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Examination of Runway Occupancy Times for General Aviation Aircraft

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EXAMINATION OF RUNWAY OCCUPANCY TIMES FOR GENERAL AVIATION

AIRCRAFT

by

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Bachelor of Science, University of North Dakota, 2006

A Thesis

Submitted to the Graduate Faculty

of the

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in partial fulfillment of the requirements

for the degree of

Master of Science

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This thesis, submitted by Scott J. Lookabill in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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Dean of the Graduate School

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Title   Examination of Runway Occupancy Times for General Aviation Aircraft

Department   Aviation

Degree   Master of Science

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ABSTRACT

Aviation is an important aspect to the global society. Improving efficiency within aviation is an area that needs continued research. The national airspace's efficiency requires performance models optimizing usage. One metric able to measure usage is through runway occupancy time.

This study looks at the impact on runway occupancy times from two independent factors. The first factor is the difference between Instrument Flight Rules (IFR) aircraft and Visual Flight Rules (VFR) aircraft. The second factor of the study deals with the influence of aircraft type on runway occupancy times. This second factor looks at the runway occupancy time with respect to specific aircraft and aircraft in their runway separation category. These aircraft are the Pilatus PC-12, the Cessna Corvalis, the Cirrus SR-22, and the Piaggio Avanti.

Data collection occurred at Rocky Mountain Metropolitan Airport (KBJC) in Broomfield, Colorado, with a computer program that stored various times into a database. The stored times allowed a runway occupancy time to be calculated for each operation.

The data analysis showed statistically significant results in two areas. The first area analyzed that showed significant difference was IFR departures. The area showing significance within flight rules were category I and category II aircraft. For aircraft categories, single engine propeller driven aircraft that weigh less than 12,500 pounds are category I aircraft; twin engine propeller driven aircraft weighing less than 12,500

pounds are category II aircraft (Federal Aviation Administration, 2009). All other aircraft are category III aircraft (Federal Aviation Administration, 2009). Also, IFR departures overall were different from VFR departures. With aircraft types, the PC-12 was found to be different from other category I aircraft on departure. On arrivals, the Piaggio Avanti was significantly different from other category II arrivals.

Future research could be conducted on the impact of flight rules on runway occupancy times to determine if it is just aircraft speed leading to the differences or if flight rules truly affect runway occupancy time. In addition, the Piaggio Avanti needs to further study to see if it should remain a category II aircraft, or if it ought to move to category III.

CHAPTER I

INTRODUCTION

Introduction

Aviation is a major force in the ever-expanding global economy. The Federal

Aviation Administration (FAA) reports in *The Economic Impact of Civil Aviation on the*

U.S. Economy that aviation generated $1.2 trillion in economic activity in 2006; this

amount equates to 5.6 percent of the gross domestic product of the United States (Federal

Aviation Administration, 2008). Improved efficiency can increase the impact of aviation.

Efficiency gains within aviation can decrease the costs associated with aviation and

therefore increase profit and allow more system capacity.

One way to increase efficiency would be to increase capacity within the air traffic

control (ATC) system. The FAA is currently developing numerous systems to help

improve capacity through a process called Next Generation Air Traffic Control System

(Federal Aviation Administration, 2009). Within this area, conducting analysis can

identify areas that influence capacity. One area that influences capacity is aircraft

separation requirements. Within separation requirements, runway occupancy time (ROT)

is an analyzable metric at the airport.

Runway occupancy time is the length of time spent on a runway by an aircraft

(Trani, 2000). This study will focus on two areas that could influence runway occupancy

time for both arrival and departure of aircraft. This study examines two questions: "Does

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the type of flight rules for an aircraft affect runway occupancy time? Do certain aircraft have statistically different runway occupancy time than other aircraft from the same runway separation category?"

Statement of Problem

The problem that this study addresses is a more in depth understanding of the factors that influence runway occupancy time. This understanding will come through analyzing two possible influences. The first influence is the type of flight rules under which the aircraft operates at the airport. The second influence on runway occupancy examines whether certain aircraft types have significantly different runway occupancy times compared to other aircraft in their separation category.

Purpose of the Study

The purpose of this study is to identify if certain factors influence runway occupancy times. The first factor to analyze for differences will be if there is a difference in runway occupancy time for aircraft operating instrument flight rules (IFR) and an aircraft under visual flight rules (VFR). The other variable to analyze is if certain high performance aircraft have a different runway occupancy time than other aircraft in their respective category. The specific aircraft included in the study are the Cessna Corvalis, Cirrus SR22, Pilatus PC-12, and the Piaggio Avanti. The selection of these aircraft was due to their state of being in production and their representing a selection of higher performance aircraft in their runway separation categories.

Significance of the Study

From the FAA's Air Traffic Activity System, VFR flight rules aircraft account for around 40 percent of all operations handled by the FAA ATC system (Federal Aviation

Administration). This fact shows that VFR traffic should be a significant factor in planning system capacity. Another aspect of this factor is that there exists an estimated annual growth rate of three percent annually for certain aviation sectors (Federal Aviation Administration, 2008). This growth factor leads to the necessity of optimizing how various types of operations affect large airports and allows effective traffic management tools to be developed.

There are other reasons this study can be significant. The first reason is that it could assist in the development of a more complete list of factors affecting runway occupancy time. This reason can be determined through an analysis of the flight rules for a statistical impact on runway occupancy time. A more thorough understanding of this factor could lead to better usage at airports that have a mix of instrument and visual flight rules aircraft.

The second reason this study is important is that it could provide a more thorough understanding of the impact of aircraft performance on runway occupancy time. Within certain runway separation categories, there can be multiple aircraft on the runway after landing. This factor becomes apparent when multiple aircraft are landing on a single runway, and the first is taxiing slowly towards the runway exit while the next aircraft is following at a high rate of speed; a potential for a collision or runway incursion between aircraft is possible.

Aircraft chosen for the study include the Cessna 350/400 Corvalis, the Cirrus SR22, the Pilatus PC-12, and the Piaggio Avanti. In the first nine months of 2009, there were 36 Cessna 350/400s delivered, 164 Cirrus SR22 delivered, 64 Pilatus PC-12s delivered, and 17 Piaggio Avanti delivered (General Aviation Manufacturers Association,

2009). These delivery figures are important for the fact that the production for these

aircraft is in quantities to make them common in the national airspace system (NAS).

Research Questions

The research questions this study will address are:

1. Is there a statistically significant difference in Runway Occupancy Time between IFR aircraft and VFR aircraft?

2. Do certain aircraft (Pilatus PC-12, Cessna Corvalis, Cirrus SR22, and Piaggio Avanti) have a statistically different runway occupancy time compared to other aircraft in their runway separation category?

Definitions

Airplane Design Group – "A grouping of airplanes based on wingspan or tail height. Where an airplane is in two categories, the most demanding category should be used" (Federal Aviation Administration, 1989). Group definitions are located in Table 1 below:

Table 1. Airplane Design Group Categories

Group #	Tail Height (ft)	Wingspan (ft)
Group I	<20	<49
Group II	20-29	49-78
Group III	40-44	79-117
Group IV	45-59	118-170
Group V	60-65	171-213
Group VI	66-79	214-261

(Federal Aviation Administration, 1989)

Instrument Flight Rules (IFR) – "Rules governing the procedures for conducting instrument flight. Also a term used by pilots and controllers to indicate a type of flight plan" (Federal Aviation Administration, 2009).

Runway Occupancy Time – The time that an aircraft spends on the surface of the runway (Trani, 2000)

Runway Separation Category – From FAA Order 7110.65S:

> "Aircraft same runway separation (SRS) categories are specified in Appendices A, B, and C and based upon the following definitions:
> CATEGORY I- small aircraft weighing 12,500 lbs. or less, with a single propeller driven engine, and all helicopters.
> CATEGORY II- small aircraft weighing 12,500 lbs. Or less, with propeller driven twin-engines.
> CATEGORY III- all other aircraft." (Federal Aviation Administration, 2009)

Visual Flight Rules (VFR) – As defined by the Aeronautical Information Manual's Pilot/Controller Glossary:

> "Rules that govern the procedures for conducting flight under visual conditions. The term "VFR" is also used in the United States to indicate weather conditions that are equal to or greater than minimum VFR requirements. In addition, it is used by pilots and controllers to indicate type of flight plan." (Federal Aviation Administration, 2009)

Assumptions

As with many studies, there are certain assumptions under which the study occurred. The following are the assumptions that are applicable to this study:

1. Aircraft of the same type will perform at a similar level, and except in rare occasions, will operate under 200 knots on approach.

2. The high elevation of the airport at which the study occurred affects all aircraft equally.

3. Pilot skill level averages out in the effect on runway occupancy time.

Limitations

In addition to the assumptions for the study, there are also limitations that are

outside of the researcher's control.

1. The weather at the time of the study was different for each observation. The consistency of the weather remains variable. Observations will occur when the wind at the airport is less than 15 knots. In addition, observations occurred when most of the airport surfaces are open and free of snow or contamination.

2. Aircraft mix is variable; therefore, the number of observations per aircraft type will be different.

3. Due to controller preference and airport design, certain exits off the runway are preferred when landing in various directions, leading to artificially inflated runway occupancy times. In addition, certain operators prefer specific turnoffs to allow for shorter taxi times.

Review of Literature

Introduction

The following review of literature seeks to give pertinent background information about the factors involved in runway occupancy times, as well as a look into the research that exists regarding runway occupancy time. The breakdown of the following sections denotes a logical sequence, starting with airport design criteria. The next area includes a look at flight rules and separation rules that could influence runway occupancy time. The next area looks at aircraft performance and its relationship to runway occupancy time. Finally, the last area looks at the previous research on runway occupancy time.

Airport Design

There are several factors relating to airport design that can affect runway occupancy time. One of these factors is where the hold short line is located for the

runway. A guiding document that the FAA has published concerning airport design is an Advisory Circular (AC) numbered 150/5300-13 Change 3 (Federal Aviation Administration, 1989). This document describes certain design criteria for airports including the distance the hold line needs to be from the runway centerline.

Within Table 2-1 and 2-2 from AC 150/5300-13 Change 3, for airports that accept aircraft in design groups IV-VI, there is a note that relates to the distance the hold line needs to be from the runway centerline. This note states that the basic distance of 250 feet "is increased 1 foot for each 100 feet above sea level" (Federal Aviation Administration, 1989). This note is important for runway occupancy time due to some measures of runway occupancy measure from when an aircraft crosses the hold line for either departure or after arrival. Therefore, this requirement could increase runway occupancy times at airports with higher elevations.

To illustrate this aspect, two airports will be compared, one at a higher elevation and one at a lower elevation. At Rocky Mountain Metropolitan Airport (KBJC), in Broomfield, Colorado, the elevation is 5673 feet (National Aeronautical Charting Office, 2009); the minimum required distance from the runway centerline to the hold line would be approximately 307 feet. Comparing this distance to another general aviation airport such as Teterboro Airport, near Newark, New Jersey, the distance the hold line needs to be is approximately 250 feet, due to the airport being near sea level in elevation (National Aeronautical Charting Office, 2010). This factor could lead to different airport capacities and different operational abilities at each airport.

Another factor influencing runway occupancy time from an airport design perspective would be the type of exit from the runway. There are generally two types of

runway exits used in airport design (Federal Aviation Administration, 1989). The first is a perpendicular type of access to the runway. This type of taxiway is generally limited to a speed of 20 miles per hour (Federal Aviation Administration, 1989). The other type is a high-speed exit or an acute angle exit (Federal Aviation Administration, 1989). This type of exit generally allows an aircraft to maintain a higher speed to get clear of the runway (Federal Aviation Administration, 1989). In AC 150/5300-13 Appendix 9, there is a chart that shows a general classification of estimates for runway exiting and probabilities of aircraft exiting at certain points along a runway given certain exit types (Federal Aviation Administration, 1989). Depending on the runway in question, types of exits can modify runway occupancy times (Goldthorpe, 2007). This change is due to the ability of aircraft to maintain a higher speed to clear the runway.

One study developed by the National Aeronautics and Space Administration has looked at factors affecting runway occupancy time. The study also looked at runway exits and how they affect the runway occupancy time (Goldthorpe, 2007). In this study, they found that the number of exits and their locations are highly dependent on aircraft mix at the airport; optimal exit location depends on aircraft mix at an airport (Goldthorpe, 2007). This shows that the placement of the exits can be a critical factor in expediting aircraft off the runway.

Another factor that the study found that could easily reduce runway occupancy time was the speed at which the aircraft is exiting the runway (Goldthorpe, 2007). The study used a factor of between 40 and 80 knots for the entry into the exit (Goldthorpe, 2007). This factor becomes important because an airport with many high-speed exits off the runway should generally have lower runway occupancy times versus an airport that

has many perpendicular exits.

Flight Rules and Runway Separation

The next area of this literature review focuses on flight rules and runway

separation. The first area of discussion focuses on flight rules concerning operations on

instrument approaches and the relationship to runway occupancy time. The next section

looks at various requirements for aircraft separation as well as how the requirements

relate to runway occupancy time.

There are numerous types of aircraft approaches available at airports. From the

FAA's Aeronautical Information Manual (AIM), there are several types of approaches for

aircraft. These systems include the Instrument Landing System (ILS), area navigation

(RNAV), and Global Positioning System (GPS) (Federal Aviation Administration, 2009).

All approaches are generally flown in similar ways as described below.

Section 5-4-7 of the AIM discusses speeds that are typically used on approach

procedures. This section discusses the speed of V_{ref} as a "speed used in establishing the

approach landing distance under the airworthiness regulations constituting the type

certification basis of the airplane" (Federal Aviation Administration, 2009). This speed

(V_{ref}), when not explicitly defined, can be calculated by 1.3 times the stall speed (V_{so}) at

maximum certified landing weight. These speeds determine approach minima and the

approach category that the aircraft fits. Approach categories and their speeds are located

in Table 2 below.

Table 2. Aircraft Approach Category Speeds

Category	Speed
A	<91 knots
B	91-120

Category	Speed
C	121-140
D	141-165
E	>165

(Federal Aviation Administration, 2009)

The reason for these airspeeds is that certain approaches require the pilot to maintain a constant airspeed while on the approach. A localizer approach commonly uses ground speed to identify the missed approach point (King Schools Inc., 2008). In addition, during an ILS approach, if the glideslope fails, the approach should revert to a localizer approach and timing again becomes important (Federal Aviation Administration, 2009).

The next portion of the literature review deals with separation utilized by air traffic controllers. Separation standards are interrelated with runway occupancy times as the two aspects combine to facilitate the creation of runway capacity models. In addition, certain types of operations can have two or more aircraft on the runway at the same time. Aircraft type determines all separation standards. All aircraft exist in two types of separation groups: one for runway separation and the other for wake turbulence separation (Federal Aviation Administration, 2009). The specific breakdown in the runway separation group is in the definitions section under runway separation category. The focus for this section will be on runway separation and the requirements influencing departures and arrivals.

For departures on the same runway, an initial requirement is that the preceding landing aircraft needs to be off the runway (Federal Aviation Administration, 2009). The next set of requirements utilizes the same runway separation category of an aircraft. If both aircraft are category I aircraft, then the first aircraft needs to be at least 3,000 feet

down the runway and airborne by the time the next aircraft starts its departure roll

(Federal Aviation Administration, 2009). When a category I follows a category II aircraft,

the category II aircraft needs to be at least 3,000 feet down the runway and airborne

(Federal Aviation Administration, 2009). If the second aircraft is a category II and the

first one is either category I or category II, then the first aircraft needs to be 4,500 feet

down the runway and airborne before the next aircraft starts its departure roll (Federal

Aviation Administration, 2009). If either aircraft is category III, the first aircraft needs to

be at least 6,000 feet down the runway and airborne before the next aircraft starts its

departure roll (Federal Aviation Administration, 2009). Table 3 illustrates the separation

requirements described above.

Table 3. Departure Same Runway Separation

	First aircraft category I	First aircraft category II	First aircraft category III
Second aircraft category I	3000 feet	3000 feet	6000 feet
Second aircraft category II	4500 feet	4500 feet	6000 feet
Second aircraft category III	6000 feet	6000 feet	6000 feet

(Federal Aviation Administration, 2009)

These requirements begin to show the complexity of creating a feasible model

that utilizes realistic separation and runway occupancy times. With these figures, it shows

for just raw departures that you could possibly have several aircraft over a runway. With a

complete understanding of the separation rules and a breakdown in timings for aircraft

over these specific points, it can lead to a more complete model for departure runway

occupancies.

With arrivals, there are also several different requirements in terms of spacing.

For arrivals, the basic requirement for separation is for the preceding aircraft to be clear

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of the runway before the next aircraft crosses the threshold (Federal Aviation

Administration, 2009). During daylight hours, certain aircraft categories can have

reduced arrival separation (Federal Aviation Administration, 2009). When a category I

aircraft is following either a category I or a category II aircraft, the first aircraft needs to

be at least 3,000 feet down the runway before the next aircraft crosses the threshold

(Federal Aviation Administration, 2009). Next, when a category II aircraft is following

either a category I or category II aircraft the first aircraft needs to be at least 4,500 feet

down the runway before the next aircraft crosses the threshold of the runway (Federal

Aviation Administration, 2009). Table 4 summarizes the arrival same runway separation

requirements. Finally, mixing arrivals and departures follows the same basic pattern as

the departure versus departure requirements for runway separation.

Table 4. Arriving Same Runway Separation

	First aircraft category I	First aircraft category II	First aircraft category III
Second category I	3000 feet	3000 feet	Clear of Runway
Second category II	4500 feet	4500 feet	Clear of Runway
Second category III	Clear of Runway	Clear of Runway	Clear of Runway

(Federal Aviation Administration, 2009)

These separation requirements show the added complexity of creating a dynamic

model for runway usage. With a thorough understanding of runway occupancy times and

the times it takes for an aircraft to reach separation locations, a comprehensive model is

possible for predicting runway capacity.

Aircraft Performance

The next area of this literature review deals with aircraft performance issues. It

will also deal with how performance relates to runway occupancy time. The discussion

will focus on three types of aircraft. These aircraft will show how various factors affect their performance and how these factors can relate to runway occupancy time. The three aircraft discussed below include the Remos GX-C, the Piper PA-44-180 Seminole, and the Boeing 727.

The Remos GX-C is a light sport aircraft (Remos Aircraft, 2009). Some of the common speeds that the Remos has include a V_{s0} of 38 knots, a V_y of 65 knots, a V_{app} of 65 knots, and a V_h of 119 knots (Remos Aircraft, 2009). These speeds show various speeds that the aircraft can accomplish. The V_y is the typical speed at which the aircraft will climb over the runway (Remos Aircraft, 2009). The V_{app} and V_{s0} show the speed decrease needed for the aircraft to fly a general approach and then land. The V_h shows the maximum allowable speed to which the aircraft is limited in straight and level flight (Remos Aircraft, 2009). Table 5 summarizes the above speeds for the Remos GX-C. Each of these speeds work together to create a sample for a slower category I type aircraft.

Table 5. Remos GX-C Speeds

V Speed	Speed
V_{s0}	38 knots
V_y	65 knots
V_{app}	65 knots
V_h	119 knots

(Remos Aircraft, 2009)

The discussion below focuses on other factors applicable to the performance of an aircraft. On departure, using a Neuform propeller, a basic take-off distance is 121 feet with wind calm at standard atmospheric conditions (Remos Aircraft, 2009). A number of factors can modify this distance including the type of runway, wind, and temperature (Remos Aircraft, 2009). For example, if the departure is on a runway that is wet grass, the

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take-off distance increases by 30 percent (Remos Aircraft, 2009). Another factor to account for is wind. For each 2 knots of tail wind, the take-off distance increases by 10 percent (Remos Aircraft, 2009). On the other hand, for each 10 knots of headwind the take-off distance decreases by 10 percent (Remos Aircraft, 2009). Finally, temperature and pressure combine with altitude to form a calculation of density altitude; for each 1,000 foot increase in density altitude above sea level, take-off distance increases by 5 percent (Remos Aircraft, 2009).

Each of these factors has a cumulative effect on the take-off distance of the aircraft. It also shows some factors that can influence if the aircraft can be airborne by specific points used for separation as mentioned in the previous section concerning runway separation. While the Remos GX-C may be towards the lower end of the speed range that a runway capacity model would have to take into account, it does show in raw percentages some factors that affect its performance in given situations.

Another common aircraft is the twin engine Piper, PA-44-180, Seminole. Like the Remos, the Seminole has various operational speeds optimized for certain practices. One of speed that is common to the Remos is the best rate of climb speed (V_y) which is 88 knots in the Seminole (The New Piper Aircraft, Inc., 1995). A more precise chart illustrates the stall speeds for the Seminole that takes into account various factors that affect the aerodynamics (The New Piper Aircraft, Inc., 1995). Some of these factors include angle of bank, weight of the aircraft, and flap settings (The New Piper Aircraft, Inc., 1995). An example in the Seminole's performance chart uses a bank of 30 degrees and a weight of 3,430 pounds, and flaps up to generate a stall speed (V_{s0}) of 58.5 knots (The New Piper Aircraft, Inc., 1995).

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Each of these factors influences runway performance and time on the runway. The aircraft will generally start at a speed of zero for departure, increase to a speed near V_y, and continue to climb out at that speed. With these figures, a formula could be developed that could calculate a theoretical runway occupancy time for specific aircraft under certain conditions.

A partial formula for this type of data already exists in many certified airplanes. This data, usually found in charts or performance data, shows expected distances to rotation point on a runway under given conditions. For example, the chart for the Piper Seminole takes into account numerous criteria for figuring out the distance including wing flaps setting, cowl flaps setting, type of runway, temperature, altitude, weight, and wind component (The New Piper Aircraft, Inc., 1995).

This type of data is available in many certified aircraft types in various levels of detail. With comprehensive data for numerous types of aircraft, various simulations could calculate accurate runway occupancy times. In the next section, the discussion moves to additional factors affecting jet operations.

The Boeing 727 is another type of aircraft that depicts various performance factors influencing runway occupancy time. While this aircraft type is not commonly used at most general aviation airports, it can illustrate certain performance requirements on jet aircraft operating near runways. For departure, some of the conditions that can be taken into account include: engine variant utilized, runway slope/gradient, air conditioning on, temperature, flaps setting, airport elevation, wind, and bleed air shutoff valve being operative (Boeing, 1985). For arrivals, conditions that can affect runway length needed and runway occupancy time include: type of anti-skid and its status,

brakes, dry or wet runway, wind, slope of the runway, spoiler status, weight, elevation of the airport, and flaps setting (Boeing, 1985). The above factors show that under certain instances changes in certain design elements at an airport could modify the runway occupancy time, while other factors are in the control of the operator of the aircraft.

Each of these types of aircraft demonstrates various aspects and considerations that can influence the runway occupancy time of aircraft. The explicit numbers of the Remos GX-C show how certain conditions affect the performance of the aircraft. With the Piper Seminole, the discussion introduced factors that could influence the creation of a runway capacity model. Finally, the Boeing 727 discussed various factors influencing performance. Next, the literature review will move into an examination of previous research on runway occupancy time.

Runway Occupancy Time

There are many ways to get data for calculating runway occupancy times. One way is to utilize surface radar in the form of Airport Surface Detection Equipment Model X (ASDE-X) (Kumar, Sherry, & Kicinger, 2009). ASDE-X utilizes numerous sensors to track vehicles and aircraft on airport movement areas (Federal Aviation Administration, 2009). Utilizing this technology it is possible to determine runway occupancy times for an airport (Kumar, Sherry, & Kicinger, 2009).

A process for determining runway occupancy times utilizes specific data from ASDE-X tracking data including latitude, longitude, altitude, time, aircraft identification, and aircraft type (Kumar, Sherry, & Kicinger, 2009). Next, a process determining runway occupancy time is described (Kumar, Sherry, & Kicinger, 2009). First, the track is classified by its type of operation at the airport of landing or departing (Kumar, Sherry, &

Kicinger, 2009). Next, the used runway is identified (Kumar, Sherry, & Kicinger, 2009).

Finally, the runway occupancy time is calculated using the runway information (Kumar, Sherry, & Kicinger, 2009). This process quickly analyzes large amounts of runway occupancy time data, and would be a useful way to evaluate runway occupancy time at large airports (Kumar, Sherry, & Kicinger, 2009).

The disadvantage for this technology solution is that it relies on ASDE-X. This disadvantage exists due to the FAA planning to install ASDE-X at only 35 major airports (Federal Aviation Administration, 2009). Few airports classified as general aviation airports expect to get this technology (Federal Aviation Administration, 2009); because of this limitation, the ability to gather data that could affect runway safety at smaller airports must be gathered another way.

Only a few studies have looked at capacity from the point of having two aircraft on the runway at the same time. One study uses a mathematical model to evaluate the risk of collision if two aircraft are on the runway at the same time (Xie & Shortle, 2005). This study looks at runway safety through the creation of a model for the probability of runway occupancy by two aircraft at the same time (Xie & Shortle, 2005). This model can help optimize and analyze arrivals between category I and category II aircraft in a general aviation airport setting.

Another study proposed by Eurocontrol, the European air traffic control agency, would look at various pilot and airline practices (Eurocontrol, 2003). This study would examine factors relating to runway occupancy time and companies since there appears to be evidence that certain factors with airlines or pilots are noticeable in runway occupancy time (Eurocontrol, 2003). Since increasing the physical elements of runways is difficult

in many airports, optimizing techniques and other solutions is needed (Eurocontrol, 2003). Another objective of the study is to create an understanding of pilot reaction times and optimize airline procedures (Eurocontrol, 2003). An additional object of this study is to find the best in class in operational efficiency at delay prone airports for a group of airlines, aircraft, or pilots (Eurocontrol, 2003). This aspect of the study would allow best practices to be utilized by all operators and eventually all for more system capacity (Eurocontrol, 2003).

Each of the areas that have been discussed above from airport design, to flight rules and runway separation, to aircraft performance, impact the overall picture of runway occupancy time. In previous studies, ASDE-X sampling has been utilized to analyze runway occupancy time. Aircraft performance can affect the runway occupancy time and varies among aircraft types. In each of these cases, runway occupancy time is directly linked to the requirements for runway separation and how the airport is designed. Next, this paper will discuss the methodology for this study.

CHAPTER II

METHODOLOGY OF THE STUDY

Introduction

This study facilitates an increase in knowledge of the factors relating to runway

occupancy time. The two factors being studied are the flight rules under which the

aircraft operates, and if certain aircraft are consistently on the runway longer than other

aircraft in their respective runway separation category. The study looks at aircraft landing

and departing at the Rocky Mountain Metropolitan Airport (KBJC). A diagram of Rocky

Mountain Metropolitan Airport is located in Figure 3 in Appendix B.

Population

The population for this study is general aviation aircraft. More specifically the

population for this study is aircraft operating at airports with an elevation of

approximately 5600 feet.

Sample

The study sampled randomly selected aircraft landing and departing from Rocky

Mountain Metropolitan Airport (KBJC) in Broomfield, Colorado. The goal will be to

sample a wide cross section of aircraft types in various categories.

Study Design

The study utilized a quantitative design. Data collection occurred while observing

the aircraft from the air traffic control tower at Rocky Mountain Metropolitan airport.

Data collection occurred using a computer program that will record the data into a database for later analysis.

Data Collection Methods and Procedures

Data collection occurred with a program that saved various times into a database after the researcher clicked a button to record the times. Data collection included both arrivals and departures. The departure screen is located in Figure 1. The screen for arrival data collection is located in Figure 2. Both of these figures are located in Appendix A. For the purposes of data collection, arrival datasets consider aircraft making practice instrument approaches to the runway as IFR.

For departures, the following data points are collected:

- Aircraft Identification, only if aircraft type is unknown

- Aircraft type

- Runway utilized

- Time initial take-off clearance issued

- Time for start of roll

- Time the aircraft crosses 3,000 feet from start of the runway

- Time the aircraft crosses 4,500 feet from start of the runway

- Time the aircraft crosses 6,000 feet from start of the runway

- Time the aircraft crosses the departure end of the runway

- If position and hold was used

- Flight Rules operated under

- Any notes

For arrivals, the following data points are collected:

- Aircraft identification, only if aircraft type is unknown

- Aircraft type

- Runway used

- Runway exit utilized

- Time aircraft crosses the landing threshold

- Time the aircraft crosses 3,000 feet from start of the runway

- Time the aircraft crosses 4,500 feet from start of the runway

- Time the aircraft clears the runway

- Flight Rules operated under

- Any notes

Instrument Reliability and Validity

During a trial run of data collection, the instrumentation for the study was tested and refined. Since the instrument records times, the instrument was valid for the purposes of this study. Reliability for the instrument comes from the fact that operator of the computer program is telling the program when to record the appropriate data points for the study and therefore believed to be reliable.

Proposed Data Analysis

Data analysis for this study will be broken into two categories. The first category will look at the differences in flight rules. The analysis will be broken down first by arriving versus departing aircraft. Next, the analysis separated data by runway separation category. Within each runway separation category, a student's t-test was conducted to determine if there is a statistically significant difference between the aircraft operating under IFR and VFR.

The second question utilizes a student's t-test for the analysis. The analysis separated aircraft type first. Next, the analysis separated aircraft arrival and departure status. Next, a t-test was conducted to determine if there is a difference between the specified aircraft and their runway separation category. This analysis was accomplished by removing the aircraft being analyzed from their category and seeing if the t observed is greater than the critical value of t.

<div align="center">Protection of Human Subjects</div>

After submission to the Institutional Review Board, this study did not meet the criteria needed for review by the board due to no direct interaction with the human subjects. No human subjects will be used; only data from aircraft will be examined.

CHAPTER III

RESULTS

Introduction

The following sections give the results from the data collection for the study. The two research questions divide the results for the study. The first section will address results relating to the difference in runway occupancy time for IFR versus VFR arrivals and departures. The second section presents the analysis results relating to the aircraft types. Table 6 displays the total amount of data collected below broken down by aircraft category and type of operation.

Table 6. Types of Operation by Category

Aircraft category	Departures	Arrivals
Category I	68	71
Category II	32	23
Category III	26	27
Total	127	121

Flight Rules

Departures

The first area analyzed was departures for significance of flight rules. This analysis first looked at each runway separation category then the entire departure dataset. The data for category I departures is located in Table 7. From the data in Table 7, a t-test statistic can be computed with a value of t_{obt}=-2.99. With the comparison of $|t_{obt}| \geq |t_{crit}|$ and a t_{crit}= 2.000, a two-tailed test with α=.05 leads to the conclusion that there is a statistical difference between IFR and VFR category I departure runway occupancy

times.

Table 7. Category I Departures by Flight Rules

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Category I IFR	7	46 sec	66 sec	55.71 sec	55 sec	7.32 sec
Category I VFR	61	40 sec	97 sec	66.72 sec	67 sec	9.39 sec
Total category I	68	40 sec	97 sec	65.59 sec	64.5 sec	9.75 sec

For departing category II aircraft, general statistical information is located in

Table 8. From this data, a t statistic can be computed of t_{obt}=-3.23. For this dataset, a t_{crit}

of 2.042 is applicable for α=.05 and for a two-tailed test. Using the previous equation for

comparing the t_{obt} and t_{crit}, it shows that there is a statistical difference between the

runway occupancy times for IFR versus VFR category II aircraft.

Table 8. Category II Departures by Flight Rules

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Category II IFR	18	39 sec	70 sec	49.61 sec	50 sec	7.41 sec
Category II VFR	15	44 sec	65 sec	57.40 sec	58 sec	6.22 sec
Total category II	33	39 sec	70 sec	53.15 sec	52 sec	7.85 sec

For departing category III aircraft, the general data and statistics is located in

Table 9. From the dataset, a t-statistic can be computed of t_{obt}=-1.87. With the dataset, a

t_{crit} of 2.064 is applicable for α=.05 and for a two-tailed test. Therefore, when comparing

the t_{obt} and t_{crit} of this dataset, it indicates that there is not a statistical significance

between IFR and VFR category III aircraft in regards to runway occupancy times.

Table 9. Category III Departures by Flight Rules

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Category III IFR	21	35 sec	56 sec	42.86 sec	42 sec	5.25 sec
Category III VFR	5	40 sec	59 sec	48.40 sec	46 sec	8.68 sec
Total category III	26	35 sec	59 sec	42.92 sec	42 sec	6.25 sec

Overall, the data for all aircraft departing is located in Table 10. For this dataset, a

calculation reveals t_{obt} of -9.36. This t_{obt} is compared with a t_{crit} of 1.980 when using a

two-tailed test with α=.05. This comparison implies that there is a statistical difference

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between runway occupancy times for IFR and VFR aircraft on departure.

Table 10. Departures by Flight Rules

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
All IFR	46	35 sec	70 sec	47.46 sec	46 sec	7.90 sec
All VFR	81	40 sec	97 sec	63.86 sec	63 sec	10.28 sec
Total	127	35 sec	97 sec	57.92 sec	58 sec	12.33 sec

Arrivals

The analysis for arrivals is similar to the analysis for departures. First, the data for

category I arrivals is located in Table 11. From the dataset, the t statistic can be calculated

of t_{obt}=-0.252. This t_{obt} is compared to a t_{crit} of 2.000 using a two-tailed test with α=.05.

Therefore, there is no significant statistical implication of flight rules on category I arrival

runway occupancy times.

Table 11. Category I Arrivals by Flight Rules

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Category I IFR	24	48 sec	81 sec	62.21 sec	60 sec	9.11 sec
Category I VFR	47	42 sec	106 sec	63.02 sec	61 sec	14.30 sec
Total category I	71	42 sec	106 sec	62.75 sec	60 sec	12.72 sec

Next, looking at category II arrivals, the basic statistical information from the

dataset is located below in Table 12. From the dataset a t_{obt} can be calculated to be

t_{obt}=0.803. This statistic can be compared to the t_{crit} of 2.080 using a two-tailed test and

α=.05. The conclusion for this data is that there is no statistically significant impact of

flight rules on runway occupancy times for arriving category II aircraft.

Table 12. Category II Arrivals by Flight Rules

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Category II IFR	15	41 sec	80 sec	64.13 sec	65 sec	12.49 sec
Category II VFR	8	48 sec	72 sec	60.25 sec	59.5 sec	7.29 sec
Total category III	23	41 sec	80 sec	62.78 sec	63 sec	10.94 sec

Next, category III arrival statistics are located below in Table 13. From the

dataset, a t_{obt} can be calculated to be t_{obt}=-0.170. This statistic would be compared with a

t_{crit} of 2.080 with a two-tailed test with α=.05. Comparing these two values leads to the conclusion that there is no statistically significant impact of flight rules on arrival occupancy times for category III aircraft.

Table 13. Category III Arrivals by Flight Rules

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Category III IFR	24	37	87	60.54 sec	59 sec	10.99 sec
Category III VFR	3	53	71	61.67 sec	61 sec	9.02 sec
Total category III	27	37	87	60.67 sec	59 sec	10.64 sec

Finally, the statistics for the entire arrival dataset are located below in Table 14.

From this portion of the dataset, a t_{obt} can be calculated at t_{obt}=-0.248. This statistic would need to be compared to a t_{crit} of 2.00 using a two tailed test with α=.05. The comparison of these two values leads to the conclusion that there is not a statistically significant impact on runway occupancy times for arriving aircraft concerning flight rules.

Table 14. Arrivals by Flight Rules

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
All IFR	63	37 sec	87 sec	62.03 sec	60 sec	10.62 sec
All VFR	58	42 sec	106 sec	62.57 sec	60.5 sec	13.24 sec
Total	121	37 sec	106 sec	62.29 sec	60 sec	11.9 sec

Aircraft Differences

Pilatus PC-12

The second question on which the research focuses deals with specific aircraft types. This question deals with whether or not the specific aircraft types were significantly different statistically from other aircraft in their runway separation category. The first aircraft type to analyze is the Pilatus PC-12. The summary statistics from this aircraft type are located in Table 15. This table contains both information for arrivals and departures, with the PC-12 data and the category I data without the PC-12.

For departures, a t_{obt} statistic can be calculated of t_{obt}=-2.489. A two-tailed test

with α=.05, a t_{crit} of 2.000 will be utilized. Comparing these two statistics, it can be

shown that the PC-12 is statistically different from other category I aircraft for departure

runway occupancy times.

For arrivals, a t_{obt} statistic can also be calculated with t_{obt}=0.082. Again utilizing a

two-tailed test with α=.05, a t_{crit} of 2.000 is needed. Comparing these two values, it shows

that there is no difference between the PC-12 and other category I aircraft's runway

occupancy times on arrival.

Table 15. Pilatus PC-12 Compared with Category I Aircraft

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	Σ
PC-12 Departures	4	46 sec	59 sec	54.25 sec	56 sec	5.91 sec
Category I Departures	64	40 sec	97 sec	66.5 sec	66.5 sec	9.53 sec
PC-12 Arrivals	6	54 sec	80 sec	59 sec	59 sec	9.81 sec
Category I Arrivals	65	42 sec	106 sec	60 sec	60 sec	13.02 sec

Cessna Corvalis

The next aircraft analyzed is the Cessna Corvalis as it compares to other category

I aircraft. Table 16 contains the relevant statistics for this analysis. From the dataset, for

departures and arrivals a calculation of a t_{obt} occurs. For departures, the t_{obt} can be

calculated to be t_{obt}=-1.345. For arrivals, a t_{obt} can be calculated as t_{obt}=-0.058. For both

of these values, a t_{crit} of 2.000 should be utilized for the two-tailed test with α=.05.

Therefore, for both departures and arrivals, there is no statistically significant difference

between the runway occupancy times of the Cessna Corvalis and other category I aircraft.

Table 16. Cessna Corvalis Compared with Category I Aircraft

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Corvalis Departures	2	55 sec	58 sec	56.5 sec	56.5 sec	2.12 sec
Category I Departures	66	40 sec	97 sec	65.5 sec	65.5 sec	9.76 sec
Corvalis Arrivals	1	62 sec	62 sec	62 sec	62 sec	0 sec
Category I Arrivals	70	42 sec	106 sec	60 sec	60 sec	12.81 sec

Cirrus SR22

The next aircraft analyzed is the Cirrus SR22 as compared to other category I aircraft. Overview statistical data for the Cirrus SR22 versus category I aircraft is located below in Table 17. For both departures and arrivals, a t_{obt} was calculated. For departures, t_{obt} is calculated at $t_{obt}=-1.963$. For arrivals, t_{obt} is calculated at $t_{obt}=-1.390$. For both arrivals and departures, the t_{crit} is the same at $t_{crit}=2.000$. Therefore, when comparing the t_{obt} and t_{crit} for both arrivals and departures, there is no significant difference in runway occupancy times for the SR22 versus other category I aircraft.

Table 17. Cirrus SR22 Compared with Category I Aircraft

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
SR22 Departures	4	53 sec	60 sec	56.5 sec	56.5 sec	2.89 sec
Category I Departures	64	40 sec	97 sec	66.16 sec	66.5 sec	9.75 sec
SR22 Arrivals	2	49 sec	52 sec	50.5 sec	50.5 sec	2.12 sec
Category I Arrivals	69	42 sec	106 sec	63.1 sec	60 sec	12.73 sec

Piaggio Avanti

Finally, the last aircraft analyzed is the Piaggio Avanti. General statistical data for the dataset is located below in Table 18. For departures, a t_{obt} can be calculated of $t_{obt}=-1.651$. Utilizing a two-tailed test with $\alpha=.05$, a t_{crit} for this dataset is 2.042. With these two numbers, the conclusion is that for departures, the Piaggio Avanti has no statistical difference from other category II departures concerning runway occupancy times.

For arrivals, a t_{obt} can be calculated at $t_{obt}=2.271$. Again utilizing a two-tailed test with $\alpha=.05$, a t_{crit} will be calculated at $t_{crit}=2.080$. Therefore, with the two comparisons the conclusion drawn concerning runway occupancy times is that the Piaggio Avanti is statistically different for arrivals.

Table 18. Piaggio Avanti Compared with Category II Aircraft

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Piaggio Departures	2	43 sec	46 sec	44.5 sec	44.5 sec	2.12 sec

Aircraft category	N	Min	Max	$\bar{X}$	$\tilde{X}$	σ
Category II Departures	31	39 sec	70 sec	53.71 sec	53 sec	7.76 sec
Piaggio Arrivals	5	63 sec	76 sec	71.8 sec	73 sec	5.07 sec
Category II Arrivals	18	41 sec	80 sec	60.28 sec	52 sec	10.88 sec

The above sections have presented various statistics with regard to the research

questions. Within the flight rules section, there were some statistically significant aspects

shown for certain operations and categories. In the aircraft section, the PC-12 was found

to be statistically different from other category I aircraft. The Piaggio Avanti was

statistically different from other category II aircraft. A discussion of possible reasons for

these differences, and possible future areas of consideration follows.

CHAPTER IV

DISCUSSION

Introduction

As denoted above, there were some significant results in both research question areas. Concerning flight rules differences between IFR and VFR, several categories of departures were significant. Concerning aircraft type, the Pilatus PC-12 and Piaggio Avanti were significantly different from their respective runway separation category. In the next sections, the discussion will focus on possible explanations for these results.

Flight Rules

In the previous section, there were areas that showed significant results regarding the effect of IFR and VFR on runway occupancy times. The first analysis that showed a significant difference in runway occupancy times was departures for category I aircraft. The mean runway occupancy time for the IFR category I departures was 55.71 seconds. The mean runway occupancy time for VFR category I departures was 66.72 seconds.

Looking at the data, one of the key reasons for this difference is the aircraft type. The aircraft flying IFR were often aircraft types that are faster than the aircraft flying VFR. The aircraft that were IFR departing included aircraft such as the Cessna Corvalis (COL4), the Pilatus PC-12 (PC12), and the Piper Meridian (P46T). The aircraft predominately flying VFR were the Cessna 172 (C172), Piper Cherokee (P28A), and the Diamond Katana (DV20).

The next area that had showed a significant difference between IFR and VFR was in the runway occupancy time for category II departures. As presented above, the mean for the IFR departures was 49.61 seconds, and the mean for VFR departures was 57.4 seconds. Aircraft types explain this result. For the IFR departures, there were again the faster aircraft including the Piaggio Avanti (P180). For the VFR departures, the primary aircraft in the dataset was the Piper Seminole (PA44). The differences in speed between the aircraft lead to the differences in runway occupancy times.

Finally, the last area of significance in runway occupancy times was an overall comparison between IFR and VFR aircraft of departures. Again, with this dataset the mean for the IFR departures was 47.46 seconds versus the VFR departure mean of 63.86 seconds. These data points show that the IFR aircraft were more often the faster of the two groups.

Aircraft Type

The other part of the research dealt with aircraft types and the differences between certain aircraft types and their respective runway separation category. The first area of significance in runway occupancy time was with the Pilatus PC-12 departures versus other category I aircraft departures. From the dataset above, the PC-12 had an average 54.25 second runway occupancy time on departure compared with an average 66.3 second runway occupancy time for category I aircraft excluding the PC-12. This explanation for this difference is through the PC-12 being generally faster than the other category I aircraft including the Cessna 172 (C172), the Piper Cherokee (P28A), and Cirrus SR20 (SR20).

The other significant area for arrivals was between the Piaggio Avanti and other

category II aircraft. As shown above, the Piaggio Avanti had a 71.8 second average arrival runway occupancy time compared to other category II aircraft which had a 60.28 second average arrival runway occupancy time. This time difference indicates that something is different about the Piaggio Avanti versus other category II aircraft.

One factor recorded but not shown above was aircraft exit location. With the Piaggio Avanti, the general distance to exit the runway was approximately 6000 feet down the runway. Other category II aircraft were able to exit the runway at approximately 3300 feet down the runway or 4500 feet down the runway; an average approximate distance for the arrivals to exit was 4083 feet. With both of these figures, an average speed is available for arrivals over the length of the runway they occupied.

For the Piaggio Avanti, an average speed was 83.6 feet per second or 49.5 knots, whereas other category II aircraft were 67.7 feet per second or 40.1 knots. These speeds indicate that the Piaggio Avanti is traveling down the runway at a faster rate, or unable to slow down as quickly as other aircraft. With a higher rate of speed than other aircraft, there is a need for further research on these issues and the safety aspect concerning arrival separation and the Piaggio Avanti.

Future Research

There should be a focus on two different aspects for future research. The first area on which to focus research is the verifiability of the flight rules results. With this study, an examination of two factors should occur. The first area is a break down by the type of approach. This area would break out aircraft that are operating on a visual approach versus those aircraft operating a specific approach requiring constant speed to time the approach. The second aspect to examine in future research on the factor of IFR versus

VFR aircraft is a comparison of the same aircraft type under both conditions instead of through an analysis of the entire category. This examination did not occur in this study due to the types of aircraft operating at the airport and the limited observations. This aspect would be useful in eliminating differences of speed between aircraft of the same category.

The next area for future research is a determination of the safety aspect of allowing the Piaggio Avanti to remain a category II aircraft or if its separation category ought to be changed. This section of research should look at the possibility of a collision on the runway under the current separation rules utilizing runway occupancy models and data from ASDE-X for performance data.

Conclusion

The research discussed in this study explains possible reasons for the differences found in the results of the study. These differences generally relate to aircraft speed being a critical factor. Future research regarding runway occupancy times could determine if airspeed is a factor or if there are other factors relating to the differences between IFR and VFR aircraft. In addition, future research could analyze the Piaggio Avanti and the safety impact of it being in the same runway separation category as other category II aircraft. In future research, the key objective should be improving the performance of the system, keeping safety paramount above other considerations.

APPENDICES

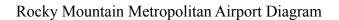Appendix A

Data Collection Program Screens

Figure 1: Departure Data Collection

Figure 2: Arrival Data Collection

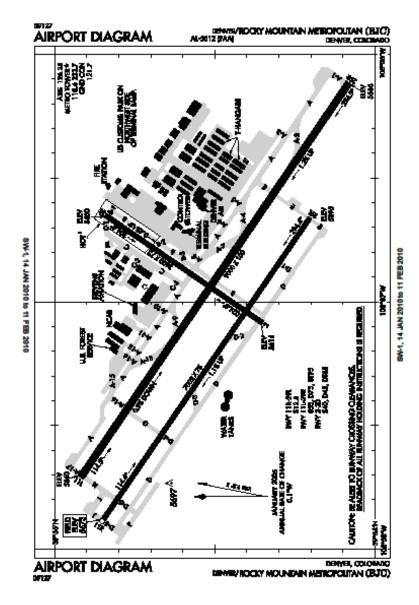Appendix B

Rocky Mountain Metropolitan Airport Diagram

Figure 3: KBJC Airport Diagram
(National Aeronatuical Charting Office)

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