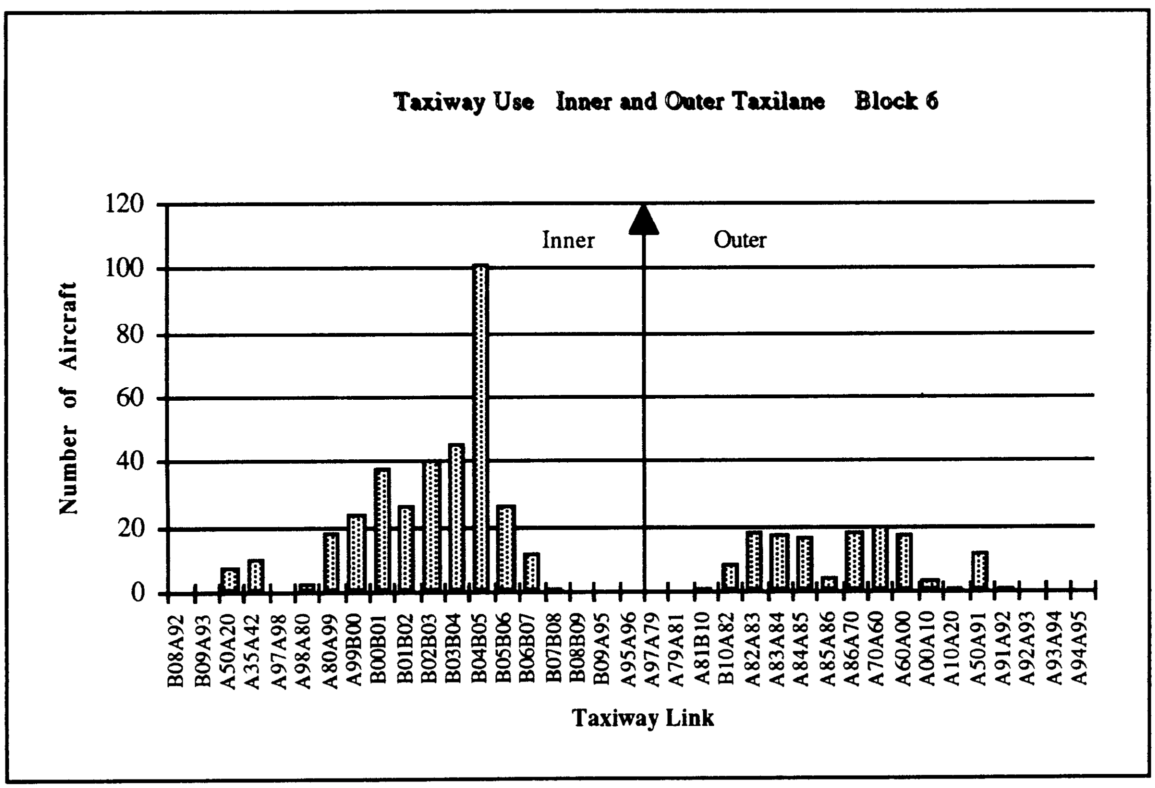


Figure 3.6.2.6

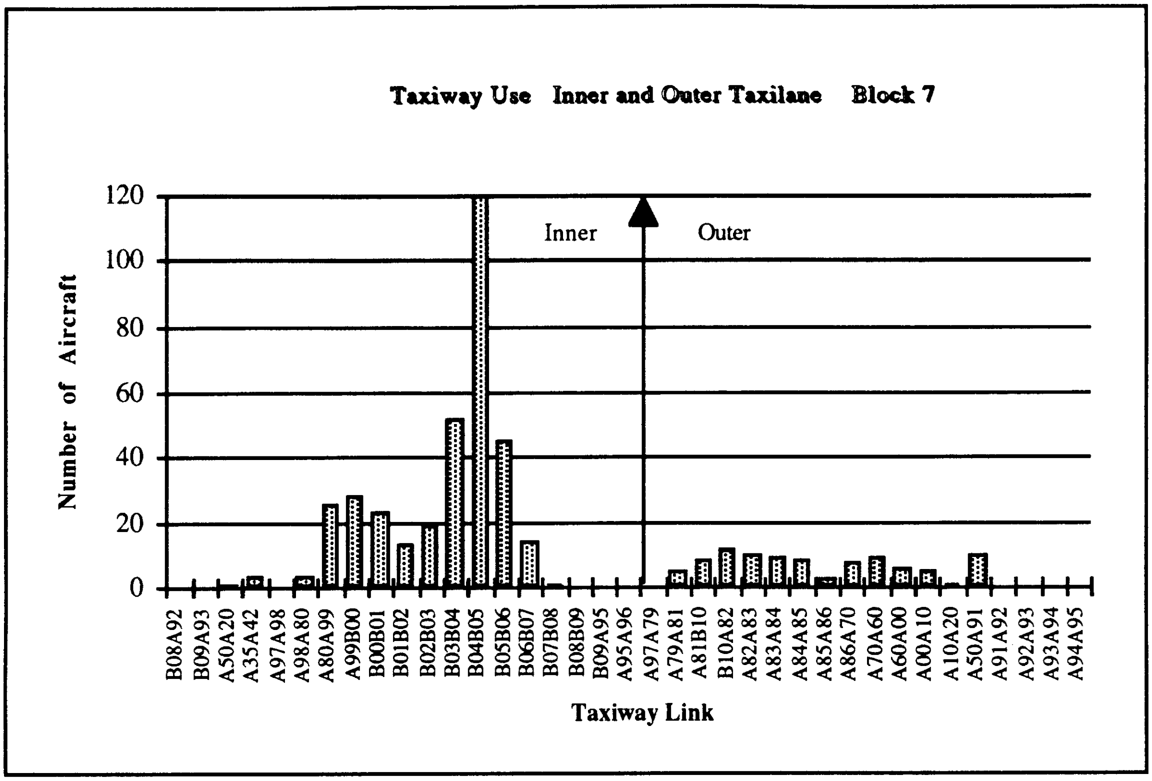


Figure 3.6.2.7

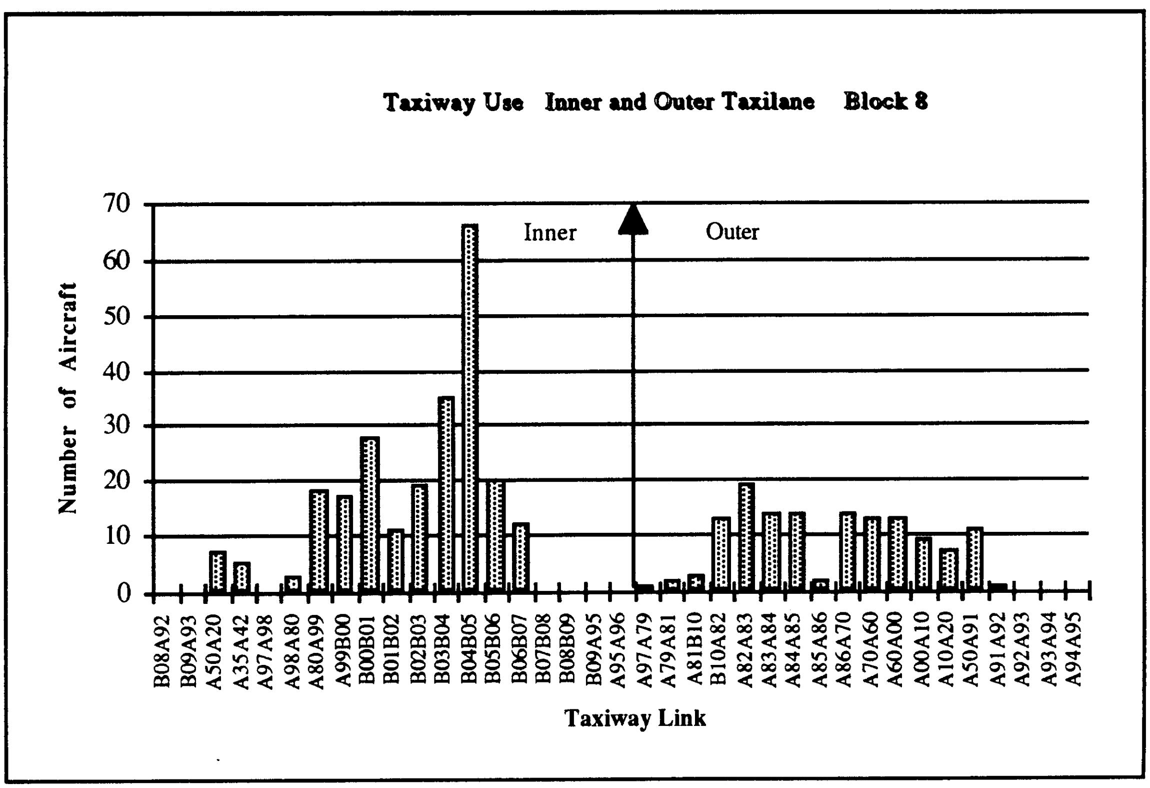


Figure 3.6.2.8

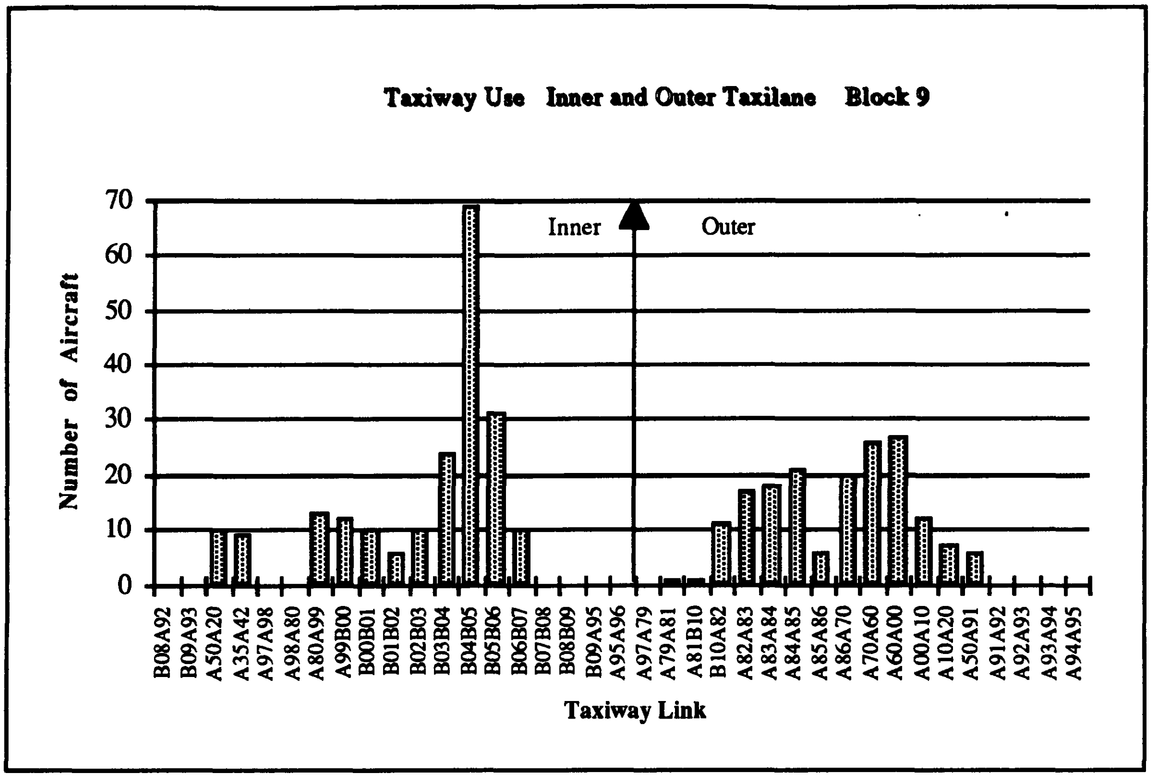


Figure 3.6.2.9

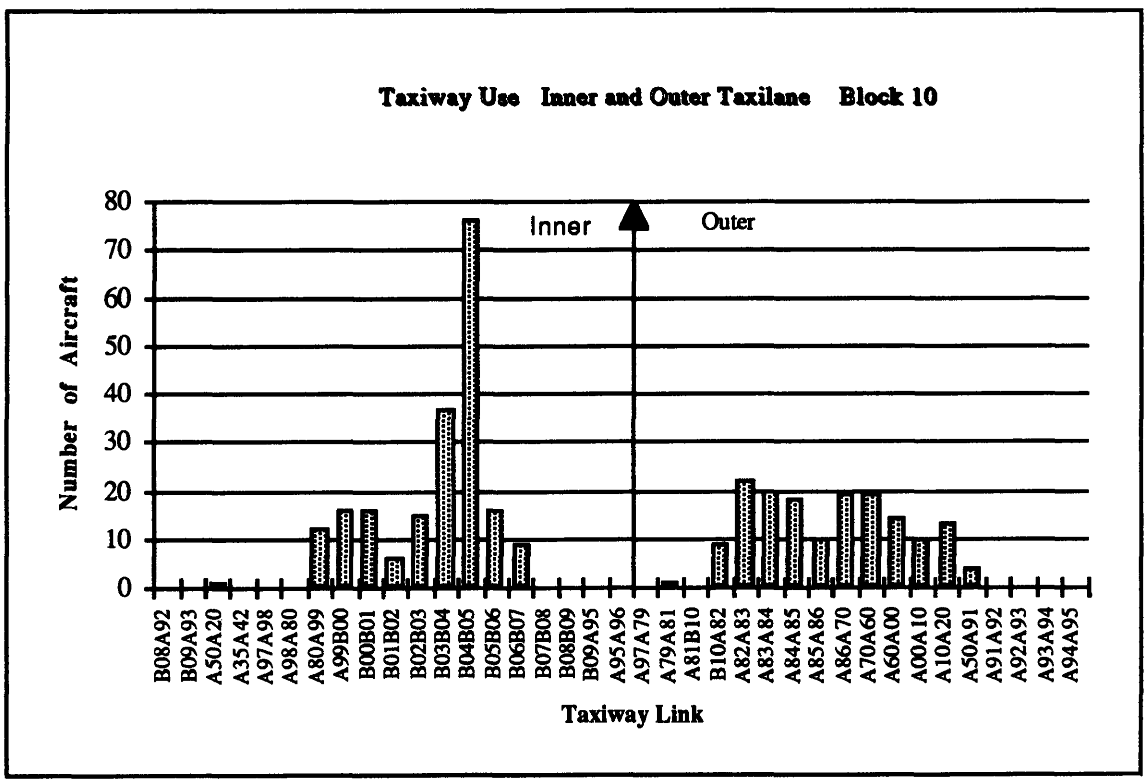


Figure 3.6.2.10

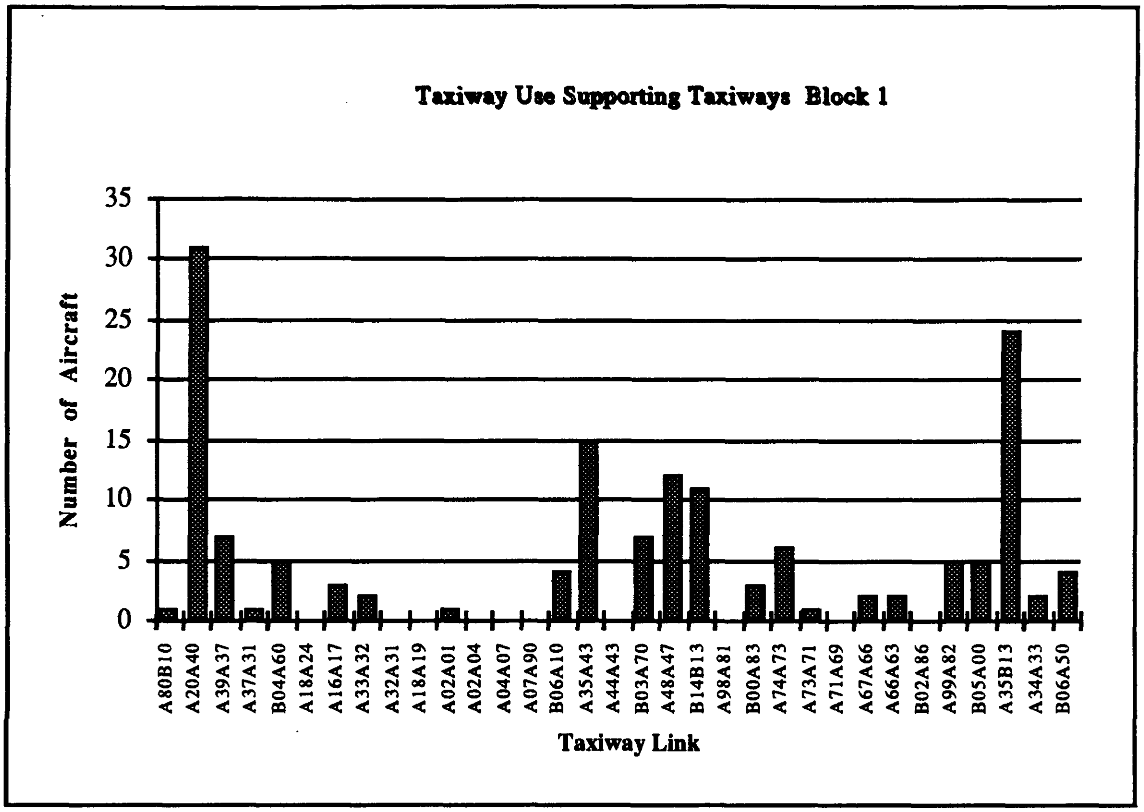
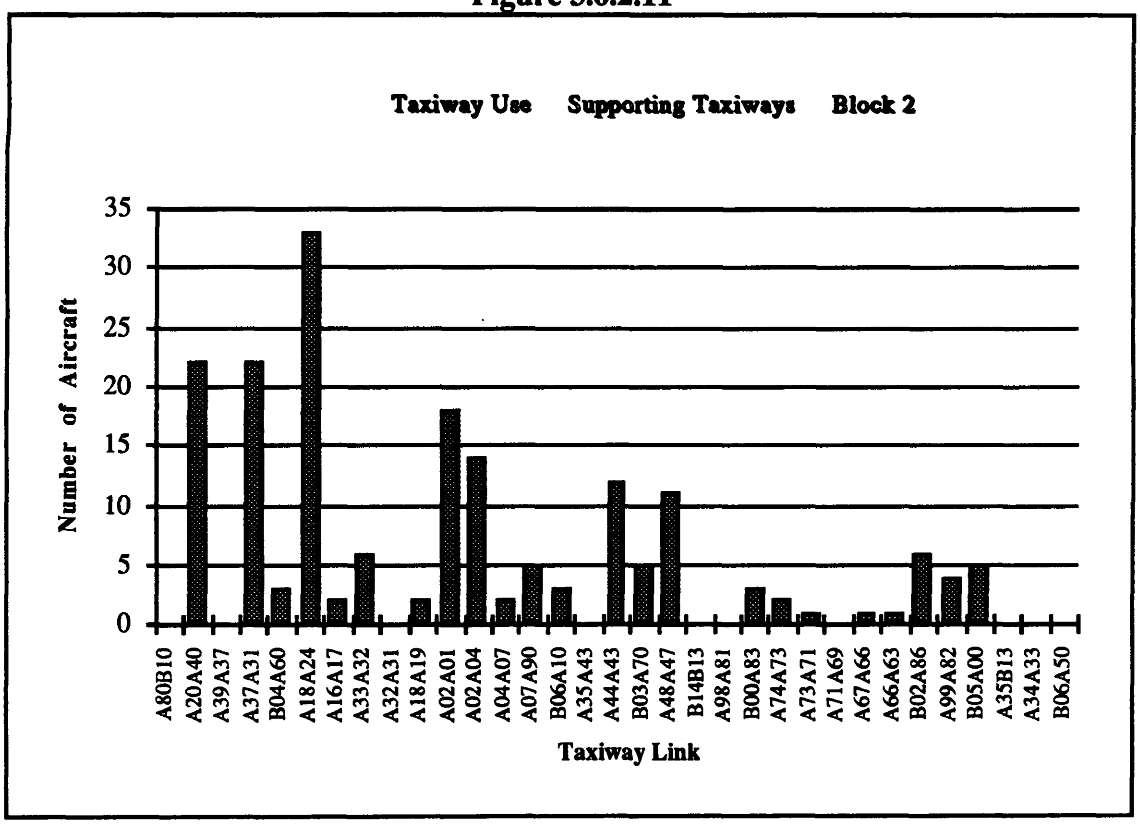


Figure 3.6.2.11



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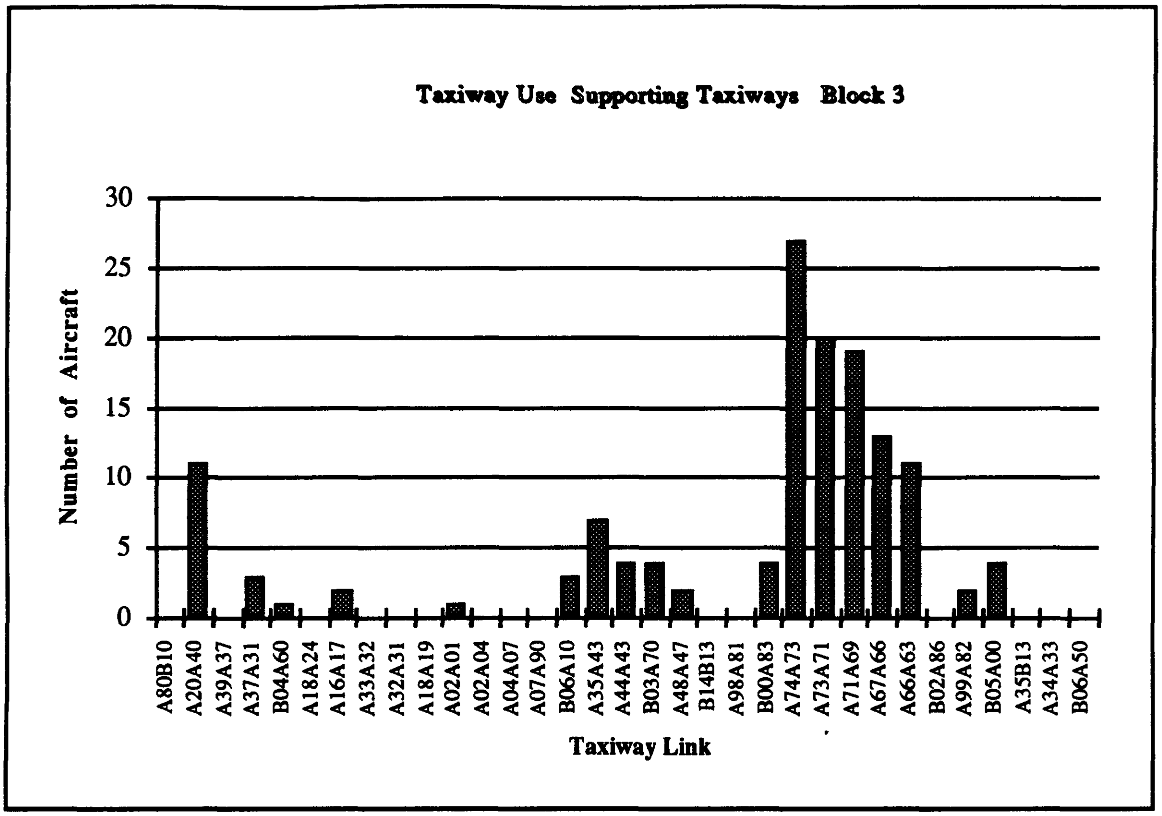

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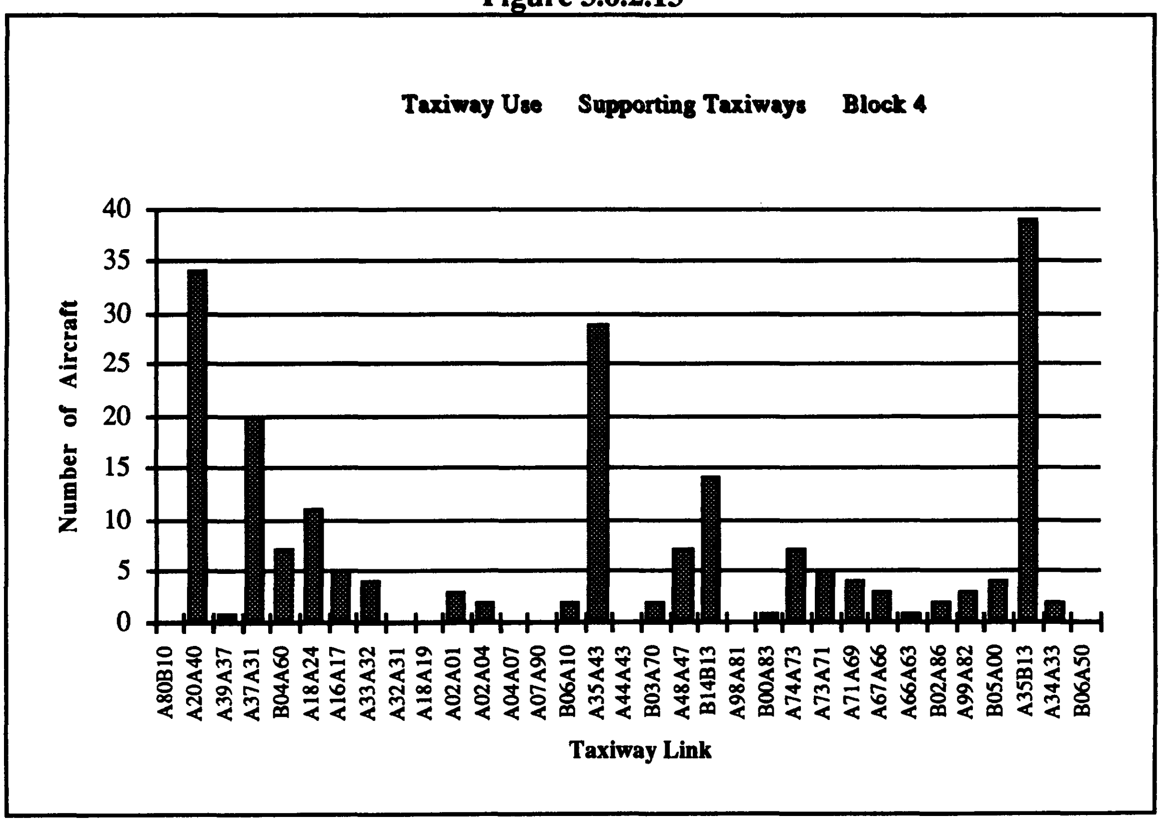
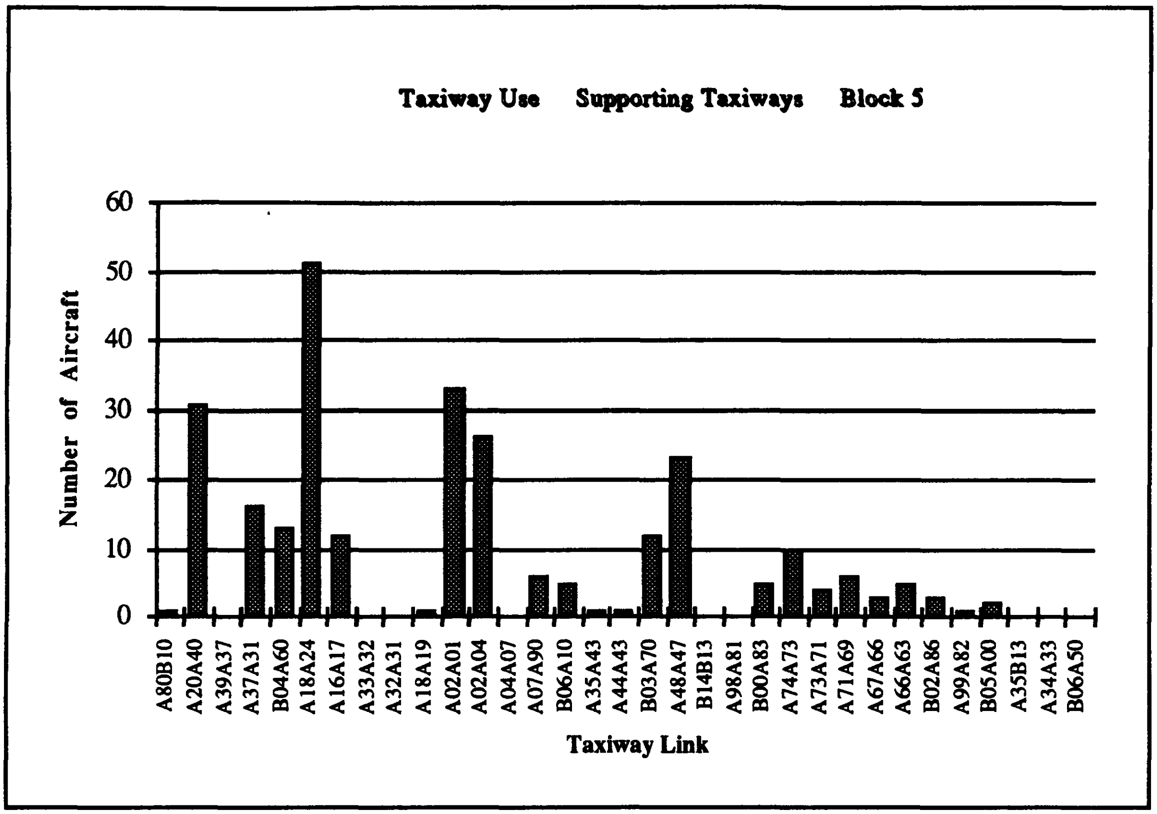


Figure 3.6.2.14



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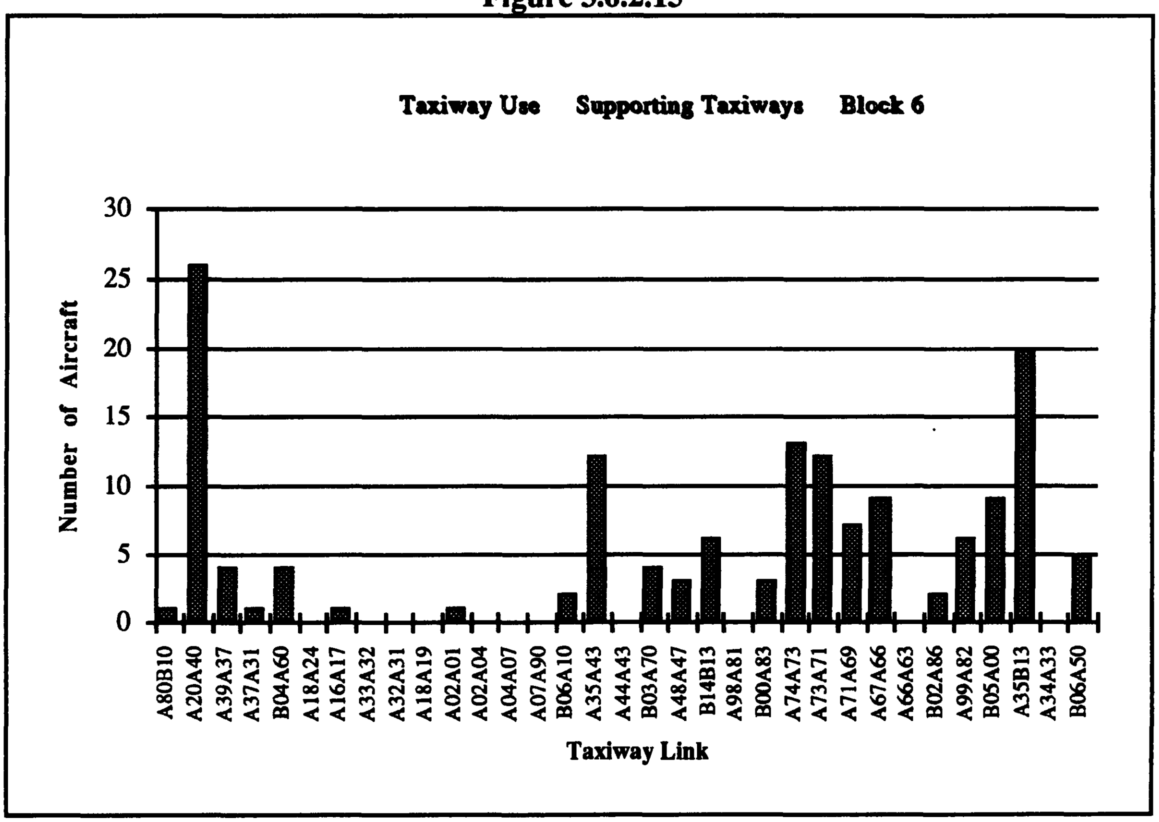

Figure 3.6.2.16

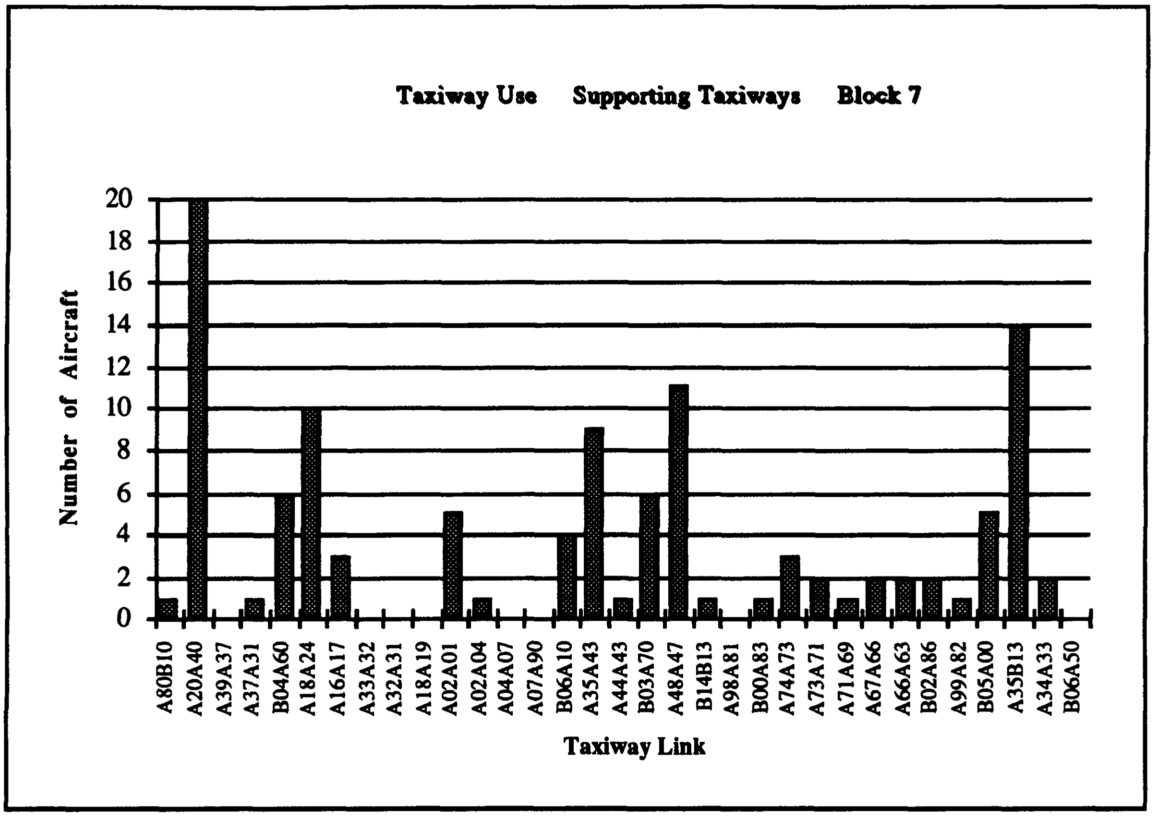

Figure 3.6.2.17

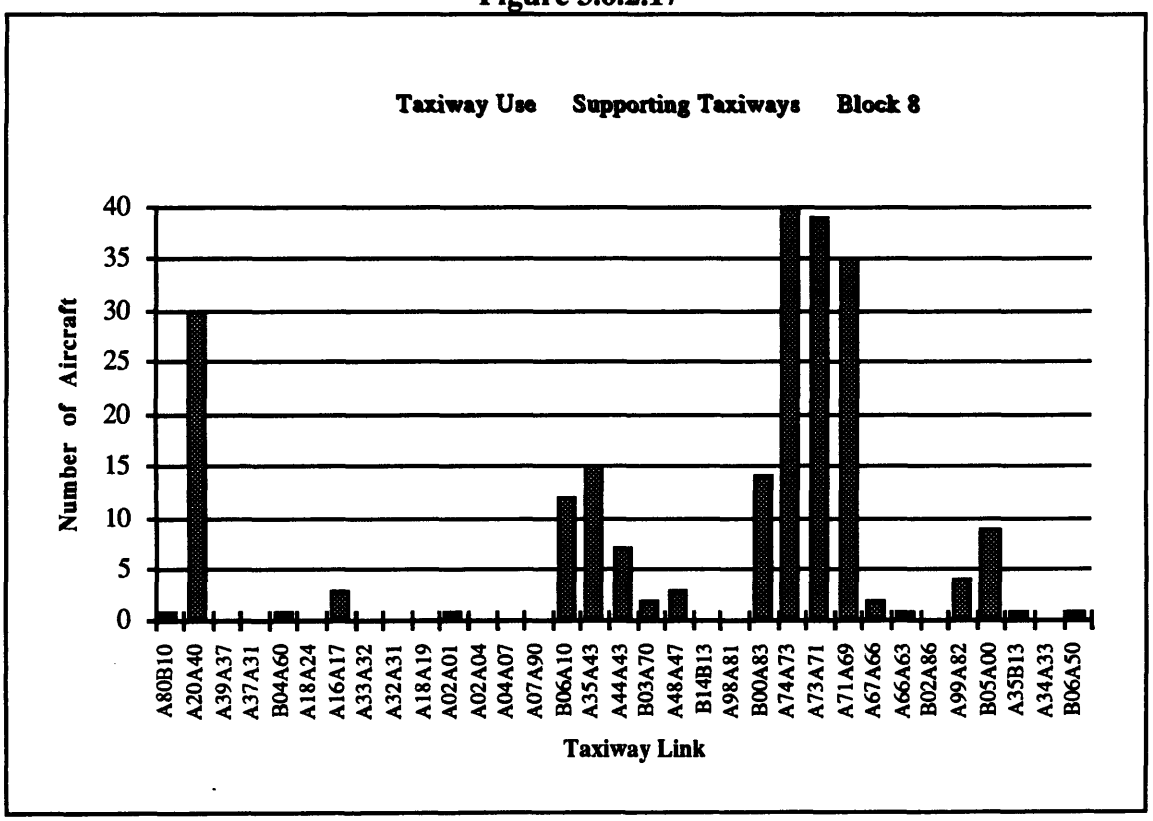

Figure 3.6.2.18

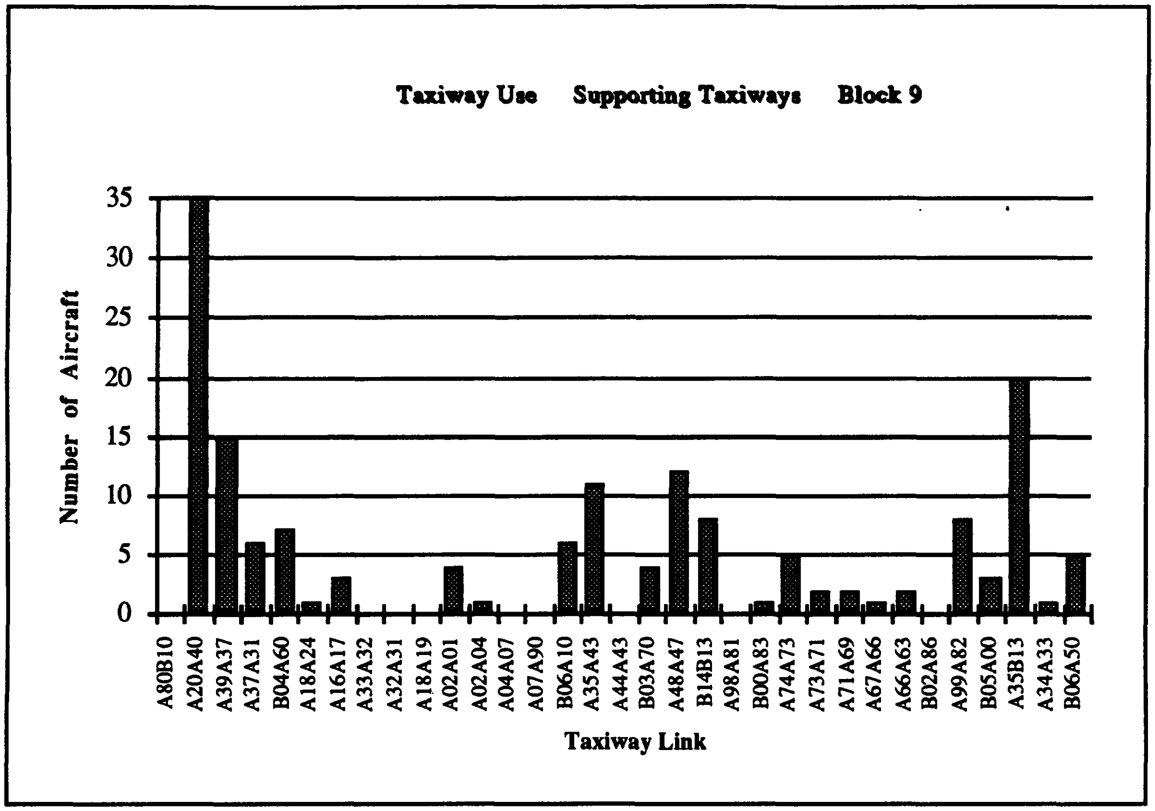

Figure 3.6.3.19

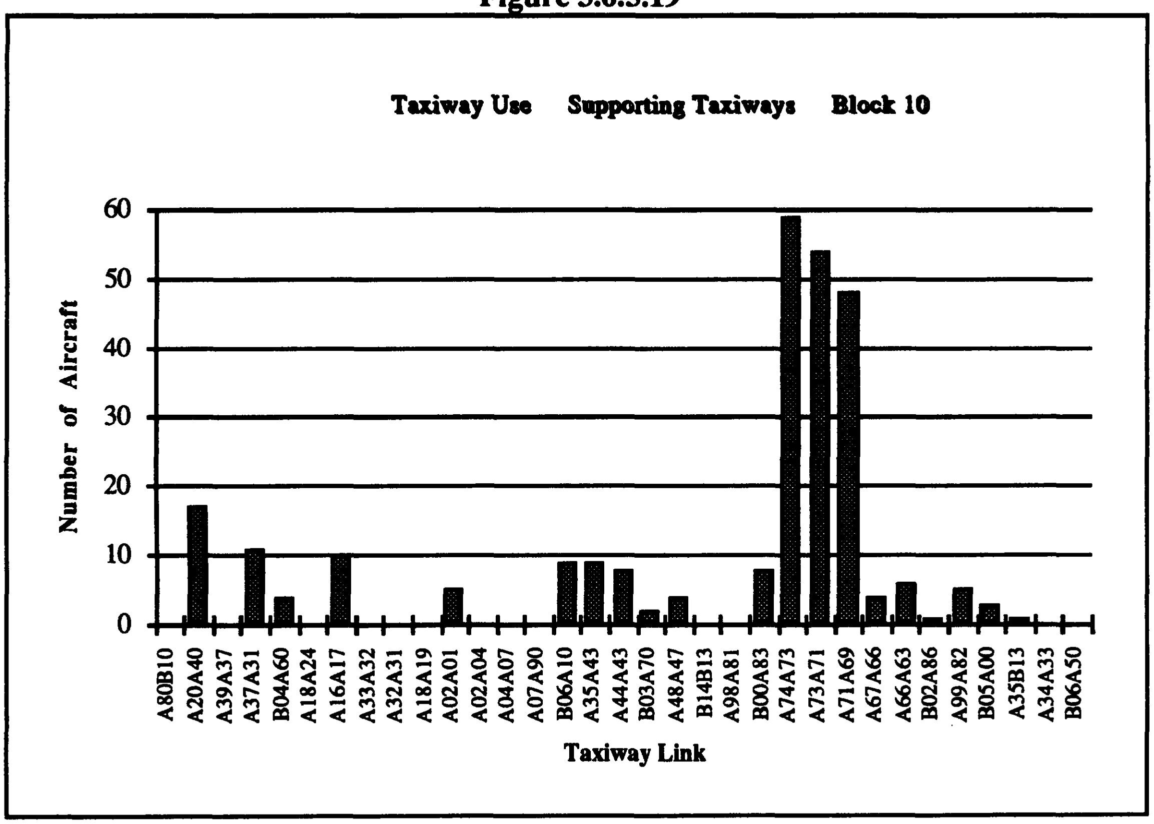

Figure 3.6.2.20

Chapter 4

Conclusions

4.1 Introduction

In this chapter the major observations of the previous analyses are discussed and final conclusions are drawn. These conclusions are divided into three sections; runways, intersections and taxiways. Finally, the last part provides some directions for future research.

4.2 Runways

The runway analysis showed some interesting results. The occupancy time on landing does vary, as expected, with aircraft size but this variation is mainly due to the fact that heavier aircraft tend to exit further down the runway, resulting in higher occupancy times. However, aircraft using a given exit have similar occupancy time, independently of aircraft size. The particular angle of the exit used also plays a very significant role. Aircraft that use obtuse angled exits, usually exit at higher speeds, and therefore maintain a higher average landing velocity resulting in similar occupancy times compared to exits that are located much closer to the runway threshold. The standard deviation of the occupancy time is usually smaller for aircraft using the first exits, than those exiting further down the runway. Visibility also affected the occupancy time, mainly due to the increased use of exits located further down the runway. In similar weather conditions, aircraft using exit 6 (high speed) of runway 27, in day light had average occupancy times of 35 seconds (lowest overall), while at night, in similar weather conditions, most aircraft used exit 8 (low speed) and their occupancy times were significantly increased (53 seconds).

In the analysis of exit usage, as mentioned above, heavier aircraft tend to use exits located further away from the threshold, while smaller sized ones require shorter landing distances and exit earlier. The specific turning angle of the exit was also a determinant factor of its use. As a result, independently of runway, most aircraft tended to prefer the use of obtuse angled (high speed) exits.

Exit velocities, as expected, were closely related to the angle of the exit, and whenever aircraft where using obtuse angled exits they exited at significantly higher speeds. However, this was only true, for high speed exits that were accompanied with long exit segments and allowed the pilot enough distance to brake. The exit velocity did not vary uniformly between aircraft classes and it seemed that exit velocity does not depend on aircraft size.

The landing velocity profiles showed a close relationship between the amount of deceleration and the type of exit (high or low speed) used after landing. In the final approach, we observed a slight deceleration as the aircraft were approaching the threshold. Data from runway 27, illustrated the importance of visibility, as in day light, this deceleration was quite significant whereas during night operations we saw a much smoother final approach profile. In runway 15R, under different weather conditions, aircraft seem to even accelerate before the threshold.

4.3 Intersections

There is a significant difference in average crossing time depending on the runway configuration and thus in the direction of use of some intersections. For example, when intersections 10, 11, 12, 13 and 14 are used in the inbound direction (towards the terminal area), usually after arrivals in runway 27, the crossing times seem to be much smaller compared to those of departing aircraft which use the same intersections but in the opposite direction (outbound), and often have to form a queue while waiting to depart from runway 9 and thus cross these intersections very slowly.

Comparing the crossing times of the two different segments of each intersection (time 1 and time 2), we observe that usually when an intersection is used in the inbound direction time 2 is larger than time 1 and when it used in the outbound time 1 is larger. This could be due to the fact that often pilots slow down and approach the terminal area cautiously, while on their way to the departing runway, they accelerate faster out of an intersection since the taxiways that lead away from the terminal are usually longer. Aircraft size did not seem to be a determinant of crossing times as larger size aircraft had longer crossing times only in few blocks. Exit usage was closely tied to the operating runway configuration.

4.4 Taxiways

In the taxiway analysis we saw that there exists a close relationship between the length of the taxiway and its velocity. Taxiways far away from the terminal almost always exhibit higher average velocities since they tend to be less congested and free of surrounding obstacles. We must note though, that in periods of heavy traffic the differences in speed between longer and shorter taxiways become smaller. The use of the inner and outer taxilanes under different configurations is almost identical. However, a very strong relationship between the use of the supporting taxiways around the terminal area, and the particular runway configuration seems to exist.

4.5 Directions for Future Research

Although after the analysis of the data many questions regarding the motion characteristics of aircraft moving on the surface of Logan airport have been answered, many more have been raised. More research should be done on the factors that affect airport surface traffic in order to successfully develop and implement future surface traffic automation systems. This study was limited to only Logan airport but a future one should include and compare data from a wide variety of airports.

Such a study could include analysis of other variables that affect surface traffic such as congestion and examine in further detail their potential effects. Most importantly, a much larger size of data must be gathered. This requires some form of radar surveillance at the airport. In our case, even though almost 12 hours of airport operation data were made available for this study, after the breakdown of all aircraft by aircraft type, runway and exit used we were left with very small sample for each variable that we wanted to measure, limiting the accuracy of our results. There is much more data available for Logan if further confidence in the measurements is required.

Hopefully, the content of this thesis will act a catalyst in attracting interest and consequently, more studies will be under taken in the future, for a more complete understanding of the surface traffic variables and a more efficient use of the airport surface.

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