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ANALYSIS OF AIRCRAFT SURFACE MOTION
AT BOSTON LOGAN INTERNATIONAL AIRPORT

Robert Elias Alhanatis

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ANALYSIS OF AIRCRAFT SURFACE MOTION
AT
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by

Robert Elias Alhanatis

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Boston University, 1992

Submitted to the Department of Aeronautics and Astronautics
in Partial Fulfillment of the Requirements for the
Degree of

MASTER OF SCIENCE

at the

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September 1994

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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
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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 taxiing. 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).

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\textsuperscript{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\textsuperscript{3}.

The configurations\textsuperscript{4} that are used most often at Logan are:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>VFR</th>
<th>IFR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Arrivals</td>
<td>Departures</td>
</tr>
<tr>
<td>1</td>
<td>4L &amp; 4R</td>
<td>4L, 4R &amp; 9</td>
</tr>
<tr>
<td>2</td>
<td>22L &amp; 27*</td>
<td>22R &amp; 22L</td>
</tr>
<tr>
<td>3</td>
<td>33L &amp; 33R</td>
<td>27 &amp; 33L</td>
</tr>
<tr>
<td>4</td>
<td>9, 15R &amp; 15L*</td>
<td>15R &amp; 9</td>
</tr>
</tbody>
</table>

\textsuperscript{*} These configurations employ hold-short procedures.

\textsuperscript{2,4} Boston Logan International Airport Capacity Enhancement Plan, October 1992 published by the FAA.
\textsuperscript{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.
Figure 2.2.3
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. 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

<table>
<thead>
<tr>
<th>Runway Configuration</th>
<th>Table 2.4.1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arrivals</strong></td>
<td><strong>Departures</strong></td>
</tr>
<tr>
<td>4R</td>
<td>9, 4L</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weather / ATIS</th>
<th>Table 2.4.2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temp</strong></td>
<td><strong>Ceiling</strong></td>
</tr>
<tr>
<td>n/a</td>
<td>500ft ovc</td>
</tr>
<tr>
<td>n/a</td>
<td>1800ft ovc</td>
</tr>
<tr>
<td>n/a</td>
<td>1100ft ovc</td>
</tr>
</tbody>
</table>
Block-2

Day:   Friday, March 26, 1993
Time:  10:35-11:35  Local

Runway Configuration | Table 2.4.3

<table>
<thead>
<tr>
<th>Arrivals</th>
<th>Departures</th>
<th>Switched to</th>
<th>Arrivals</th>
<th>Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>9</td>
<td></td>
<td>33L, 27</td>
<td>33L, 22R</td>
</tr>
</tbody>
</table>

Weather / ATIS | Table 2.4.4

<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>55 °F</td>
<td>800ft. scat</td>
<td>7 miles</td>
<td>160°@7knots</td>
<td>Heavy Traffic, All Taxiways OK.</td>
</tr>
</tbody>
</table>

Block-3

Day:   Wednesday, April 21, 1993
Time:  17:35-18:35  Local

Runway Configuration | Table 2.4.5

<table>
<thead>
<tr>
<th>Arrivals</th>
<th>Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>22R</td>
</tr>
</tbody>
</table>

Weather / ATIS | Table 2.4.6

<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 °F</td>
<td>2500ft ovc</td>
<td>15 miles</td>
<td>180°@17knots</td>
<td>Heavy Traffic.</td>
</tr>
</tbody>
</table>

Block-4

Day:   Tuesday, March 26, 1993
Time:  13:15-14:15  Local

Runway Configuration | Table 2.4.7

<table>
<thead>
<tr>
<th>Arrivals</th>
<th>Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>15R</td>
<td>9</td>
</tr>
</tbody>
</table>

Weather / ATIS | Table 2.4.8

<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 °F</td>
<td>Sunny</td>
<td>12 miles</td>
<td>140°@7knots</td>
<td>Busy Traffic, later quieting down</td>
</tr>
</tbody>
</table>
**Block-5**

Day: Thursday, March 11, 1993  
Time: 14:50-16:10  Local  

- **Runway Configuration**: Table 2.4.9  
  - Arrivals  
    - 33L
  - Departures  
    - 22R, 33L

- **Weather / ATIS**: Table 2.4.10  
<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 °F</td>
<td>5500ft</td>
<td>15 miles</td>
<td>300'@15knots</td>
<td>Snow in the morning</td>
</tr>
</tbody>
</table>

**Block-6**

Day: Wednesday, March 31, 1993  
Time: 19:15-20:15  Local  

- **Runway Configuration**: Table 2.4.11  
  - Arrivals  
    - 4R, 4L
  - Departures  
    - 9, 4L

- **Weather / ATIS**: Table 2.4.12  
<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 °F</td>
<td>6500ft</td>
<td>15 miles</td>
<td>110'@8knots</td>
<td>Snow in the morning</td>
</tr>
</tbody>
</table>

**Block-7**

Day: Saturday, March 13, 1993  
Time: 09:45-10:45  Local  

- **Runway Configuration**: Table 2.4.13  
  - Arrivals  
    - 15R
  - Departures  
    - 9, 15R

- **Weather / ATIS**: Table 2.4.14  
<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 °F</td>
<td>5000 ft</td>
<td>5 miles</td>
<td>127'@8knots</td>
<td>ILS approaches 15R</td>
</tr>
<tr>
<td>33 °F</td>
<td>3800 ft</td>
<td>12 miles</td>
<td>110'@17knots</td>
<td>ILS approaches 15R, light snow</td>
</tr>
<tr>
<td>32 °F</td>
<td>1500ftovc</td>
<td>1 mile</td>
<td>110'@15knots</td>
<td>ILS approaches 4R, light snow</td>
</tr>
</tbody>
</table>
Block-8
Day: Wednesday, April 21, 1993
Time: 19:50-20:50 Local

Runway Configuration Table 2.4.15

<table>
<thead>
<tr>
<th>Arrivals</th>
<th>Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>22L, 27</td>
<td>22R, 22L</td>
</tr>
</tbody>
</table>

Weather / ATIS Table 2.4.16

<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>59°F</td>
<td>2500 ft</td>
<td>scat</td>
<td>15 miles</td>
<td>225°@11 knots</td>
</tr>
</tbody>
</table>

Block-9
Day: Tuesday, March 30, 1993
Time: 07:45-08:45 Local

Runway Configuration Table 2.4.17

<table>
<thead>
<tr>
<th>Arrivals</th>
<th>Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>

Weather / ATIS Table 2.4.18

<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>43°F</td>
<td>700 ft</td>
<td>2 miles</td>
<td>40°@12 knots</td>
<td>Light drizzle &amp; Fog</td>
</tr>
</tbody>
</table>

Block-10
Day: Wednesday, April 21, 1993
Time: 09:00-10:02 Local

Runway Configuration Table 2.4.19

<table>
<thead>
<tr>
<th>Arrivals</th>
<th>Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>22L, 27</td>
<td>22R, 27</td>
</tr>
</tbody>
</table>

Weather / ATIS Table 2.4.20

<table>
<thead>
<tr>
<th>Temp</th>
<th>Ceiling</th>
<th>Visibility</th>
<th>Wind</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>60°F</td>
<td>2500 ftovc</td>
<td>15 miles</td>
<td>225°@16 knots</td>
<td>n/a</td>
</tr>
</tbody>
</table>
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).

<table>
<thead>
<tr>
<th>Tgt:11584</th>
<th>Length: 287</th>
<th>Start time: 57995.3</th>
<th>End time: 58588.6</th>
<th>States: DEP TAX STP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target ID</td>
<td>ASDE ID</td>
<td>Time</td>
<td>Stamp</td>
<td>State</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>57995.375</td>
<td>1</td>
<td>TAX</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>57997.126</td>
<td>2</td>
<td>TAX</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>57998.878</td>
<td>3</td>
<td>TAX</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>58000.629</td>
<td>4</td>
<td>TAX</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>58002.382</td>
<td>5</td>
<td>TAX</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>58004.134</td>
<td>6</td>
<td>TAX</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>58005.885</td>
<td>7</td>
<td>TAX</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>58007.637</td>
<td>8</td>
<td>TAX</td>
</tr>
<tr>
<td>11584</td>
<td>5575</td>
<td>58009.388</td>
<td>9</td>
<td>TAX</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Taxiway</th>
<th>Series of Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>B08 A92</td>
</tr>
<tr>
<td>V</td>
<td>B09 A93</td>
</tr>
<tr>
<td>X</td>
<td>A50 A20 A42 A35 A36</td>
</tr>
<tr>
<td></td>
<td>A55</td>
</tr>
<tr>
<td>---</td>
<td>-----</td>
</tr>
<tr>
<td>INNER</td>
<td>A97</td>
</tr>
<tr>
<td></td>
<td>B07</td>
</tr>
<tr>
<td>OUTER</td>
<td>A97</td>
</tr>
<tr>
<td></td>
<td>A00</td>
</tr>
<tr>
<td>Z</td>
<td>A80</td>
</tr>
<tr>
<td>N2</td>
<td>A71</td>
</tr>
<tr>
<td>B</td>
<td>A20</td>
</tr>
<tr>
<td>S1</td>
<td>A37</td>
</tr>
<tr>
<td>C</td>
<td>B04</td>
</tr>
<tr>
<td>S2</td>
<td>A33</td>
</tr>
<tr>
<td>D</td>
<td>A18</td>
</tr>
<tr>
<td>NA</td>
<td>A73</td>
</tr>
<tr>
<td>E</td>
<td>B06</td>
</tr>
<tr>
<td>NB</td>
<td>A63</td>
</tr>
<tr>
<td>S2A</td>
<td>A32</td>
</tr>
<tr>
<td>F</td>
<td>B03</td>
</tr>
<tr>
<td>G</td>
<td>A21</td>
</tr>
<tr>
<td>S01</td>
<td>B14</td>
</tr>
<tr>
<td>H</td>
<td>A49</td>
</tr>
<tr>
<td>J</td>
<td>A48</td>
</tr>
<tr>
<td>K</td>
<td>A98</td>
</tr>
<tr>
<td>L</td>
<td>A79</td>
</tr>
<tr>
<td>N</td>
<td>B00</td>
</tr>
<tr>
<td>DA</td>
<td>A02</td>
</tr>
<tr>
<td>P</td>
<td>A44</td>
</tr>
<tr>
<td>DB</td>
<td>A04</td>
</tr>
<tr>
<td>Q</td>
<td>B02</td>
</tr>
<tr>
<td>R</td>
<td>A66</td>
</tr>
<tr>
<td>I00</td>
<td>A99</td>
</tr>
<tr>
<td>S</td>
<td>B05</td>
</tr>
<tr>
<td>I01</td>
<td>B06</td>
</tr>
<tr>
<td>T</td>
<td>B02</td>
</tr>
</tbody>
</table>

**Runway**

<table>
<thead>
<tr>
<th></th>
<th>22L</th>
<th>A61</th>
<th>A62</th>
<th>A64</th>
<th>A65</th>
<th>A57</th>
<th>A29</th>
<th>A14</th>
<th>A23</th>
<th>A49</th>
<th>A24</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4R</td>
<td>A45</td>
<td>A09</td>
<td>A28</td>
<td>A27</td>
<td>A26</td>
<td>A25</td>
<td>A87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4R</td>
</tr>
<tr>
<td>4L</td>
<td>22R</td>
<td>A68</td>
<td>A67</td>
<td>A72</td>
<td>A59</td>
<td>A54</td>
<td>A53</td>
<td>A51</td>
<td>A47</td>
<td>A46</td>
<td>A43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A42</td>
<td>A88</td>
<td>N1</td>
<td>A39</td>
<td>4L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15R</td>
<td>33L</td>
<td>A11</td>
<td>A12</td>
<td>A13</td>
<td>A01</td>
<td>A21</td>
<td>A22</td>
<td>A14</td>
<td>A52</td>
<td>A53</td>
<td>A75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B11</td>
<td>A78</td>
<td>A77</td>
<td>A76</td>
<td>15R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15L</td>
<td>33R</td>
<td>A58</td>
<td>A57</td>
<td>A55</td>
<td>A54</td>
<td>A74</td>
<td>A89</td>
<td>15L</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>27</td>
<td>A15</td>
<td>A06</td>
<td>A05</td>
<td>A03</td>
<td>A13</td>
<td>A17</td>
<td>A08</td>
<td>A28</td>
<td>A36</td>
<td>A34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A38</td>
<td>B14</td>
<td>N1</td>
<td>N2</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.2.2**

32
Figure 3.2.1

Zooming to full airport view.

Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.
Starting simulation...
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

<table>
<thead>
<tr>
<th>Runway</th>
<th>Data Block</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>4R</td>
<td>1, 6, 9</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>4L</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>22R</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>22L</td>
<td>8, 10</td>
<td>4, 5</td>
</tr>
<tr>
<td>27</td>
<td>2, 3, 8, 10</td>
<td>6, 7, 8, 9</td>
</tr>
<tr>
<td>9</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>33R</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>33L</td>
<td>2, 5</td>
<td>10, 11</td>
</tr>
<tr>
<td>15R</td>
<td>4, 7</td>
<td>12, 13</td>
</tr>
<tr>
<td>15L</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

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.
<table>
<thead>
<tr>
<th>Exit Number</th>
<th>Runway 27</th>
<th>Runway 9</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>12</td>
<td>A06-A90</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>11</td>
<td>A05-A04</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10</td>
<td>A03-A02</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9</td>
<td>A13-A01</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>8</td>
<td>A17-A18</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>7</td>
<td>A08-A09</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>6</td>
<td>A09-A28</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5</td>
<td>A36-A35</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>4</td>
<td>A34-B13</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>3</td>
<td>B14-A37</td>
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Table 3.4.1.2

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<td>A13-A17</td>
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<td>12</td>
<td>A01-A19</td>
</tr>
<tr>
<td></td>
<td>4</td>
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<td>10</td>
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<td>9</td>
<td>A14-A23</td>
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<td>A77-A79</td>
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</table>

Table 3.4.1.3
Figure 3.4.1.2  Runway 27/9

Zooming out by 1.50...

Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.
<table>
<thead>
<tr>
<th>Exit Number</th>
<th>Runway 4L</th>
<th>Runway 22R</th>
<th>Link</th>
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<tbody>
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<td>13</td>
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<td>A43-A00</td>
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<td>1</td>
<td></td>
<td>A67-69</td>
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Table 3.4.1.4

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<th>Runway 4R</th>
<th>Runway 22L</th>
<th>Link</th>
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</thead>
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<td>A27-A33</td>
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<td>A28-A36</td>
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<td>A09-A44</td>
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<tr>
<td>16</td>
<td>1</td>
<td></td>
<td>A62-A63</td>
</tr>
</tbody>
</table>

Table 3.4.1.5
Rotating airport by 30 degrees...

Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.
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 3.4.1.6
Average Occupancy Time During Landing Runway 22L
Block 8

Figure 3.4.1.7

Average Occupancy Time During Landing Runway 22L
Block 10

Figure 3.4.1.8
Average Occupancy Time During Landing Runway 27
Block 2

Figure 3.4.1.9

Average Occupancy Time During Landing Runway 27
Block 3

Figure 3.4.1.10
Figure 3.4.1.11

Average Occupancy Time During Landing  Runway 27
Block 8

Figure 3.4.1.12

Average Occupancy Time During Landing  Runway 27
Block 10

Figure 3.4.1.12
Figure 3.4.1.13

Average Occupancy Time During Landing  Runway 33L
Block 2

Average Occupancy
Time (sec)

Landing Direction

Exit

Figure 3.4.1.14

Average Occupancy Time During Landing  Runway 33L
Block 5

Average Occupancy Time (sec)

Landing Direction

Exit

Figure 3.4.1.14
Figure 3.4.1.15

Average Occupancy Time During Landing  Runway 15R  Block 4

Figure 3.4.1.16

Average Occupancy Time During Landing  Runway 15R  Block 7

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:

<table>
<thead>
<tr>
<th>Class</th>
<th>Weight Range ('000 LB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>300-900</td>
</tr>
<tr>
<td>Large</td>
<td>12.6-299</td>
</tr>
<tr>
<td>Small</td>
<td>0-12.5</td>
</tr>
</tbody>
</table>

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.
Exit Use per Aircraft Class Runway 4R Block 1 37 Landings

- Small
- Large
- Heavy

Landing Direction

Exit Use per Aircraft Class Runway 4R Block 6 23 Landings

- Small
- Large
- Heavy

Landing Direction

Figure 3.4.2.1

Figure 3.4.2.2
Exit Use Runway 4R Block 9 29 Landings All Classes

% Use

Landing Direction

Exit

Figure 3.4.2.3
Exit Use Runway 22L  Block 8  16 Landings

Figure 3.4.2.4

Exit Use per Aircraft Class  Runway 22L  Block 10  16 Landings

Figure 3.4.2.5
Figure 3.4.2.10

Exit Use per Aircraft Class Runway 33L Block 2 27 Landings

- Small
- Large
- Heavy

Landing Direction

Figure 3.4.2.11

Exit Use per Aircraft Class Runway 33L Block 5 37 Landings

- Small
- Large
- Heavy

Landing Direction

Figure 3.4.2.11
Exit Use per Aircraft Class  Runway 15R  Block 4  21 Landings

Figure 3.4.2.12

Exit Use per Aircraft Class  Runway 15R  Block 7  28 Landings

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.

![Average Exit Velocity All Classes Runway 4R Block 1](image)

*Figure 3.4.3.1*
Figure 3.4.3.2

Average Exit Velocity All Classes Runway 4R Block 6

- A.E.V. + SD
- A.E.V. - SD

Landing Direction

Figure 3.4.3.3

Average Exit Velocity All Classes Runway 4R Block 9

- AvgExVel
- A.E.V. + SD
- A.E.V. - SD
- AvgExVel

Landing Direction
Average Exit Velocity All Classes Runway 22L Block 8

Figure 3.4.3.4

Average Exit Velocity All Classes Runway 22L Block 10

Figure 3.4.3.5
Figure 3.4.3.6

Average Exit Velocity All Classes Runway 27 Block 2

Landing Direction

Figure 3.4.3.7

Average Exit Velocity All Classes Runway 27 Block 3

Landing Direction
Average Exit Velocity All Classes Runway 27 Block 8

Figure 3.4.3.8

Average Exit Velocity All Classes Runway 27 Block 10

Figure 3.4.3.9
Average Exit Velocity All Classes Runway 15R Block 4

Figure 3.4.3.12

Average Exit Velocity All Classes Runway 15R Block 7

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 3.4.3.17

Average Exit Velocity per Aircraft Class Runway 27 Block 2

Figure 3.4.3.18
Figure 3.4.3.19

Average Exit Velocity per Aircraft Class Runway 33L Block 2

Exit

Figure 3.4.3.20

Average Exit Velocity per Aircraft Class Runway 33L Block 5

Exit
Average Exit Velocity per Aircraft Class Runway 15R Block 4

- Heavy
- Large
- Small

Landing Direction

Figure 3.4.3.21

Average Exit Velocity per Aircraft Class Runway 15R Block 7

- Heavy
- Large
- Small

Landing Direction

Figure 3.4.3.22

69
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
Figure 3.4.4.1.2
Figure 3.4.4.1.3
Figure 3.4.4.1.4
Figure 3.4.4.1.5
Figure 3.4.4.1.6

Landing Velocity Profile  Runway 27  Block 2

Mean(Landing Velocity / Threshold Velocity)

Radar Hits from Runway Threshold

Figure 3.4.4.1.6
Figure 3.4.4.1.7
Landing Velocity Profile  Runway 27  Block 8

Mean(Landing Velocity / Threshold Velocity)

Radar Hits from Runway Threshold

File 3.4.4.1.8
Landing Velocity Profile  Runway 27  Block 10

Figure 3.4.4.1.9
Landing Velocity Profile  Runway 33L  Block 2

Figure 3.4.4.1.10

Radar Hits from Runway Threshold

Mean(Landing Velocity / Threshold Velocity)
Figure 3.4.4.1.11

Landing Velocity Profile  Runway 33L  Block 5

Mean(Landing Velocity / Threshold Velocity)

Radar Hits from Runway Threshold

Figure 3.4.4.1.11
Figure 3.4.4.1.12
Landing Velocity Profile Runway 15R Block 7

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 3.4.4.2.4

Final Approach Velocity Profile Runway 22L Block 8

Mean Landing Velocity / Threshold Velocity

Radar Hits from Runway Threshold

Figure 3.4.4.2.5

Final Approach Velocity Profile Runway 22L Block 10

Mean Landing Velocity / Threshold Velocity

Radar Hits from Runway Threshold
Figure 3.4.4.2.8

Final Approach Velocity Profile  Runway 27  Block 8

Radar Hits from Runway Threshold

Figure 3.4.4.2.9

Final Approach Velocity Profile  Runway 27  Block 10

Radar Hits from Runway Threshold
Final Approach Velocity Profile  Runway 33L  Block 2

Radar Hits from Runway Threshold

Figure 3.4.4.2.10

Final Approach Velocity Profile  Runway 33L  Block 5

Radar Hits from Runway Threshold

Figure 3.4.4.2.11
Final Approach Velocity Profile  Runway 15R  Block 4

Radar Hits from Runway Threshold

Figure 3.4.4.2.12

Final Approach Velocity Profile  Runway 15R  Block 7

Radar Hits from Runway Threshold

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](image)

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
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.

<table>
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<tr>
<th>Intersection</th>
<th>Series of Links</th>
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<tbody>
<tr>
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<td>A16 A17 A18</td>
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<tr>
<td>2</td>
<td>A02 A01 A19</td>
</tr>
<tr>
<td>3</td>
<td>A22 A23 A48</td>
</tr>
<tr>
<td>4</td>
<td>A18 A24 A46</td>
</tr>
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</tr>
<tr>
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<td>A35 A43 A10</td>
</tr>
<tr>
<td>14</td>
<td>A35 A42 A20</td>
</tr>
</tbody>
</table>

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 ciruferential 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).
Average Intersection Crossing Times Block 1

Average Intersection Crossing Times Block 2

Figure 3.5.1.3

Figure 3.5.1.4
Average Intersection Crossing Times  Block 5

Figure 3.5.1.7

Average Intersection Crossing Times  Block 6

Figure 3.5.1.8
Average Intersection Crossing Times

Figure 3.5.1.9

Average Intersection Crossing Times
Block 7

Figure 3.5.1.10
Average Intersection Crossing Times

Figure 3.5.1.11

Average Intersection Crossing Times  Block 9

Average Intersection Crossing Times  Block 10

Figure 3.5.1.12
Figure 3.5.1.17

Average Intersection Crossing Times per Aircraft Class
Block 2

Figure 3.5.1.18
Average Intersection Crossing Times per Aircraft Class

Block 4

<table>
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<tr>
<th>Intersection</th>
<th>Avg. TI Heavy</th>
<th>Avg. T2 Heavy</th>
<th>Stdev TI Heavy</th>
<th>Stdev T2 Heavy</th>
<th>Avg. TI Large</th>
<th>Avg. T2 Large</th>
<th>Stdev TI Large</th>
<th>Stdev T2 Large</th>
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<td>9</td>
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Figure 3.5.1.19

Average Intersection Crossing Times per Aircraft Class

Block 5

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Avg. TI Heavy</th>
<th>Avg. T2 Heavy</th>
<th>Stdev TI Heavy</th>
<th>Stdev T2 Heavy</th>
<th>Avg. TI Large</th>
<th>Avg. T2 Large</th>
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</table>

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

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<th>Block 4</th>
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Table 3.5.2
Number of Aircrafts Using Each Intersection Configuration:
Arrivals 4R, 4L and Departures 9, 4L

Figure 3.5.2.1

Number of Aircrafts Using Each Intersection Configuration:
Arrivals 33L and Departures 33L, 22R

Figure 3.5.2.2
Number of Aircrafts Using Each Intersection Configuration:
Arrivals 27, 22L and Departures 22R, 22L

Figure 3.5.2.3

Number of Aircrafts Using Each Intersection Configuration:
Arrivals 15R and Departures 9, 15R

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.

![Average Velocity in Taxiways](image)

**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.
Average Velocity in Taxiways Location: Close / Far

Figure 3.6.1.3

Average Velocity in Taxiways Location: Close / Far Length: Short / Long

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 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
Figure 3.6.2.5

Figure 3.6.2.6
Figure 3.6.2.9

Figure 3.6.2.10
Figure 3.6.2.11

Taxiway Use Supporting Taxiways Block 2

Figure 3.6.2.12
Figure 3.6.2.17

Figure 3.6.2.18
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 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.

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 undertaken in the future, for a more complete understanding of the surface traffic variables and a more efficient use of the airport surface.
References


