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Use of Rounded Base Turns in General Aviation Traffic Patterns: A Quantitative Analysis

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USE OF ROUNDED BASE TURNS IN GENERAL AVIATION TRAFFIC PATTERNS: A
QUANTITATIVE ANALYSIS

by

Lewis Robert James Archer

Bachelor of Science, University of North Dakota, 2011

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

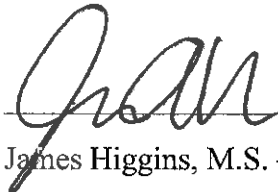
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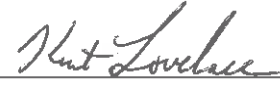
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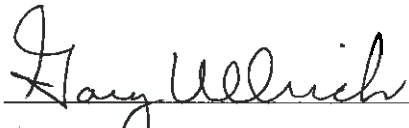
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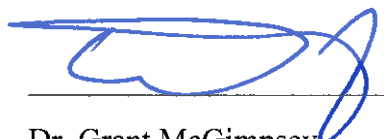
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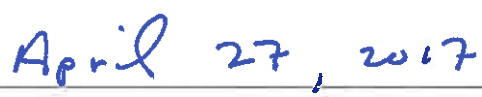

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Lewis Robert James Archer

March 5, 2017

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ABSTRACT

Prevention of in-flight loss of control (I-LOC) in General Aviation (GA) continues to be identified as a most-wanted safety improvement by the National Transportation Safety Board (NTSB), with emphasis on low-altitude maneuvering. A possible technique to mitigate I-LOC is modification of the rectangular traffic pattern used by aircraft arriving and maneuvering within the airspace around an airport. The rectangular pattern is used to align the aircraft with the runway for landing and consists of a “base leg” in which two 90-degree directional changes are accomplished. A “rounded-base” could instead be conducted, consisting of a constant 180-degree turn, potentially resulting in lower angles-of-attack (AOA), thereby keeping the aircraft further from the critical AOA at which I-LOC may occur.

Using flight data monitoring equipment, a comparative statistical analysis was conducted between the rectangular method and rounded base method to evaluate variables that influence AOA and determine if the rounded-base method provides an increased level of safety. Results suggest that the rounded base method does allow for lower bank angles, lower pitch attitudes, lower vertical speeds, and more consistent indicated airspeeds throughout the maneuver. Additionally, the rounded-base method considerably reduces the likelihood of runway overshoot during the turn to final.

CHAPTER I

INTRODUCTION

On May 3, 2012, a Beechcraft Bonanza crashed at the Lake in the Hills Airport (3CK) in northern Illinois upon arrival from a cross-country flight. The wind was reported out of the south-southwest, visibility was unrestricted, and sky conditions were reported as few. In the right seat was an 82 year-old commercial pilot with over 18,000 hours of flight experience. In the left seat; a 62 year-old flight instructor and commercial pilot with almost 8,000 hours of flight experience. A witness on the ground observed the aircraft in the traffic pattern for runway 26, then witnessed the aircraft enter a very steep bank during the base-to-final turn. A scene of horror quickly unfolded as the aircraft uncontrollably traversed into the ground, abruptly ending the lives of the two experienced aviators. The National Transportation Safety Board (NTSB) determined the probable cause to be “the pilot’s excessive bank angle while on approach to land, which resulted in an inadvertent aerodynamic stall and spin”. Additionally, investigators noted that the wind conditions during the base-to-final turn were conducive to a runway overshoot. It was theorized that the pilot was attempting to aggressively re-align the aircraft with the runway on final, leading to a stall and an unrecoverable flight condition (National Transportation Safety Board, 2013).

Statement of the Problem

The scenario described is one of many examples of in-flight loss of control (I-LOC) in the airport traffic pattern. Prevention of I-LOC in general aviation (GA) has been on the NTSB's "most wanted" list of safety improvements for the past three years (2015, 2016, and 2017). Between 2008 and 2014, I-LOC was a factor in almost 48 percent of fixed-wing GA accidents. Maneuvering at low altitude, such as during a traffic pattern, has been identified as an area of concern due to the limited time and altitude in which a pilot would have to recover from an inadvertent aerodynamic stall (National Transportation Safety Board, 2016). In 2015, a forum hosted by the NTSB convened to gather potential solutions to the I-LOC problem. One recommendation, proposed by the Aircraft Owner's and Pilot's Association's (AOPA) Air Safety Institute (ASI), was to promote the use of a "circular pattern" during the approach and landing phase of flight versus the traditional rectangular ("box") pattern, which has long been the standard method of operating in the airport terminal environment under visual flight rules (Perry, 2016).

The standard traffic pattern, as described by the Federal Aviation Administration's (FAA) Airplane Flying Handbook (AFH), consists of five legs; departure, crosswind, downwind, base, and final. All turns in the rectangular pattern consist of a 90 degree change of direction to maneuver the aircraft into a position for landing (United States Department of Transportation, 2016). The transition from the base leg to the final leg may be the most challenging phase of the pattern, as it requires the pilot to estimate when to begin the turn based on wind conditions which, due to the variability of wind and its effect on aircraft performance, can be difficult to predict. A turn that starts late will result in the pilot undershooting or overshooting the runway,

often leading to dangerous control inputs that increase the angle-of-attack (AOA) and place the aircraft close to, or in, a stalled condition. A multitude of accidents have occurred in which this scenario resulted in a low altitude stall and unrecoverable loss of aircraft control (AOPA Air Safety Institute, 2015).

The proposed circular pattern includes a rounded base leg in which the pilot conducts a constant 180-degree turn from downwind to final instead of the traditional squared base in which the pilot conducts a 90-degree heading change, flies a ground track perpendicular to the extended runway centerline, then conducts an additional 90-degree heading change to align with the runway while making configuration changes after each turn. Moore (2015) theorized that the use of a rounded base turn would result in a safer approach and would reduce the likelihood of runway overshoot during the base-to-final turn which could lead to I-LOC if the pilot attempts an aggressive correction.

Currently, the literature contains little information regarding the use of an alternative style of traffic pattern to reduce the likelihood of I-LOC accidents. Several studies have examined I-LOC, including a 2015 AOPA report which identified I-LOC as the cause of 40 percent of fatal general aviation accidents. While alternatives to the traditional rectangular pattern have been proposed (Snow, 2001), a quantitative analysis of a rounded base method has yet to be conducted. Advocates of the maneuver assert that it would increase the margin of safety during the approach-to-landing phase of flight by reducing the maximum AOA encountered during the procedure, thereby keeping the aircraft further away from the critical AOA at which the aircraft stalls while also creating a more stabilized approach (Perry, 2016). Combined with

other safety initiatives, including the use of angle-of-attack (AOA) indicators, the rounded base method may validate itself as a safer method of conducting a traffic pattern in a GA aircraft.

Purpose of the Study

The purpose of this study is to determine, using flight data analysis, whether the use of a rounded base leg would result in a safer and more stabilized traffic pattern for general aviation aircraft than the traditional squared base. Specifically, the study will determine to what extent the use of the rounded base method would influence the following variables; bank angle, vertical speed, indicated airspeed, pitch attitude, and runway alignment as the aircraft joins the extended runway centerline. It is hypothesized that the use of the rounded base method will result in lower bank angles, greater descent rates, faster indicated airspeeds, and lower pitch attitudes, while also resulting in an increased likelihood of being aligned with the runway upon rollout on final. This study will provide a scientific conclusion on whether the rounded base method should be further investigated as a potential mitigation technique for reducing GA I-LOC accidents.

Research Questions

Through statistical analysis of flight data, this study will answer the following questions:

- 1) Is there a statistically significant difference in bank angles between the rounded base and rectangular base methods?
- 2) Is there a statistically significant difference in descent rates between the rounded base and rectangular base methods?
- 3) Is there a statistically significant difference in indicated airspeeds between the rounded base and rectangular base methods?

- 4) Is there a statistically significant difference in pitch attitudes between the rounded base and rectangular base methods?
- 5) Is there a statistically significant relationship between the method used (rounded or rectangular base) and alignment with the runway upon completion of the turn to final?

LITERATURE REVIEW

Loss of Control

Several studies conducted by a variety of organizations have highlighted I-LOC as a significant factor in aviation fatalities. A National Aeronautics and Space Administration (NASA) study of aircraft accidents and incidents between 1988 and 2004 revealed that more than half of all aircraft fatalities occurred in conjunction with I-LOC. Reveley, Briggs, Evans, Sandifer, and Monica Jones (2010) found that 56 percent of 14 CFR Part 91 (general aviation) accidents in the approach/landing phase of flight during this time period were a result of pilot-induced control upset (Table 1).

Reveley et al. (2010) also revealed that inadequate airspeed and/or stall was the primary cause of I-LOC in 14 CFR Part 91 operations during the approach/landing phase of flight (Table 2), indicating that AOA management during this phase of flight should be a point of emphasis in future safety initiatives.

An analysis by Veillette (2009) of 59 I-LOC accidents in business jets between 1991 and 2007 revealed that 37 of these accidents occurred within 1000 feet of the surface and 26 occurred during the approach-to-landing phase of flight. The most common cause of these accidents was an unintentional stall, 16 of which occurred during approach and landing. Of the 16 approach

and landing stalls, 6 occurred during approaches in which the aircraft was banked. Veillette outlined the threats encountered while banking an aircraft including less focus inside the aircraft, sensory illusions due to the movement of the vestibular system, and increased AOA. Veillette recommended a multi-layered approach to include the use of improved procedures to reduce the frequency of I-LOC accidents.

Table 1

Adverse Conditions Leading to Part 91 I-LOC Accidents in Approach/Landing Phase of Flight

Adverse Condition	Number of Accidents
Total system/component failure/malfunction	157 (10 percent)
Damage, fire	12
Damage, collision	62
Damage, weather	0
Damage, pilot	9
Total damage	83 (5 percent)
Control upset, pilot	921 (56 percent)
Control upset, low-altitude maneuver	0
Control upset, severe weather	111
Control upset, other events	363
Total control upset	1395
Total	1635 (100 percent)

Note. Adapted from *Causal Factors and Adverse Conditions of Aviation Accidents and Incidents Related to Integrated Resilient Aircraft Control*, by Reveley, M., Briggs, J., Evans, J., Sandifer, C., & Monica Jones, S., 2010, Technical Memorandum No. NASA/TM-2010-216261, p. 9. National Aeronautics and Space Administration.

An analysis by Michales (2012) of 52 LOC accidents in multiengine turbine aircraft found similar results to the 2010 NASA study; the most frequent casual factor in these accidents was control upset in conjunction with low altitude maneuvering. The study also found that these accidents frequently occurred in conjunction with pilot-induced loss of control, thereby supporting the theory that these accidents were a result of pilot error, rather than other factors

such as flight control malfunctions. Based on these findings, Michales described the need for increased emphasis of I-LOC avoidance in training programs.

Table 2

Primary Cause of I-LOC in Part 91 Accidents in Approach/Landing Phase of Flight

Primary Cause	Number of Accidents
Inadequate airspeed and/or stall	675 (48.4 percent)
Weather (WX), icing	38
WX, thunderstorm	4
WX, wind shear	29
WX, turbulence	2
WX, adverse winds	267 (19 percent)
WX, obscuration	20
Visual flight rules into instrument meteorological conditions	18
Spatial disorientation	52
Diverted attention	8
Wake turbulence	27
Inadequate preflight	13
Incorrect weight/balance	2
Improper use of controls	54
Improper handling	4
Incorrect or unsuitable runway	1
Procedural/decision error	33
Pilot incapacitation	18
Pilot impairment	12
Control interference	0
Passenger interference	2
Aircraft performance capability exceeded	1
Lack of experience	19
Aircraft control not maintained	85
Unknown	11
Total	1395 (100 percent)

Note. Adapted from *Causal Factors and Adverse Conditions of Aviation Accidents and Incidents Related to Integrated Resilient Aircraft Control*, by Reveley, M., Briggs, J., Evans, J., Sandifer, C., & Monica Jones, S., 2010, Technical Memorandum No. NASA/TM-2010-216261, p. 16. National Aeronautics and Space Administration.

As a result of the Colgan 3407 accident, Public Law 111-216 mandated that the FAA implement the NTSB recommendations to provide stall and upset recognition and recovery training to airline pilots. In the past, training for airline pilots has consisted of recognition and recovery from “approaches to stalls” as described in the FAA’s Airline Transport Pilot (ATP) Practical Test Standards (PTS). Due to the new regulation, the mindset has started to shift towards an emphasis on AOA management during stall recovery (Chandler, 2011). While this new perspective may help to decrease the rate of I-LOC accidents, it is primarily a teaching method to recover from a stall rather than an operational method that may reduce the likelihood of actually entering a stall.

As revealed by the NTSB’s “most-wanted” lists, prevention of in-flight loss of control in general aviation continues to be a priority. The FAA defines loss of control as “an aircraft’s unintended departure from controlled flight” that may occur as a result of pilot distraction, loss of situational awareness, or an encounter with hazardous weather. According to the FAA, however, the most common type of I-LOC accident is a stall often followed by a spin. The NTSB identified the approach-to-landing, maneuvering, and initial climb as the deadliest phases of flight for I-LOC accidents with emphasis on the traffic pattern due to the “limited time and altitude available to recover from a stall or spin” (National Transportation Safety Board, 2016).

The Traffic Pattern

The airport traffic pattern is a standardized maneuver to allow aircraft to safely arrive, depart, and operate within the airport (terminal) environment. Similar to the role of a highway on- or off-ramp, the airport traffic pattern is designed to create an orderly flow of arriving and departing aircraft traffic at both towered and non-towered airports. The maneuver has been

taught for at least several decades (Hartney, 1940) and continues to be a task that is required to be evaluated for the issuance of a pilot certificate (Federal Aviation Administration, 2016).

According to the FAA's Airplane Flying Handbook (AFH), the traffic pattern is a procedure providing specific routes for departures and arrivals at airports to ensure an orderly flow of traffic. Unless otherwise depicted by visual markings, all turns in a traffic pattern are made to the left. The traffic pattern (Figure 1) consists of six segments; the entry, downwind, base, final, departure, and crosswind leg. The focus of this study is the base leg, which is described by the AFH as the transition between the downwind and final legs. The handbook states that the pilot should begin a turn from the downwind to the base leg at a point approximately 45 degrees beyond the approach end of the runway by establishing a "medium bank turn". Upon completion of the 90 degree turn from downwind to base, the pilot is to maintain a flight path perpendicular to the extended runway centerline until ready to begin the turn to final. The handbook stresses the importance of avoiding steep bank angles during the base-to-final turn, but provides very little guidance on when to actually begin the turn (Federal Aviation Administration, 2016a).

For all public-use runways in the US, the pattern altitude, as well as the direction if non-standard, is indicated in the US Digital Chart Supplement (d-CS). For example, the d-CS indicates that the traffic pattern for runway 17R at Grand Forks International Airport in Grand Forks, ND is to the right ("right tfc."), with a traffic pattern altitude (TPA) of 1645 feet MSL (800 feet AGL) for light aircraft.

As depicted in Figure 2, the FAA's Aeronautical Information Manual (AIM) describes six legs of the traffic pattern; the upwind, crosswind, downwind, base, final approach, and

departure leg. The base leg is defined as “a flight path at right angles to the landing runway off its approach end and extending from the downwind leg to the intersection of the extended runway centerline”.

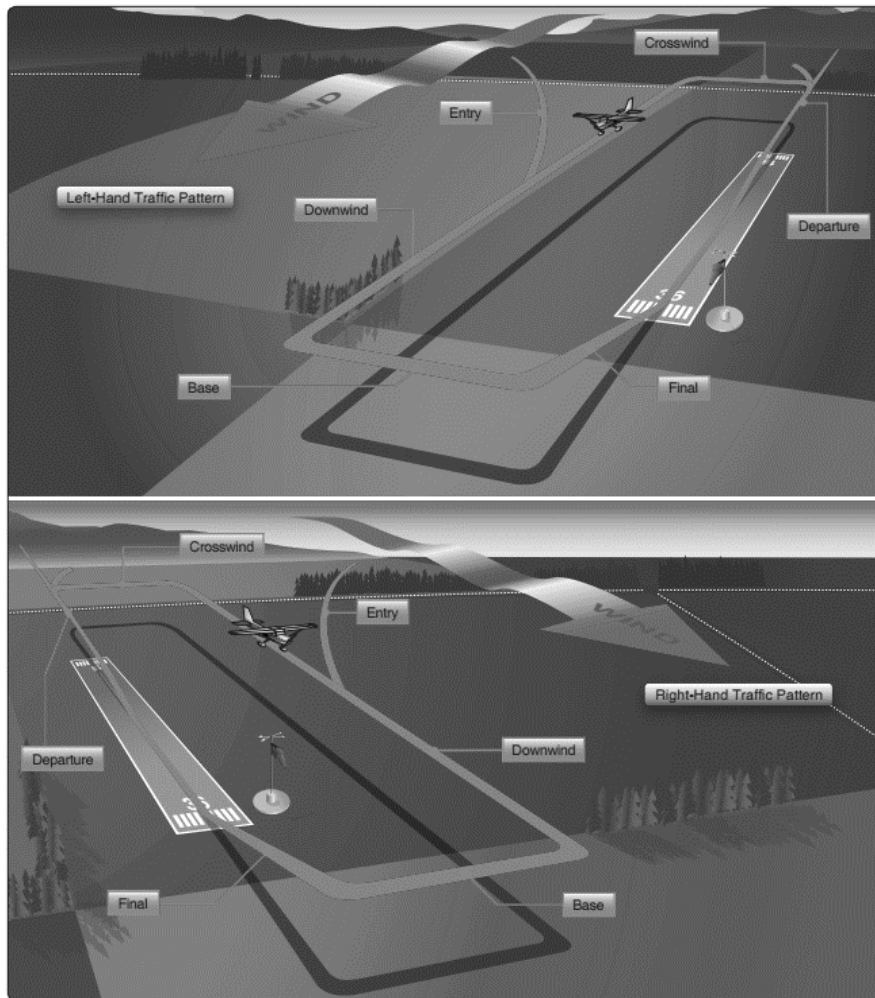


Figure 1. Traffic Patterns. From Airplane Flying Handbook, by United States Department of Transportation, Federal Aviation Administration, Flight Standards Service, 2016, p. 7-3. United States Department of Transportation, Federal Aviation Administration, Airman Testing Standards Branch.

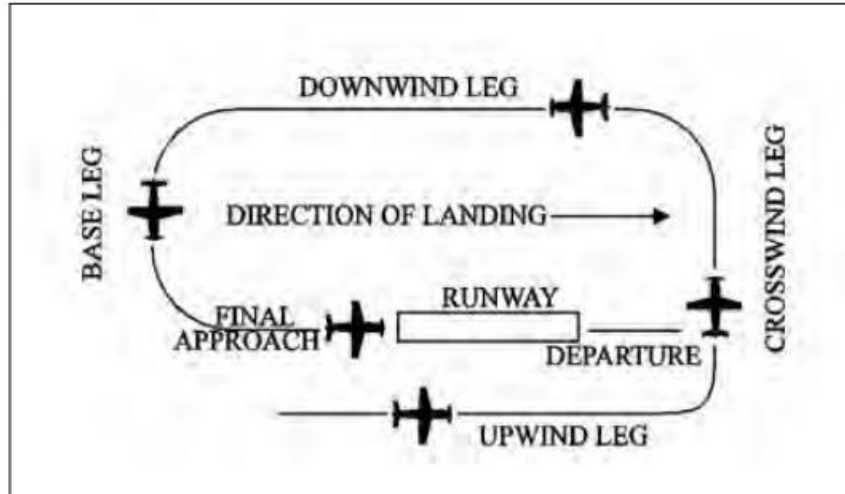


Figure 2. Components of a Traffic Pattern. From *Aeronautical Information Manual*, by United States Department of Transportation, Federal Aviation Administration, 2014, p. 4-3-1. United States Department of Transportation, Federal Aviation Administration.

The Rounded Base

In a 2001 article by Robert Snow published in AOPA Flight Training Magazine, the concept of an “asymmetrical traffic pattern” is described as an alternative to the rectangular base-to-final turn. Snow promotes the use of a shallow-banked early turn from the base leg to final, as it provides the pilot with more time to evaluate the effects of wind and adjust the turn accordingly to avoid overshooting the runway. By beginning the turn earlier and at a shallower bank angle, the pilot has a greater margin of bank available that may be used to avoid overshooting the runway without approaching the critical AOA at which the aircraft stalls.

A similar type of maneuver can be found in FAA literature. The Overhead Approach Maneuver, seen in Figure 3, is described in the AIM as a maneuver which may be performed by an aircraft on an IFR flight plan operating in visual meteorological conditions at airports in which aircraft may have an operational need to conduct the maneuver. The maneuver begins with a constant 180-degree turn from the “break point” above the runway to the downwind leg.

The maneuver is completed with an additional 180-degree turn from the downwind leg to roll-out on final (Federal Aviation Administration, 2015).

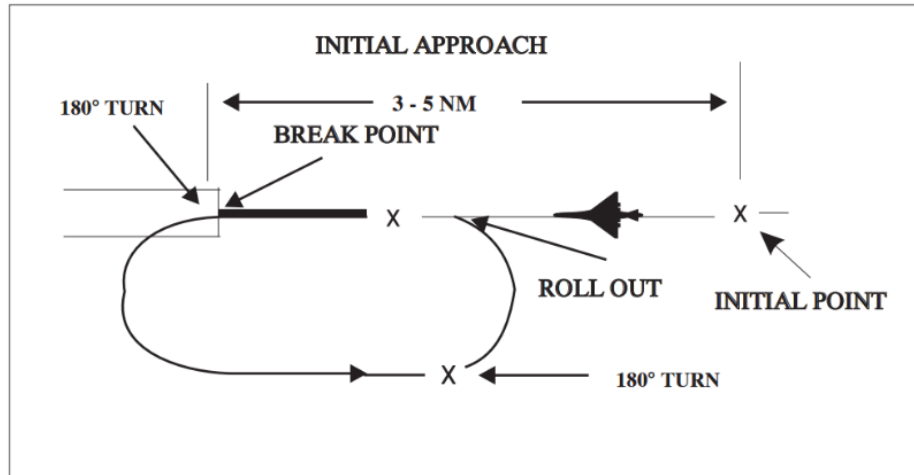


Figure 3. Overhead Maneuver. From Aeronautical Information Manual, by United States Department of Transportation, Federal Aviation Administration, 2014, p. 5-4-62. United States Department of Transportation, Federal Aviation Administration.

As illustrated in Figure 4, the US Navy’s T-6B flight training manual describes the landing pattern as a “racetrack-shaped course” consisting of an upwind leg, crosswind turn, downwind leg, approach turn, and landing line. The approach turn consists of a 180-degree turn from the downwind to either touchdown or commencement of a go-around procedure. The manual states that this type of approach develops “judgment and ability to control airspeed with nose attitude and rate of descent with power, while tracking a prescribed pattern over the ground under varying wind conditions” while developing “consistency in landing the aircraft on or near the intended point of landing”.

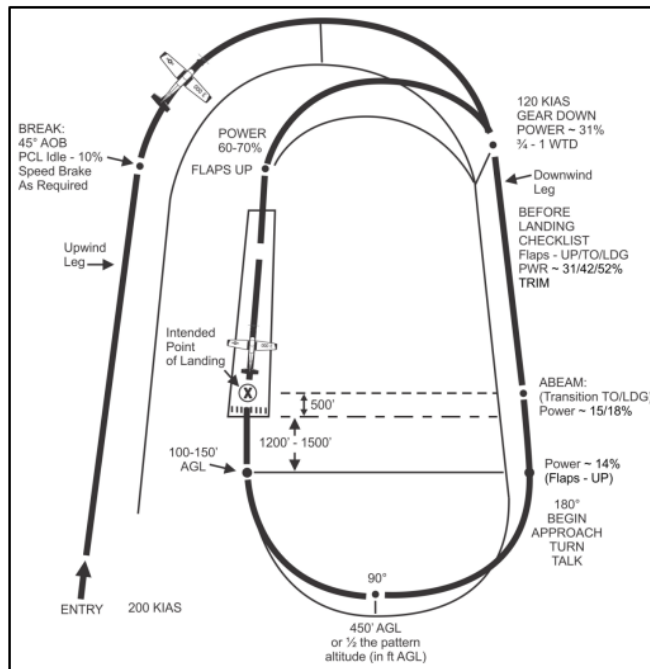


Figure 4. Landing Pattern. From *Flight Training Instruction, Primary Contact, T-6B* by Naval Air Training Command, 2014, p. 6-5. Naval Air Training Command.

The US Air Force also incorporates a constant downwind-to-final turn in the traffic pattern. The Air Force’s T-6 flight training manual describes the “final turn” as a descending 180-degree turn beginning at the end of the downwind leg and ending with the aircraft aligned with the runway. The turn is initiated when the runway threshold is approximately 45 degrees behind the pilot’s shoulder, termed the “perch”. At the perch, the pilot configures the aircraft by adjusting power, lowering the nose, and rolling into approximately 30 degrees of bank. No configuration adjustments are made during the turn, resulting in a smooth and consistent flight path from downwind to final (Figure 5).

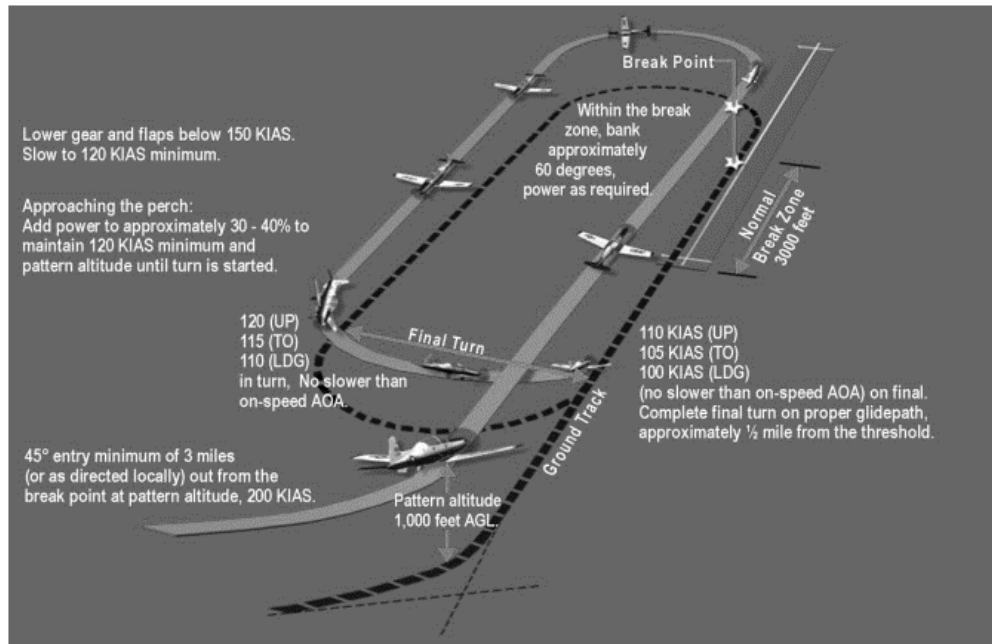


Figure 5. Normal Traffic Pattern. From *T-6 Primary Flying*, by United States Air Force Flying Operations, 2011, p. 58. Air Force Departmental Publishing Office.

The circular traffic pattern, as envisioned by the AOPA ASI in Figure 6, consists of a constant 180-degree rounded base leg. During the rounded base, no configuration changes are made to the aircraft, most having already been completed on the downwind leg. The procedure does allow for a final configuration adjustment once the aircraft is established in a wings-level condition on the final leg. This procedure was adapted from the technique used by the US Navy and US Air Force as well as several ab initio flight training programs.

Industry experts, such as Snow (2001) and Perry (2016), theorize that the rounded base turn will result in a safer and more stabilized approach for the following reasons; relatively constant angles of bank, rates of descent, and power settings; avoidance of configuration changes during the turn; and emphasis of stabilized approach concepts including energy management and AOA awareness.

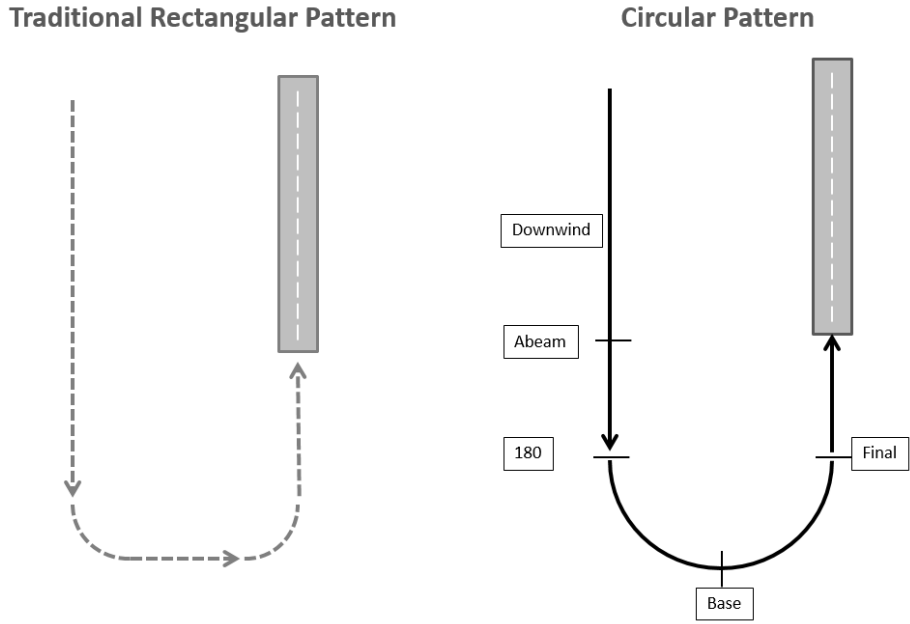


Figure 6. Comparison between Traditional Rectangular Pattern and Circular Pattern. Graphic courtesy of AOPA Air Safety Institute.

Prior to beginning the maneuver, the pilot must determine the appropriate “baseline airspeed” to be used on final prior to the roundout and flare. With the baseline airspeed determined, the pilot calculates “target airspeeds” to be used throughout the maneuver as illustrated in Figure 7. Based on the ground speed expected to be encountered during the downwind leg, the appropriate abeam distance between the runway centerline and the downwind leg must be determined using the information in Table 3.

Table 3

Abeam Distance Estimation Chart

Downwind Ground Speed	40-60 knots	60-70 knots	70-80 knots	80-90 knots	90-100 knots	100-120 knots
Abeam Distance between Runway and Downwind Leg (miles)	0.3	0.4	0.5	0.6-0.7	0.8-1.0	1.0
Abeam Distance between Runway and Downwind Leg (feet)	2000	2500	3000	4000	5000	6000

Note. Data courtesy of AOPA Air Safety Institute.

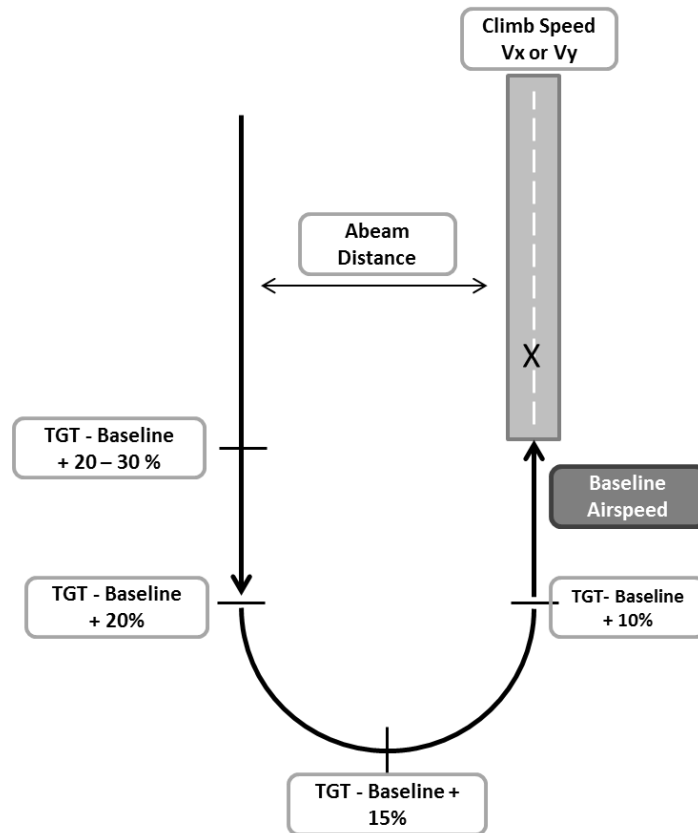


Figure 7. Target Airspeed Determination. Graphic courtesy of AOPA Air Safety Institute.

As depicted in Figure 8, the maneuver begins as the pilot configures the aircraft while approaching the abeam point on the downwind leg. An airspeed of approximately 20 to 30 percent above baseline is maintained in level flight until reaching the “timing and descent initiation point”. With a descent rate of approximately 300 to 400 feet-per-minute, the pilot begins the turn at approximately 20 to 25 seconds beyond the runway threshold using a bank angle between approximately 20 to 30 degrees. Once established in the turn, descent rate increases slightly to approximately 500 to 600 feet-per-minute. Configuration changes are not recommended during the turn to minimize destabilizing the aircraft. As the aircraft begins to align with the extended runway centerline, the pilot rolls the aircraft wings-level, then makes a final configuration adjustment to prepare the aircraft for landing.

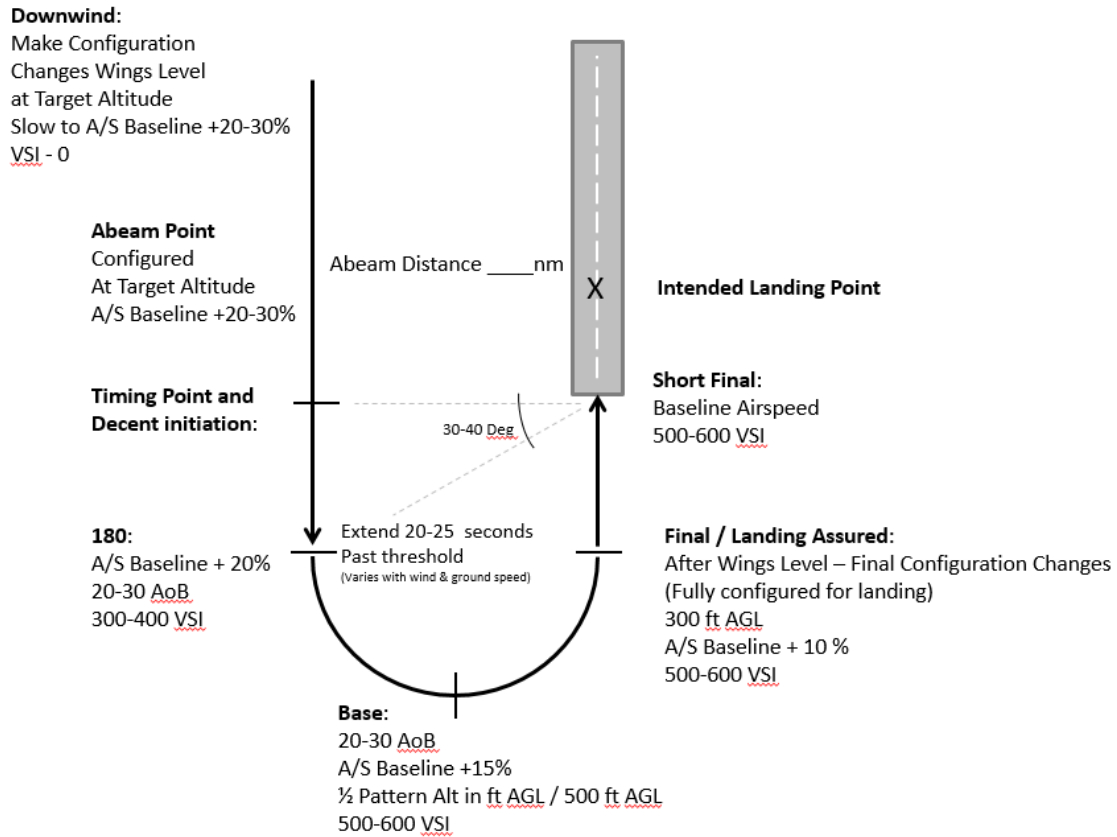


Figure 8. Circular Landing Pattern Segments. Graphic courtesy of AOPA Air Safety Institute.

Accidents and Incidents

A query of the NTSB accident database provided additional insight into the frequency and seriousness of the problem. The search criteria consisted of 14 CFR Part 91 accidents occurring in the approach phase of flight in visual meteorological conditions in reciprocating-powered airplanes. 35 reports were returned when results were filtered to include only those accidents with the phrase “base to final turn” in the synopsis and narrative. Three accidents are highlighted:

Arlington, WA – July 11, 2003

The first occurred on July 11, 2003, when an Archer S-18T impacted terrain during a traffic pattern maneuver at the Arlington Municipal Airport (AWO) in Arlington, WA. The pilot conducted an early base to final turn in which a maximum bank angle of near 60 degrees was encountered. The airplane entered a stall, causing the aircraft to roll into a 90 degree bank angle. The pilot was able to recover the aircraft to a normal attitude prior to impact, resulting in no injuries or fatalities. The NTSB determined the probable cause to be “the pilot’s failure to maintain an airspeed above V_s (stalling speed) while making a close-in base-to-final turn.”

Boyceville, WI – August 5, 2006

On August 5, 2006, a Cirrus SR22 at the Boyceville Municipal Airport (3T3) in Boyceville, WI entered a steep bank during the base to final turn leading to an inadvertent stall. Due to the low altitude at which the upset began, the stall was unrecoverable, causing the aircraft to impact terrain near the runway. The accident resulted in three injuries; one serious and two minor. The NTSB determined the probable cause to be “the pilot’s failure to maintain adequate airspeed...which resulted in an inadvertent stall during a base to final turn to the landing runway”.

Williamsburg, VA – April 19, 2013

On April 19, 2013, a Cessna 210E impacted terrain during a traffic pattern maneuver at the Williamsburg-Jamestown Airport (JGG) in Williamsburg, VA. During the base to final turn, witnesses observed the aircraft pass beyond the extended centerline of the runway, then enter a steep bank. The aircraft then entered a steep descent, impacting terrain approximately one-half mile away from the runway, resulting in two fatalities. The NTSB determined the probable cause

to be “the pilot’s failure to maintain airplane control during a base-to-final turn...which resulted in an aerodynamic stall and collision with terrain.”

Aerodynamic Stalls during Base-to-Final Turn

These three accidents, in addition to numerous others, share a common theme; they occurred as a result of an aerodynamic stall during the base-to-final turn. As the pilots increased their bank angle during the turn, AOA increased to the point at which the wing exceeded the critical AOA, causing the aircraft to stall and collide with terrain. These accidents, in addition to the plethora of research conducted on I-LOC, indicate the need for action to alleviate the likelihood of entering a stall during the base-to-final turn.

DEFINITIONS

- Accident – An occurrence associated with the operation of an aircraft, which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage.
- Angle-of-Attack – The angle at which relative wind meets an airfoil. It is the angle that is formed by the chord of the airfoil and the direction of the relative wind or between the chord line and the flight path. The angle of attack changes during a flight as the pilot changes the direction of the aircraft and is related to the amount of lift being produced.
- Bank Angle – The angle between the aircraft’s normal axis and the earth’s vertical plane containing the aircraft’s longitudinal axis.
- Critical Angle of Attack – The angle of attack at which a wing stalls regardless of airspeed, flight attitude, or weight.

- General Aviation – All flight activity of every kind except that done by the uniformed armed services and the scheduled airlines.
- In-Flight Loss of Control – The partial or complete loss of control of the airplane during an airborne phase of flight, or the period from when the wheels lift off the ground to when the wheels touch down.
- Incident – An occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations.
- Indicated Airspeed – The direct instrument reading obtained from the airspeed indicator, uncorrected for variations in atmospheric density, installation error, or instrument error.
- Pitch Attitude – The angle between the longitudinal axis of the aircraft and the horizon.
- Spin – An aggravated stall that results in an airplane descending in a helical, or corkscrew path.
- Stall – A rapid decrease in lift caused by the separation of airflow from the wing's surface, brought on by exceeding the critical angle of attack. A stall can occur at any pitch attitude or airspeed.
- Vertical Speed – A measurement of the rate of climb or descent in feet per minute.

CHAPTER II

METHODOLOGY

Introduction

I-LOC continues to be identified as the largest contributor to general aviation fatalities. Maneuvering at low altitudes, such as during a traffic pattern, poses considerable risk as the time for a pilot to recover from loss of control is greatly reduced (National Transportation Safety Board, 2016). While considerable research regarding in-flight loss of control has been conducted, a review of the literature provided very little evidence of investigations into alternative methods of conducting the traffic pattern. This study evaluates the use of a rounded base leg as an alternative to the traditional rectangular base leg using statistical flight data analysis. The independent variable is the type of method utilized (rounded base or rectangular base). The dependent variables are bank angle, vertical speed, indicated airspeed, pitch attitude, and runway alignment. The study uses a between-groups quasi-experimental design to analyze differences between the experimental condition (the rounded base method) and the control (the rectangular method).

The design of the procedure utilized in this study (Figure 9) was an adaptation of a design created by the AOPA ASI (Figure 8). The ASI developed the procedure using guidance from syllabi, procedures, and best practices available from sources including the US Navy and ab-initio flight training programs. The ASI procedure was distributed to three flight instructors who

were managers within the Standards Department at a large collegiate flight school, two of whom would also participate in the data collection phase of this study. Each of these individuals conducted the maneuver several times in a Cessna 172S with the goal of validating and refining its design. Feedback from these individuals was gathered and used to design the final version of the maneuver to be used in the study.

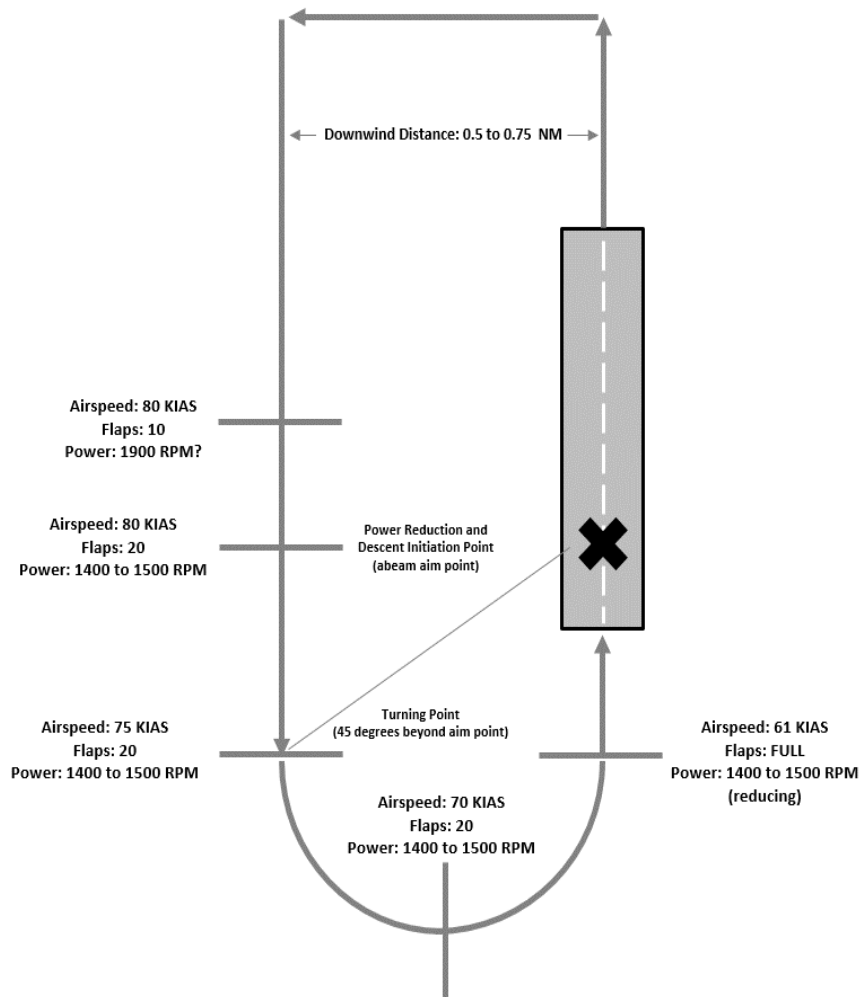


Figure 9. Rounded Base Procedure.

The rounded base method utilized for this study was refined for use in the Cessna 172S aircraft that would conduct the maneuver. The design consists of a pattern width of between 0.5

to 0.75 nautical miles away from the runway centerline with a target airspeed on the downwind leg of 80 knots indicated. Upon reaching midfield downwind, the pilot sets wing flaps to 10 degrees while maintaining level flight with an engine power setting of approximately 1900 RPM. When abeam the aim point for touchdown, the pilot reduces power to approximately 1400 to 1500 RPM, sets flaps to 20 degrees, and lowers the pitch attitude of the aircraft to allow for a descent at approximately 80 knots indicated. At a location approximately 45 degrees beyond the aim point, the pilot begins the constant downwind-to-final turn. During the turn, airspeed is expected to decrease from approximately 75 knots indicated to 61 knots indicated upon rollout. As the aircraft rolls-out on the final leg, the pilot sets flaps to the FULL position if required while adjusting power, pitch, and airspeed as necessary to maintain a stabilized approach to the touchdown point.

Population

The population in this study are pilots operating under the regulations of 14 CFR Part 91 (general aviation) in single-engine piston-powered aircraft such as the Cessna 172S. General aviation encompasses a wide range of flight operations including multi-engine and turbine-powered aircraft, however, these particular sectors were not analyzed in this study. In addition, pilots operating under other regulations such as 14 CFR Part 121 and 135 were excluded as traffic patterns are less common in these types of operations and, when they are utilized, usually differ significantly in altitude and dimensions.

Variables

Five variables are analyzed in this study; bank angle, vertical speed, indicated airspeed, pitch, and runway alignment. These variables were selected due to their influence on AOA.

According to the Pilot's Handbook of Aeronautical Knowledge (United States Department of Transportation, 2016b), a stall is "a rapid decrease in lift caused by the separation of airflow from the wing's surface, brought on by exceeding the critical angle of attack". As angle-of-attack increases, the aircraft moves closer to the critical angle-of-attack at which the stall occurs.

Bank angle, according to the Airplane Flying Handbook (United States Department of Transportation, 2016a), is defined as "the angle formed by the airplane's lateral axis, which extends from wingtip to wingtip, and the natural horizon". Simply put, bank angle is a measurement of the angular difference between the wing and the horizon. For the purposes of this study, both mean bank angles and maximum bank angles will be analyzed.

Vertical speed is a measurement of the rate of climb or descent of the aircraft in units of feet-per-minute (FPM). A vertical speed above 0 FPM indicates a climb, whereas a vertical speed below 0 FPM indicates a descent. As it is assumed the pilot is intending to descend the aircraft during this portion of the traffic pattern, a greater vertical speed indicates the aircraft is not descending as fast as an aircraft with a lower vertical speed. With weight, bank angle, engine RPM, and air density held constant, a greater vertical speed may indicate the aircraft is closer to the critical AOA as the pilot would need to add elevator force to arrest the descent. To evaluate this variable, both mean vertical speeds and maximum vertical speeds will be analyzed.

Indicated airspeed, per the Airplane Flying Handbook (United States Department of Transportation, 2016a), is defined as "the direct instrument reading obtained from the airspeed indicator, uncorrected for variations in atmospheric density, installation error, or instrument error". Stall speeds published in Airplane Flight Manuals (AFM) or Pilot Operating Handbooks (POH) are in units of indicated airspeed. An aircraft will stall at the same indicated airspeed

regardless of atmospheric conditions such as density, pressure, and temperature. Although indicated stall speed does change with weight, load factor, and aircraft configuration, the published indicated stall speed may be used as a baseline to determine approximately how far the aircraft is from the stall. The lower the indicated airspeed, the closer the aircraft is to stall speed. For the purposes of this study, both mean indicated airspeeds and minimum indicated airspeeds will be analyzed.

Pitch is defined by the Airplane Flying Handbook (United States Department of Transportation, 2016a) as “the rotation of an airplane about its lateral axis...” While pitch attitude is not a direct indication of AOA, it can provide a general idea of proximity to AOA. Generally speaking, with all other variables held constant, an aircraft at a higher pitch attitude would be at a higher AOA than an aircraft at a lower pitch attitude. To evaluate this variable, both mean pitch attitudes and maximum pitch attitudes will be analyzed.

Runway alignment, the only categorical variable to be analyzed in this study, refers to the position of the aircraft with respect to the extended runway centerline upon completion of the turn to final. It is desired that the aircraft be aligned with the runway upon rollout, however, factors such as wind, bank angle, and poor judgment for when to begin the turn often result in the aircraft either undershooting (as a result of turning too much) or overshooting (as a result of not turning enough) the extended runway centerline. Each pattern will be categorized into one of two conditions with condition 1 representing aircraft that were aligned with the runway upon completion of the turn and condition 2 representing aircraft that were not aligned upon completion of the turn.

Data Sources and Collection

The study consisted of flight data analysis from 14 CFR Part 91 flights conducted in single-engine piston-powered Cessna 172S Skyhawks. The aircraft were operated by a large 14 CFR Part 141 collegiate flight training program located in the Upper Midwest region of the United States. Two groups of data were utilized; an experimental group consisting of the rounded base method as well as a control group consisting of the traditional rectangular method.

Data from both the experimental and control groups were collected by integrated flight data monitoring (FDM) software in the Garmin G1000 avionics suite, a standard feature of the school's fleet of aircraft. The software is capable of recording a multitude of parameters (Table 4) with storage of up to 1,000 flight hours of data for every 1 GB of capacity on an SD card. Data is recorded automatically at a rate of once per second whenever the Multi-Function Display (MFD) is powered on.

The participants in the experimental group were instructed to complete a short questionnaire upon the conclusion of each flight to allow for retrieval of the flight data. The questionnaire asked for the registration number of the aircraft as well as the date, time, and location in which the maneuver was conducted. In addition, the questionnaire asked if the SRA and the organization's existing safety controls were effective in identifying and mitigating the risk and hazards encountered during the procedure. If the respondent answered this question in the negative, the questionnaire asked the respondent to provide information on additional hazards encountered that were not previously considered. Finally, the questionnaire asked for additional input that may be helpful to the researcher when analyzing the data. This questionnaire was distributed in an electronic format using the Qualtrics platform. A link to the questionnaire was

provided to the participants prior to the commencement of the flights. Upon receipt of the completed questionnaires, the data was retrieved from the aircraft.

Table 4

G1000 Flight Data Logging Parameters

Date	Pitch Attitude Angle (degrees)	Nav1/Nav2 frequency	AFCS roll/pitch commands	Engine RPM
Time	Roll Attitude Angle (degrees)	CDI deflection	GPS fix	Oil Pressure (psi)
GPS Altitude (MSL)	Lateral and Vertical G Force (g)	VDI/GP/GS deflection	GPS horizontal alert limit	Oil Temperature (deg. F)
GPS Altitude (WGS84 datum)	Ground Speed (kts)	Wind Direction (degrees)	GPS vertical alert limit	TIT (deg. F)
Baro-Corrected altitude (feet)	Ground Track (degrees magnetic)	Wind Speed (knots)	SBAS GPS horizontal protection level	Manifold Pressure (in. Hg)
Baro Correction (in/Hg)	Latitude (degrees; geodetic; +North)	Active Waypoint Identifier	SBAS GPS vertical protection level	CHT
Indicated airspeed (kts)	Longitude (degrees; geodetic; +East)	Distance to next waypoint (nm)	Fuel Qty (right & left)(gals)	EGT
Vertical speed (fpm)	Magnetic Heading (degrees)	Bearing to next waypoint (degrees)	Fuel Flow (gph)	
GPS vertical speed (fpm)	HSI source	Magnetic variation (degrees)	Fuel Pressure (psi)	
OAT (degrees C)	Selected course	Autopilot On/Off	Voltage 1 and/or 2	
True airspeed (knots)	Com1/Com2 frequency	AFCS roll/pitch modes	Amps 1 and/or 2	

Note. Adapted from *Garmin G1000 Cockpit Reference Guide for the Cessna Nav III*, by Garmin Ltd., 2011, p. 11-23. AOPA Membership Publications, Inc.

Instrument Reliability and Validity

The reliability and validity of FDM equipment has been well documented in the literature. FDM is utilized in a variety of general aviation operations for the purposes of research,

education, and monitoring safety trends (PR Newswire, 2010). The FDM data came in the form of multiple .csv files, with each file representing one flight from MFD power-up to power-down. Filtering was conducted within each file to remove flight data not associated with the base leg of the traffic patterns.

Proposed Data Analysis

The relevant FDM data was copied from each .csv file into IBM© SPSS© Statistics Version 23. This software was used to produce descriptive statistics and to identify statistical significance ($\alpha = .05$). As no evidence existed in the literature of prior testing of a rounded base method, this study utilized two-tailed tests to evaluate the hypotheses. The statistical tests utilized are identified in Table 5.

Table 5

Proposed Statistical Tests

Dependent Variable	Statistical Test
Bank Angle	Independent t-test
Vertical Speed	Independent t-test
Indicated Airspeed	Independent t-test
Pitch Attitude	Independent t-test
Runway Alignment	Chi-Square

Participants

Participants for the experimental group were selected out of convenience to the researcher. The group consisted of three flight instructors, all members of the school’s Standards Department, who were selected due to their high-level of experience and their role in conducting standardization flights for the flight instructor cadre. These flights were targeted by the researcher due to their frequency of occurrence, the lack of extra cost in conducting the flights,

and the high level of proficiency and experience of the individuals in command of the aircraft. Data for the control group was randomly selected from the same fleet of aircraft.

Participants within the experimental group were instructed by the researcher on how to conduct the rounded base maneuver, to conduct the maneuver only at non-towered airports and, to conduct the maneuver with only themselves acting as the PF. Two of the three participants had previously conducted an earlier version of the maneuver as designed by the AOPA ASI and had provided input in the design of the most recent version. In addition, the participants were presented with a copy of a Safety Risk Assessment (SRA) conducted in accordance with the school's FAA-approved Safety Management System (SMS).

Assumptions and Limitations

It was assumed that the rounded base turns were performed solely by the participants selected as PF by the researcher. In addition, it was assumed that the maneuver was conducted in accordance with the procedure briefed by the researcher to the participants (Figure 9). It was assumed that the participants in the control group were intending to conduct the traditional rectangular base method during 14 CFR Part 91 operations.

The most significant limitation to this study was the aeronautical experience level of the participants. For the purposes of both safety and convenience, the participants selected to conduct the rounded base turns were experienced flight instructors with considerable proficiency in the aircraft. Additionally, two of the three participants had assisted in the development of this version of the maneuver by flying the procedure developed by the AOPA ASI. The data for the control group was randomly selected without any indication of the experience level of these pilots. These limitations do present a threat to the validity of the study.

First, the experience level of the pilots using the rounded base method may confound the data as their skill may be influencing any detected advantages of the rounded base over the rectangular base. A counterbalance may exist within the control group as the experience level of these pilots may mirror that of the experimental group, although this cannot be determined due to the random nature of the control group. A within-groups design using a random sampling of participants would likely provide the counterbalance necessary to overcome this concern.

An additional threat to validity is repeated testing. As two of the three participants had assisted in the development of the maneuver, the technique may have been learned to the extent that errors such as excessive bank and misalignment with the runway were unlikely. This concern is counterbalanced for two reasons; one, the pilot who had not participated in the developmental phase was initially unfamiliar with the procedure and two, the rectangular patterns in the control group had likely been conducted by those participants many times before as it is currently the standard method, perhaps giving the control group a slight advantage over the experimental group.

The experience level of the participants in the experimental group weaken the ability to apply the results of this study to the spectrum of general aviation pilots which includes a wide variety of experience and proficiency. In addition, the repeated testing effect may lead to a false sense of confidence in any detected advantage of the rounded base procedure as well as the simplicity in learning the procedure.

A further limitation of this study is the lack of feedback from the participants regarding their perceptions of the maneuver. Anecdotal comments from pilots who have performed the maneuver have been positive, however, feedback has not been validated through the use of any

type of survey instrument. Additional research is necessary to determine how the use of a rounded base leg would be received by the GA community.

An additional concern is the extent to which the rounded base affects a pilot's visibility in the traffic pattern. A technique encouraged by the FAA is to visually check for traffic on final approach prior to beginning the turn from base to final (United States Department of Transportation, 2016b). As the aircraft does not roll into a wings-level attitude on the base leg during this maneuver, the ability to perform this visual check may be hindered. This concern may be alleviated by conducting the visual check on the downwind leg just prior to commencing the turn, although further research is necessary to determine the ability to see-and-avoid traffic while using this method.

Finally, this study lacks analysis of cognitive workload. While the data from this study may provide evidence that the rounded base method could be a safer alternative than the rectangular base, it is unknown whether the maneuver affects the level of cognitive workload encountered by the pilot during the approach-to-landing phase of flight. Additional research using survey instruments and quantitative electroencephalography (QEEG) devices will be necessary to draw conclusions in this area.

Protection of Human Subjects

The study received approval from the Institutional Review Board (IRB) of the University of North Dakota (UND). All participants conducting the rounded base method, including all other occupants on the aircraft who were not acting as the Pilot Flying (PF) during the maneuver, were asked to provide consent. Those individuals, including those occupants of the aircraft not acting as the PF, who wished to not participate in the study were provided the opportunity to

either withhold or withdraw their consent at any time. All occupants of an aircraft in which a rounded base turn was conducted had granted consent and were presented with a copy of the Safety Risk Assessment (SRA) conducted in accordance with the school's FAA-approved Safety Management System (SMS).

All flight data used in this study was de-identified, with the exception of the aircraft registration number, which did not provide any indication as to which participant was operating the aircraft. If the participant decided not to release flight data from any particular flight, they were instructed to avoid completing the post-flight questionnaire which would prevent retrieval of the flight data. Participants with questions or concerns were advised to contact either the UND IRB or the researcher via email or phone.

CHAPTER III

RESULTS

Data from the experimental group was obtained based on information provided by each pilot in an online questionnaire using the Qualtrics platform. The flight data was provided in multiple .csv files, with each file representing one flight from engine start to shutdown. An SPSS© file was created to gather the descriptive values to be used for the analysis. For the experimental group, the SPSS© file contained only the data recorded from the commencement (end of downwind) to completion (beginning of final) of each turn. This filtering was accomplished through analysis of both roll (bank) angle and aircraft track with respect to the runway heading, which was determined by analyzing geographic coordinates provided in the data.

Control group data was obtained a random sampling of flight data from the same 14 CFR Part 141 collegiate flight training program. Each .csv file was analyzed to verify the presence of traffic patterns at non-towered airports through examination of altitude, airspeed, roll (bank) angle and aircraft track with respect to runway heading, which was determined by analyzing geographic coordinated provided in the data. Files that did not include traffic patterns at non-towered airports were rejected. Once an amount of rectangular patterns equal to the amount of rounded-base patterns were identified, the data was imported into the same SPSS© file as the experimental group. For the control group, the SPSS© file contained only data recorded from the commencement to completion of each turn (downwind-to-base and base-to-final). Data recorded

between these turns (when the aircraft was approximately wings-level) was excluded as the focus of the study is on the turn and this data would have inappropriately skewed the results and subsequent statistical analysis.

Within SPSS®, the Compute Variable function was applied to the roll variable to calculate the absolute value of each data point. This was accomplished because the roll data included negative values to indicate rolls to the left and positive values to indicate rolls to the right. As the direction of the roll was not applicable to these variables and because the negative values would incorrectly skew the results, the absolute value of each data point was calculated into a new variable titled “Bank Angle”.

An additional SPSS® file was created to contain only the descriptive values to be analyzed, with each row representing one traffic pattern. In addition, the categorical variable (runway alignment) was entered into this file. The data for the categorical variable was determined by using a separate dataset containing the same data recorded during the turns, but also containing data beyond the completion of each turn, terminating at aircraft touchdown. This extra data was required to determine if the pilot made corrections to align the aircraft with the runway after completion of the turn to final. Aircraft touchdown was determined through analysis of vertical G-force, altitude, and airspeed. In addition, this file included the “wings-level” data deleted from the rectangular patterns in the original dataset.

Statistical Analysis

Using an alpha level of .05, independent samples t-tests were conducted to compare bank angle, vertical speed, indicated airspeed, and pitch attitude during rounded base turns and rectangular base turns. The t-tests indicated significant differences for all variables.

Bank Angle

Mean bank angles (Figure 10) during the rounded base method ranged from 6.58° to 14.66°. Mean bank angles during the rectangular method ranged from 11.16° to 19.23°. On average, the use of the rounded base method resulted in lower mean bank angles ($M = 10.89^\circ$, $SD = 2.55^\circ$) than the rectangular base method ($M = 14.88^\circ$, $SD = 2.29^\circ$). This difference, -3.99° , 95% CI $[-5.74^\circ, -2.24^\circ]$ was highly significant ($p < .001$) and represented a medium effect size, $d = .7$.

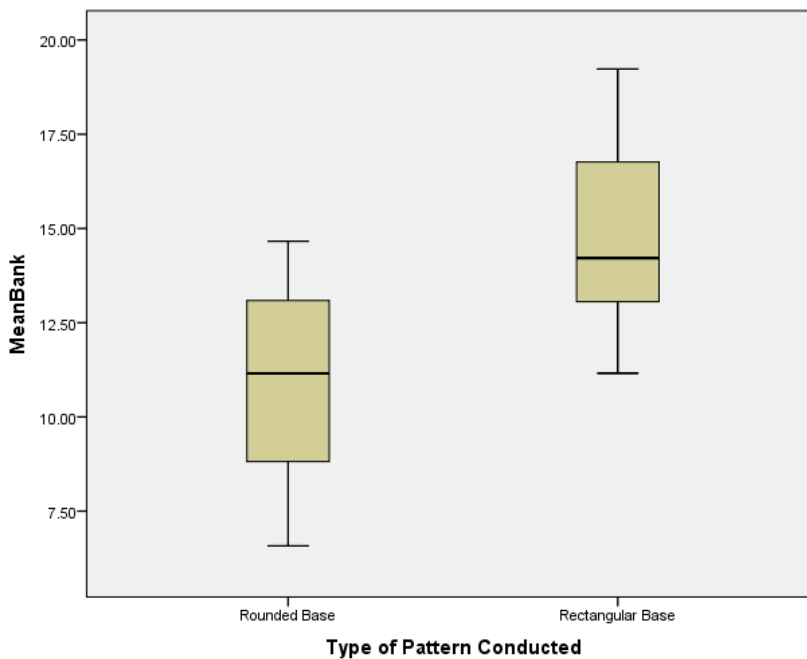


Figure 10. Boxplots of Mean Bank Angles.

Maximum bank angles (Figure 11) during the rounded base method ranged from 13.62° to 23.52° while maximum bank angles during the rectangular method ranged from 20.18° to 36.34°. On average, the use of the rounded base method resulted in lower maximum bank angles ($M = 18.32^\circ$, $SD = 3.34^\circ$) than the rectangular base method ($M = 26.71^\circ$, $SD = 4.48^\circ$). This

difference, -8.39° , 95% CI $[-11.24^\circ, -5.54^\circ]$ was highly significant ($p < .001$) and represented a medium effect size, $d = .7$.

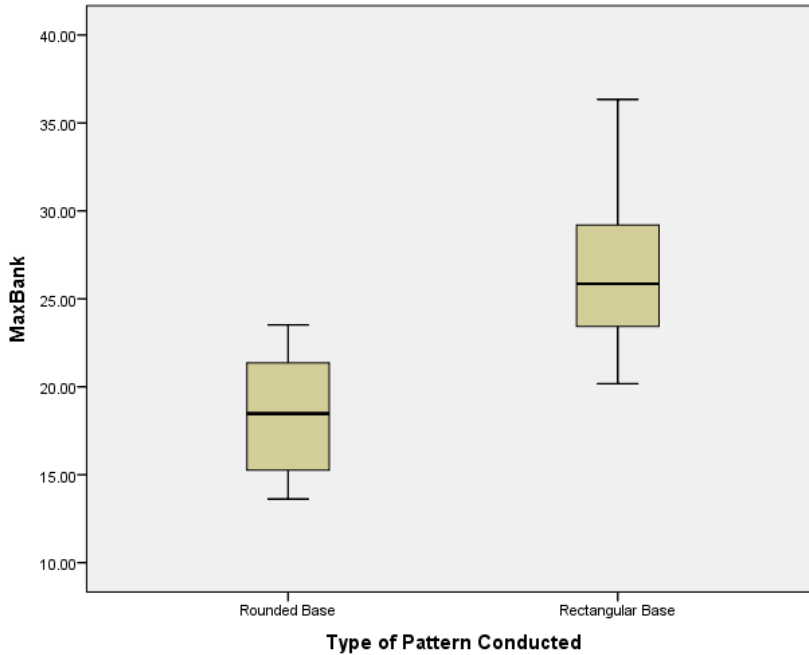


Figure 11. Boxplots of Maximum Bank Angles.

Table 6

Independent t-test; Bank Angle

	Method Used		t	df
	Rounded-Base	Rectangular Base		
Mean Bank Angle	10.89 (2.55)	14.88 (2.29)	-4.657***	30
Maximum Bank Angle	18.32 (3.34)	26.71 (4.48)	-6.006***	30

Note. *** = $p < .001$. Standard Deviations appear in parentheses below means.

Vertical Speed

As expected, vertical speeds were generally negative values, indicating that the aircraft were descending. Mean descent rates (Figure 12) during the rounded base method ranged from -449.69 FPM to -704.27 FPM. Mean descent rates during the rectangular method ranged from -

326.39 FPM to -603.27 FPM to. On average, the use of the rounded base method resulted in greater mean descent rates ($M = -568.30$ FPM, $SD = 60.57$ FPM) than the rectangular base method ($M = -456.86$, $SD = 73.37$). This difference, -111.44 FPM, 95% CI [-160.08 FPM, -62.81 FPM] was highly significant ($p < .001$) and represented a medium effect size, $d = .7$.

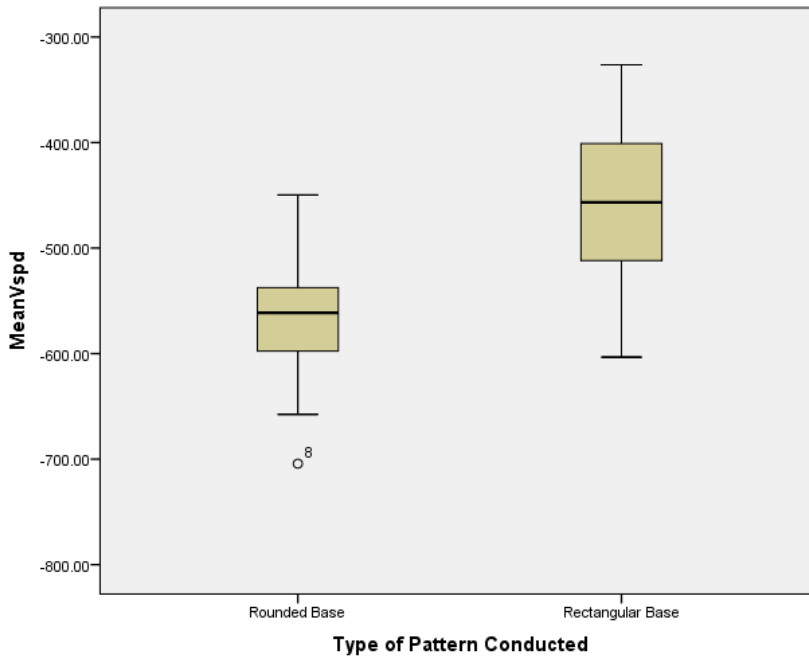


Figure 12. Boxplots of Mean Vertical Speeds.

Maximum vertical speeds (Figure 13) during the rounded base method ranged from -433.08 FPM to -23.79 FPM. Maximum vertical speeds during the rectangular method ranged from -206.53 FPM to 354.38 FPM. On average, the use of the rounded base method resulted in lower maximum vertical speeds ($M = -303.50$ FPM, $SD = 116.26$ FPM) than the rectangular base method ($M = 21.07$, $SD = 179.38$). This difference, -324.57 FPM, 95% CI [-433.70 FPM, -215.43 FPM] was highly significant ($p < .001$) and represented a medium effect size, $d = .7$.

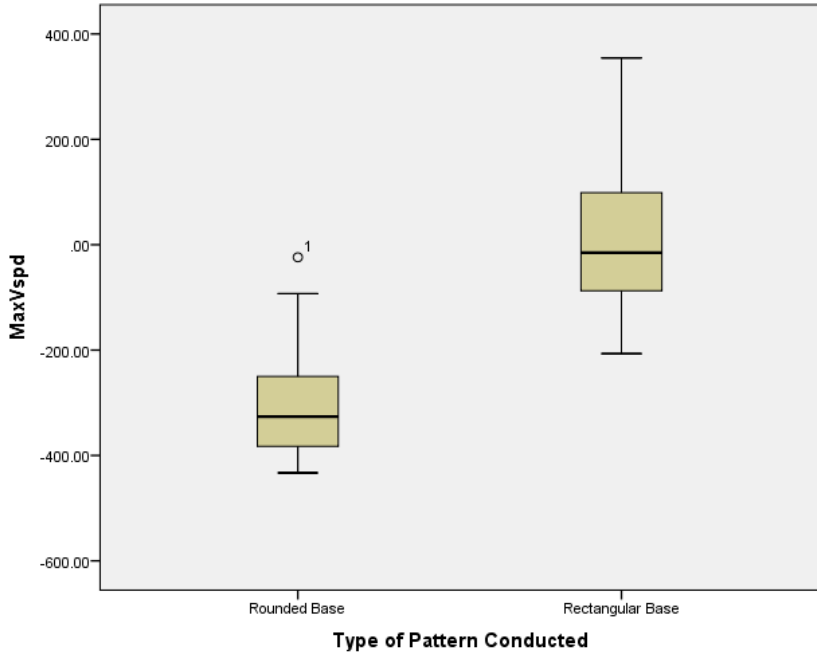


Figure 13. Boxplots of Maximum Vertical Speeds.

Table 7

Independent t-test; Vertical Speed

	Method Used		t	df
	Rounded-Base	Rectangular Base		
Mean Vertical Speed	-568.30 (60.75)	-456.86 (73.37)	-4.68***	30
Maximum Vertical Speed	-303.50 (116.26)	21.07 (179.38)	-6.07***	30

Note. *** = $p < .001$. Standard Deviations appear in parentheses below means.

Indicated Airspeed

Mean indicated airspeeds (Figure 14) during the rounded base method ranged from 66 knots to 72 knots. Mean indicated airspeeds during the rectangular method ranged from 66 knots to 96 knots. On average, the use of the rounded base method resulted in lower mean indicated airspeeds ($M = 69.06$ knots, $SD = 1.61$ knots) than the rectangular base method ($M = 75.06$ knots, $SD = 7.63$ knots). This difference, -6.00 knots, 95% CI [-10.125 knots, -1.875 knots] was significant ($p = .007$) and represented a medium effect size, $d = .6$.

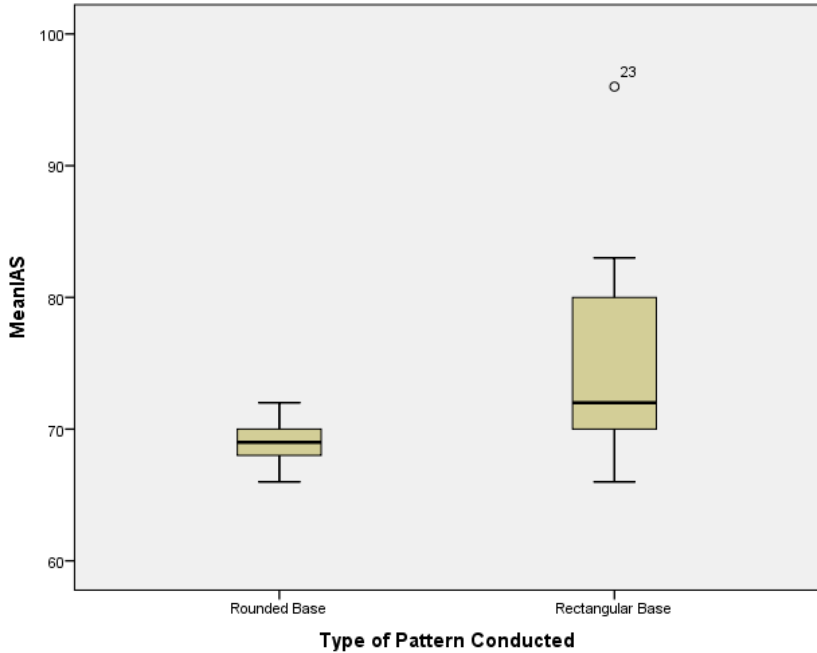


Figure 14. Boxplots of Mean Indicated Airspeeds.

Minimum indicated airspeeds (Figure 15) during the rounded base method ranged from 58 knots to 64 knots. Minimum indicated airspeeds during the rectangular method ranged from 59 knots to 92 knots. On average, the use of the rounded base method resulted in lower minimum indicated airspeeds ($M = 62.13$ knots, $SD = 1.63$ knots) than the rectangular base method ($M = 68.56$ knots, $SD = 8.10$ knots). This difference, -6.44 knots, 95% CI $[-10.81$ knots, -2.06 knots] was significant ($p = .007$) and represented a medium effect size, $d = .6$.

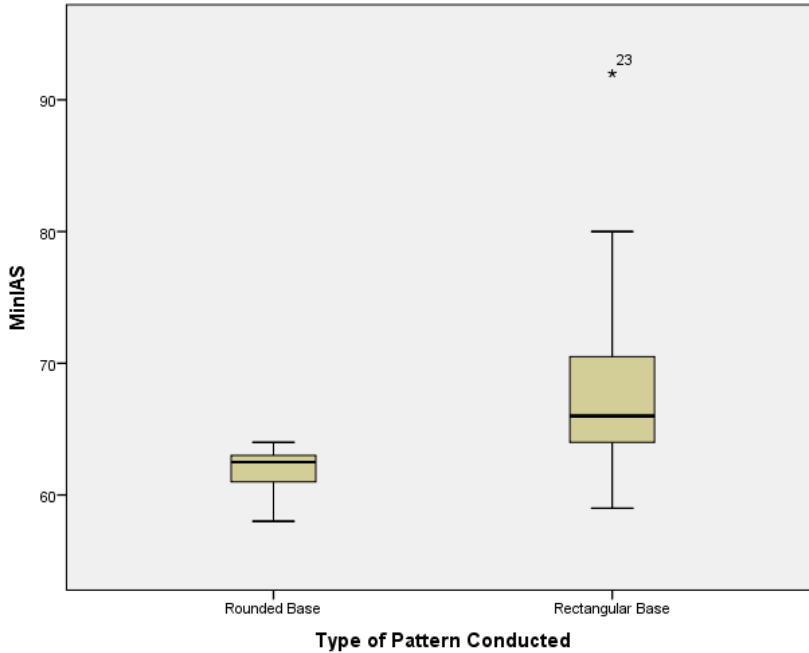


Figure 15. Boxplots of Minimum Indicated Airspeeds.

Table 8

Independent t-test; Indicated Airspeed

	Method Used		t	df
	Rounded-Base	Rectangular Base		
Mean Indicated Airspeed	69.06 (1.61)	75.06 (7.63)	-3.08*	16.34
Minimum Indicated Airspeed	62.13 (1.63)	68.56 (8.10)	-3.12*	16.21

Note. * = $p < .05$. Standard Deviations appear in parentheses below means.

Pitch Attitude

Mean pitch attitudes (Figure 16) during the rounded base method ranged from -3.77° to -1.50° . Mean pitch attitudes during the rectangular method ranged from -3.56° to $.72^\circ$. On average, the use of the rounded base method resulted in lower mean pitch attitudes ($M = -2.53^\circ$, $SD = .66^\circ$) than the rectangular base method ($M = -1.25^\circ$, $SD = 1.22^\circ$). This difference, -1.27° , 95% CI $[-1.98, -.57]$ was significant ($p = .001$) and represented a medium effect size, $d = .6$.

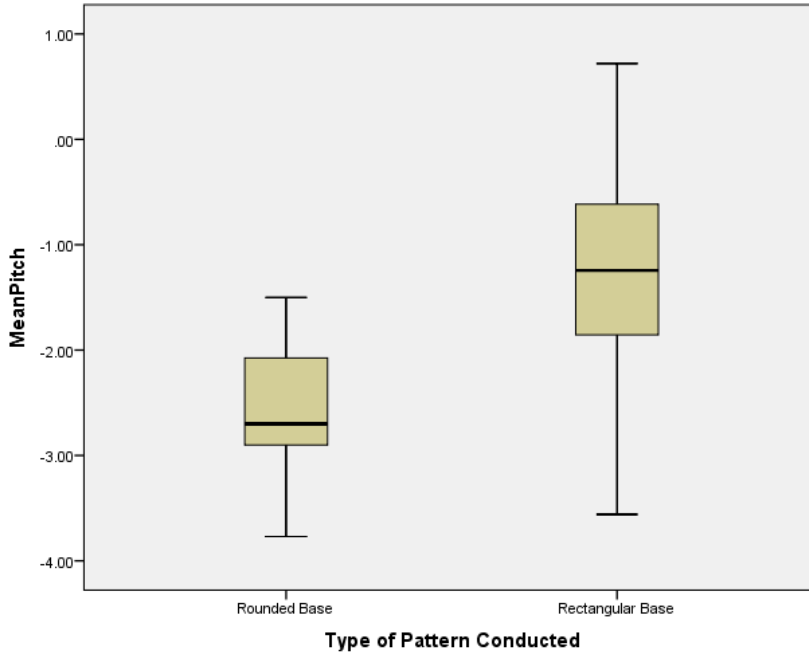


Figure 16. Boxplots of Mean Pitch Attitudes.

Maximum pitch attitudes (Figure 17) during the rounded base method ranged from -1.67° to 2.35° . Maximum pitch attitudes during the rectangular method ranged from -1.37° to 8.42° . On average, the use of the rounded base method resulted in lower maximum pitch attitudes ($M = -1.13^{\circ}$, $SD = 1.04^{\circ}$) than the rectangular base method ($M = 2.88^{\circ}$, $SD = 2.50^{\circ}$). This difference, -3.01° , 95% CI $[-4.42, -1.59]$ was highly significant ($p < .001$) and represented a medium effect size, $d = .7$.

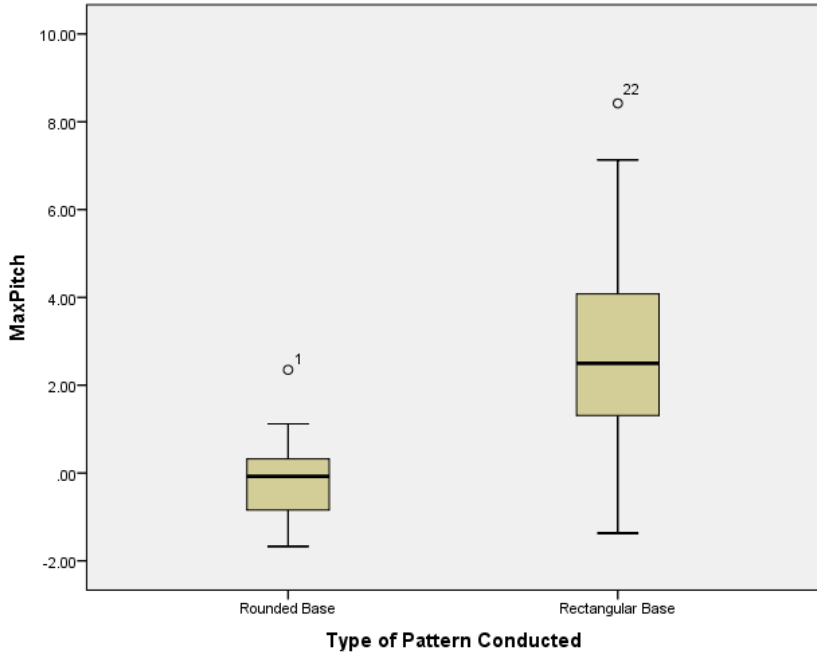


Figure 17. Boxplots of Maximum Pitch Attitudes.

Table 9

Independent t-test; Pitch Attitude

	Method Used		t	df
	Rounded-Base	Rectangular Base		
Mean Pitch Attitude	-2.53 (.66)	-1.25 (1.22)	-3.68*	30
Maximum Pitch Attitude	-.13 (1.04)	2.88 (2.50)	-4.44***	20.04

Note. * = $p < .05$, *** = $p < .001$. Standard Deviations appear in parentheses below means.

Runway Alignment

To determine whether the aircraft was aligned with the runway upon rollout from the turn to final, the roll variable from each pattern was individually analyzed in the form of a line chart. This was used to determine if the aircraft re-initiated a turn shortly after establishing a wings-level attitude (0° roll). If the aircraft rolled no more than 5° left or right after establishing wings-level, it was assumed that the aircraft was aligned with the runway upon rollout from the turn to final. If the aircraft exceeded 5° of roll shortly after establishing wings-level, it was assumed that

the pilot was correcting for a misalignment with the runway. If the aircraft exceeded 5° of roll shortly before touchdown, it was assumed that this was due to the pilot establishing a crosswind correction for landing, therefore, this data was ignored.

The data revealed that all rounded-base turns ended with the aircraft aligned with the runway upon rollout. Of the 16 rectangular patterns, 5 were not aligned with the runway upon rollout on final (Figures 14 through 18). This information was coded into a separate SPSS© file, with each pattern assigned a value of “1” to indicate runway alignment or a value of “2” to indicate the aircraft was not aligned.

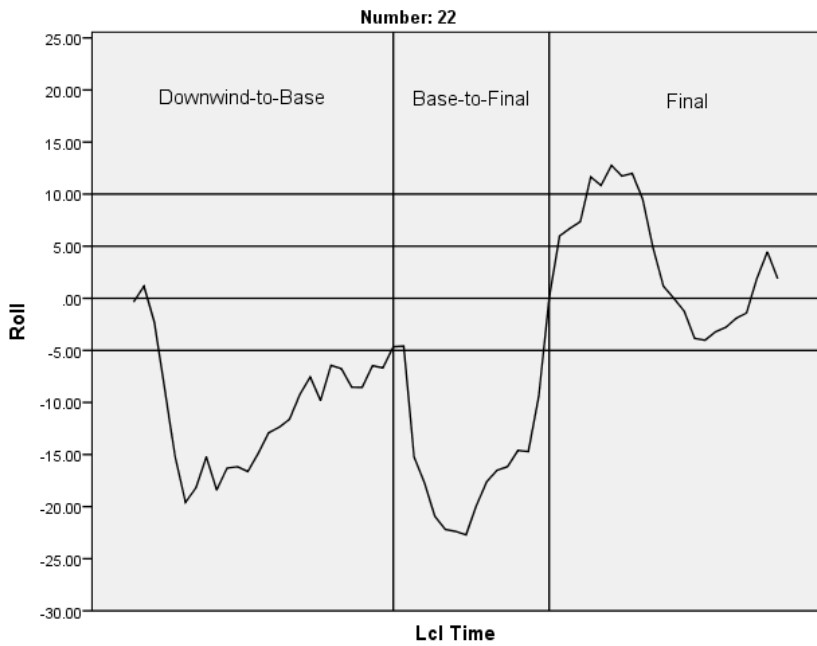


Figure 18. Line Chart of Pattern 22; Rectangular Method.

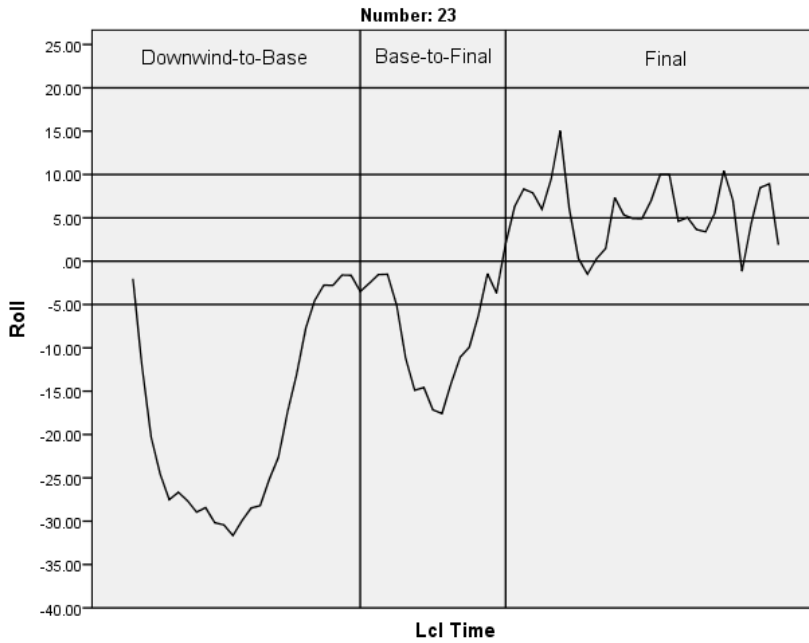


Figure 19. Line Chart of Pattern 23; Rectangular Method.

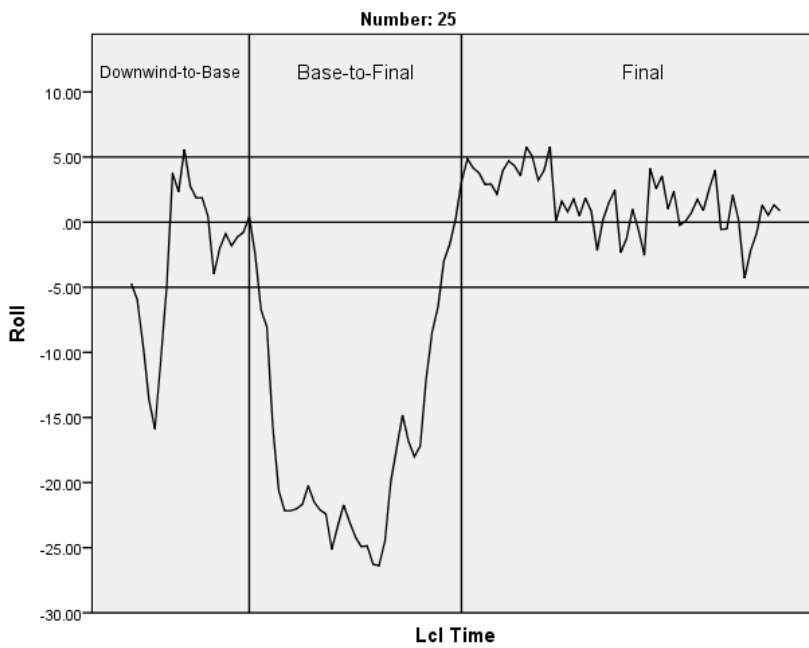


Figure 20. Line Chart of Pattern 25; Rectangular Method.

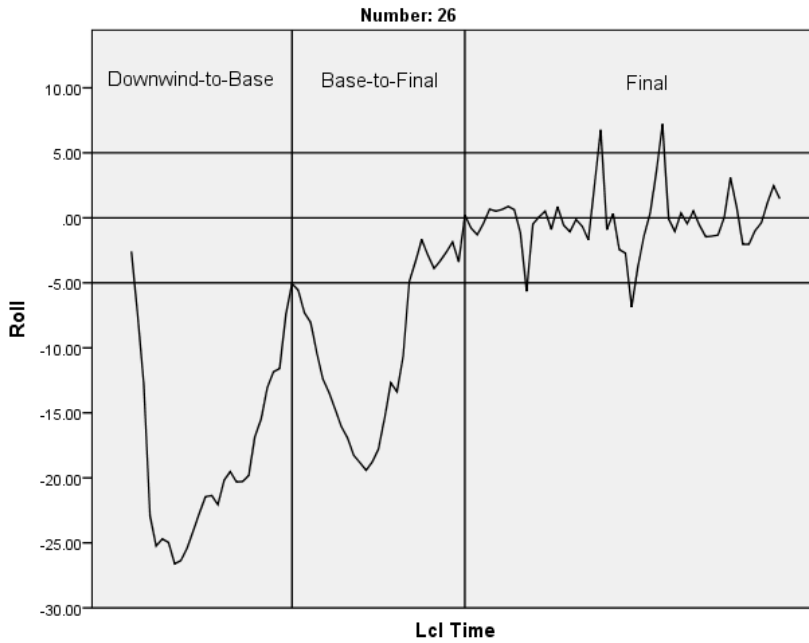


Figure 21. Line Chart of Pattern 26; Rectangular Method.

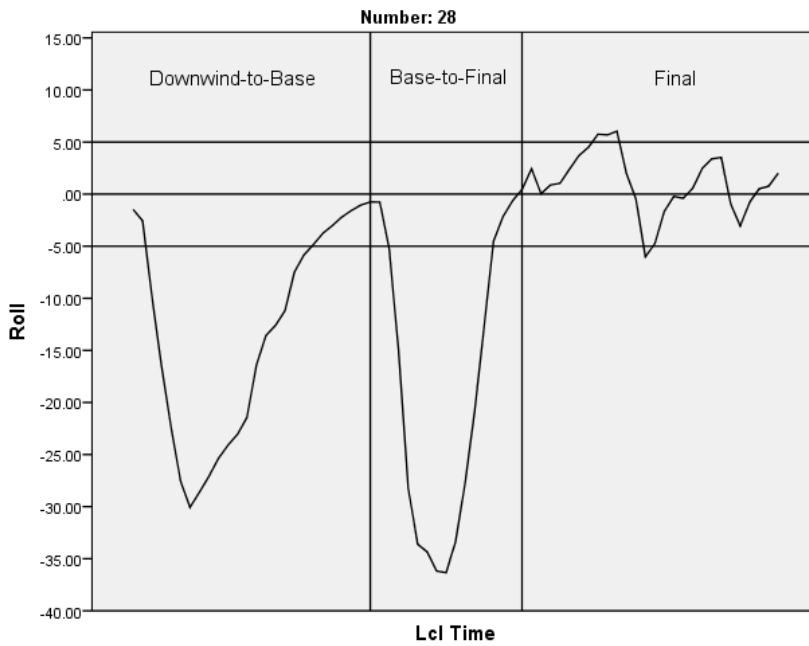


Figure 22. Line Chart of Pattern 28; Rectangular Method.

Chi-Square Test

Due to the categorical nature of the runway alignment variable, a Chi-Square Test was conducted to determine if the method used to conduct the base turn (rounded or rectangular) influenced the alignment of the aircraft with respect to the extended runway centerline upon rollout on final. A significant association was discovered between the method used and whether or not the aircraft was aligned with the runway upon rollout $\chi^2 (1) = 5.93, p = .015$, however, because 50% of the cells had an expected count less than 5, Pearson's Chi-Square should be considered unreliable. In this scenario, Fisher's exact test provides a more reliable indication of statistical significance, which in this case did report a significant association between the method used and runway alignment ($p = .043$).

Table 10

Crosstabulation of Method Used and Runway Alignment

Aligned With Runway?	Method Used		Fisher's Exact Test
	Rounded-Base	Rectangular Base	
Yes	16	11	5.93*
No	0	5	

Note. * = $p < .05$.

CHAPTER IV

DISCUSSION

The purpose of this study was to determine whether the use of a rounded base leg would result in a safer and more stabilized traffic pattern for general aviation aircraft than the traditional squared base. This chapter provides a detailed discussion of the results, the implications of the results with respect to general aviation safety, and suggestions for future research.

Research Question 1

Research question 1: Is there a statistically significant difference in bank angles between the rounded base and rectangular base methods?

A significant difference existed between the type of base turn conducted and the bank angles encountered during the maneuver. Use of rounded base turns resulted in lower bank angles, both in terms of the mean and maximum bank angles. While the difference between means was not substantial (3.99°), the difference in maximum bank angles was much larger (8.39°), indicating that the rounded base is beneficial in avoiding high bank angles that increase the AOA of the aircraft. The highest bank angles encountered using the rounded base method and rectangular method were approximately 24° and 36° respectively. As seen in Figure 23, stall speed begins to rapidly increase as bank angles exceed 30° . The pilot of the aircraft that encountered the maximum bank angle of 24° using the rounded base method would have encountered about a 6% to 7% increase in stall speed, whereas the pilot of the aircraft that

encountered the maximum bank angle of 36° while conducting the rectangular method would have encountered about a 12% increase in stall speed.

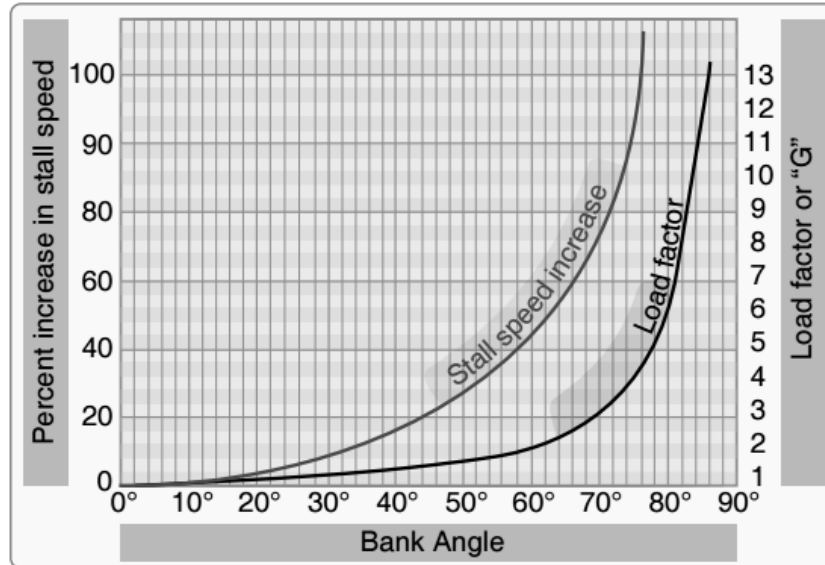


Figure 23. Increase in Stall Speed and Load Factor. From *Pilot's Handbook of Aeronautical Knowledge*, by United States Department of Transportation, Federal Aviation Administration, Flight Standards Service, 2016, p. 5-26. United States Department of Transportation, Federal Aviation Administration, Airman Testing Standards Branch.

A potential criticism of the rounded base method may be a perceived inability to perform an effective traffic scan of the final approach path while on the base leg, due to the constant banking nature of the maneuver. While this concern may hold some validity, the relatively low mean bank angle (10.89°) should provide some reassurance in the ability for pilots to adequately perform a visual check for traffic during the turn. In addition, the pilot could conduct this visual check just prior to beginning the turn from downwind while facing in the direction of potential oncoming traffic.

Research Question 2

Research question 2: Is there a statistically significant difference in vertical speeds between the rounded base and rectangular base methods?

A significant difference existed between the type of base turn conducted and the vertical speeds encountered during the maneuver. Use of the rounded base method resulted in lower vertical speeds, both in terms of mean and maximum, than the rectangular method. A difference of approximately 111 FPM between the mean values indicates that, on average, the rounded base method results in a greater descent rate than the rectangular method. Additionally, a difference of approximately 325 FPM between the maximum values is substantial, indicating that the rounded base method is much more likely to produce a consistent descent throughout the maneuver. An arrested descent is not usually desired as this likely means that pressure is being increased on the elevator, assuming all other variables are constant, thereby increasing AOA.

Research Question 3

Research question 3: Is there a statistically significant difference in indicated airspeeds between the rounded base and rectangular base methods?

A significant difference existed between the type of base turn conducted and the indicated airspeeds encountered during the maneuver. Use of the rounded base method resulted in lower indicated airspeeds, both in terms of mean and minimum, than the rectangular method. A difference of approximately 6 knots for both measurements indicates that the rounded base method results in slightly lower indicated airspeeds than the rectangular method. While this is concerning, the difference in means could be a result of differences in the profiles used between each maneuver. The rounded base turn profile used in this study (see figure 8) required the pilot

to maintain an airspeed of 75 knots prior to commencing the turn and a speed of 70 knots once established in the turn, gradually reducing to a speed of 61 knots upon rollout on final.

According to the standardization manual that was assumed to have been followed by the control group, pilots are expected to maintain a slightly higher airspeed of 80 knots prior to commencing the turn from downwind to base and a speed of 70 knots for the duration of the base leg (UND Aerospace, 2016). The data indicated that the participants in the experimental group were very close to the profile ($M = 69.06$ KIAS) during the maneuver whereas the control group participants appeared to be slightly faster than the profile ($M = 75.06$ KIAS). Although the lower indicated airspeed values during the rounded base turns cannot be neglected, the means between the two groups may have been slightly more equal if the control group had operated the aircraft closer to the prescribed profile. For this reason, it is not possible to conclude that the rounded base method provides a safety advantage over the rectangular method in terms of indicated airspeed. Of note, the standard deviations between the mean indicated airspeeds were noticeably different. The rounded base method resulted in a standard deviation of approximately 2 knots, while the rectangular method resulted in a standard deviation of approximately 8 knots, indicating that airspeed during the rounded base method was more consistent and stable.

Research Question 4

Research question 4: Is there a statistically significant difference in pitch attitudes between the rounded base and rectangular base methods?

A significant difference existed between the type of base turn conducted and the pitch attitudes encountered during the maneuver. Use of rounded base turns resulted in lower pitch attitudes, both in terms of the mean and maximum pitch attitudes. While the difference between

means was quite small (1.27°), the difference in maximum pitch attitudes was slightly more noticeable (3.01°). Although pitch attitude is not the most reliable indicator of angle-of-attack, one may assume that if all conditions and forces are relatively equal, an aircraft at a higher pitch attitude is likely to be at a higher AOA. The highest pitch attitudes encountered using the rounded base method and rectangular method were approximately 3° and 8° respectively, again indicating an advantage for the rounded base method.

Research Question 5

Research question 5: Is there a statistically significant relationship between the method used (rounded or rectangular base) and alignment with the runway upon completion of the turn to final?

As both the independent variable (method used) and dependent variable (aligned or not aligned) were categorical, a cross-tabulation analysis was performed to determine if a relationship existed. Fisher's exact test revealed a significant relationship between the type of method used and whether the aircraft was aligned with the runway upon completion of the maneuver. 100% of the aircraft that conducted the rounded base method were aligned with the runway upon completion, versus 69% of the aircraft that conducted the rectangular method.

Runway alignment is perhaps the most critical variable analyzed during this study as numerous accidents have resulted from the pilot conducting an aggressive correction to re-align the aircraft with the runway after overshooting the base-to-final turn (AOPA Air Safety Institute, 2015). The rounded base method appears to provide a solution to this scenario, which would considerably contribute to aviation safety.

Conclusions

While the rounded-base method will not completely solve the I-LOC issue in general aviation, it has proven to be an effective alternative to the rectangular base method of conducting traffic patterns. The rounded-base method reduces bank angles and pitch attitudes encountered during the traffic pattern while providing a more stabilized approach throughout the maneuver. In addition, the rounded-base method considerably reduces the likelihood of runway overshoot during the turn to final.

The purpose of this study was not necessarily to find a replacement for the rectangular traffic pattern, but rather to test an alternative method to determine if further research is warranted. An important aspect that necessitates additional investigation is visibility, both in terms of the pilot's ability to scan for traffic on the final approach path as well as the ability for other aircraft to make visual contact with the aircraft conducting the rounded-base method. Additionally, the ability for the rounded-base method to be conducted while other aircraft are conducting the rectangular method should be investigated, especially at tower-controlled airports in which the term "square the turn" is often used for traffic spacing. This study also assumed that aircraft would be established on downwind prior to beginning the turn and descent, which would obviously not be the case for aircraft conducting a base entry or straight-in approach. Furthermore, this study focused only on the base leg of the pattern. A rounded-crosswind method is likely to provide similar advantages over a rectangular crosswind, especially due to the high angles-of-attack encountered during this phase of the pattern.

Additional potential areas of research include an analysis of cognitive load to determine if the rounded-base method is "easier" to fly, a qualitative assessment to determine pilot's

perceptions of the rounded-base method, a quantitative evaluation of the procedure using participants with a wide range of experience, and a quantitative analysis of angle-of-attack using data recorded from angle-of-attack indicators installed on the aircraft. Perhaps the greatest limitations of this study were the inability to control for experience level of the participants and the inability to gather an accurate measure of angle-of-attack, which was presumed based on the relationship between each variable and angle-of-attack.

The general aviation community should embrace the opportunity to reduce I-LOC occurrences by considering the use of the rounded-base method to fly a traffic pattern. I-LOC will continue to present itself as an issue until more creative mitigation strategies such as the rounded-base method are developed and introduced to the aviation community.

APPENDICES

APPENDIX A

Experimental Group Post-Flight Questionnaire

Q1 IMPORTANT - PLEASE READ: Information from this survey will be used to retrieve flight data from the aircraft. Data that will be acquired will include all aircraft and engine parameters, but will NOT include any audio or visual recordings. Once the data has been retrieved, all identifying information including aircraft registration, date, time, and location will be removed prior to analysis with the rest of the research team. The only individuals able to view the aircraft registration, date, time, and location will be the Principle Investigator (Mr. Lewis Archer) and the UND Aerospace Flight Data Analyst (Mr. John Walberg). If ANY front-seat occupant of the aircraft wishes not to release data from this particular flight, you should NOT complete this survey.

Q2 Aircraft registration (tail number):

Q3 On what date was this circular pattern conducted? (mm/dd/yy)

Q4 At approximately what time did you begin the first circular pattern? (use local 24-hour time, ex. 13:30)

Q10 At approximately what time did you begin the second circular pattern? (leave blank if not conducted)

Q11 At approximately what time did you begin the third circular pattern? (leave blank if not conducted)

Q5 At which airport was this circular pattern conducted? (three-letter identifier)

Q7 Were our current procedures and the Safety Risk Assessment effective in identifying and mitigating the risks and hazards encountered during the circular landing pattern that was conducted during this flight?

- Yes
- No

Q8 What additional risks/hazards were encountered?

Q9 Enter any other comments that may be helpful:

APPENDIX B

Safety Risk Assessment

Page # 1 of 1		Outcome (Pre-Mitigation) See SMS Manual for Risk Matrix					Outcome (post-Mitigation) See SMS Manual for Risk Matrix			16. Process owner(s) for Risk Mitigation	17. How and when to implement, Monitor, and Review	18. Controls Effective?	
5. Item Number:	6. Hazard Description	7. Hazard Consequence Description	8. Existing Controls	9. Severity	10. Probability	11. Risk Tolerability	12. Further Actions to Reduce Risk	13. Severity	14. Probability				15. Risk Tolerability
1	Too focused inside	<ul style="list-style-type: none"> Do not see conflicting traffic, resulting in loss of separation Not looking outside, resulting in CFIT Over controlling the airplane, resulting in unstabilized approach Over shooting or undershooting final, resulting in unstabilized approach 	Second Pilot on board, experienced pilots	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE	None	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE		Lewis Archer will develop a survey for pilots to utilize after conducting the circular approach to landing procedures.	
2	Too focused outside	<ul style="list-style-type: none"> Not looking inside, loss of aircraft state awareness, airspeed, bank, descent rate, etc Fixation on the runway, resulting in stall/spin scenario 	Second Pilot on board, experienced pilots	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE		E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE			
3	Distraction associated with new flying procedure	<ul style="list-style-type: none"> Not looking inside, loss of aircraft state awareness, airspeed, bank, descent rate, etc Fixation on the runway, resulting in stall/spin scenario Increased pilot workload, loss of situational awareness 	Second Pilot on board, minimum experience requirements	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE	None	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE			
4	Other aircraft in the traffic pattern, flying a different ground track	<ul style="list-style-type: none"> Loss of separation Loss of predictability of traffic pattern ops 	Second Pilot on board, minimum experience requirements	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE	None	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE			
5	High wing aircraft blocking visibility in a turn (traffic end/or aim point)	<ul style="list-style-type: none"> Loss of visual reference to the runway during the first part of the turn, resulting in loss of positional awareness 	Second Pilot on board, minimum experience requirements	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE	None	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE			
6	Might be less stabilized: high/low/fast/slow,	<ul style="list-style-type: none"> Resulting in unstabilized approach 	Current standardized criteria for go around, second pilot on board, experience minimums,	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE	None	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE			
7	Overshooting crosswind	<ul style="list-style-type: none"> Resulting in a high bank angle during the final turn 	Current standardized criteria for go around, second pilot on board, experience minimums,	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE	None	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	ZE			

8	Making the configuration changes are different.	Resulting in unstabilized approach.	Current standardized criteria for go around, second pilot on board, experience minimums.	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	2E	None	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	2E			
9	Spacing between aircraft may be different	Loss of separation	Current standardized criteria for go around, second pilot on board, experience minimums.	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	2E	None	E - Negligible - Little Consequence	2- Improbable - Very unlikely to occur (not known to have occurred)	2E			
Meeting minutes are documented in quattris													
19. Overall Risk Level After controls are implemented (Circle one)				20. Risk Decision Authority per SMS Manual				21. Director of Aviation Safety					
							1)						4)
							2)						
							3)						
							Signature			Date	Signature		Date
							1) Dick Schultz - Director of Flight Operations				2) Dana Siewert - Director of Aviation Safety		
Edition 8 Sept 16, 2015				Printed Name & Duty Position:				Printed Name & Duty Position:					
UNCONTROLLED COPY WHEN DOWNLOADED													
Check The Master List To Verify That This is The Correct Edition/Revision Before Use													

APPENDIX C

Consent Form

The University of North Dakota Consent to Participate in Research

TITLE: Use of Circular Landing Patterns in General Aviation

PROJECT DIRECTOR: Lewis Archer

PHONE # 701-777-6039

DEPARTMENT: John D. Odegard School of Aerospace Sciences –
Department of Aviation

STATEMENT OF RESEARCH

A person who is to participate in the research must give his or her informed consent to such participation. This consent must be based on an understanding of the nature and risks of the research. This document provides information that is important for this understanding. Research projects include only subjects who choose to take part. Please take your time in making your decision as to whether to participate. If you have questions at any time, please ask.

WHAT IS THE PURPOSE OF THIS STUDY?

You are invited to be in a research study about the use of circular landing patterns in general aviation because you are a qualified pilot and flight instructor.

The purpose of this research study is to determine if the use of a circular landing pattern results in a more stabilized approach versus a traditional rectangular pattern. The goal is to determine whether the widespread use of circular landing patterns in the general aviation community would result in a decrease of loss-of-control accidents in the traffic pattern.

HOW MANY PEOPLE WILL PARTICIPATE?

Only a select few (approximately 3 to 5) people will conduct this procedure as Pilot Flying (PF) at a non-towered airport within the University of North Dakota practice areas. On each flight (of which approximately 30 to 40 are expected to be conducted), there will be an

additional person on board the aircraft acting as the Pilot Monitoring (PM) during a time in which this procedure is being conducted.

HOW LONG WILL I BE IN THIS STUDY?

Your participation in the study should last no greater than 2 months. You will need to report to the UND Aerospace campus in Grand Forks, ND on a date and time to be determined for an informational briefing. You will be advised of the specific date, time, and location approximately 1 week prior. The informational briefing will take no longer than 1 hour.

WHAT WILL HAPPEN DURING THIS STUDY?

1. You will receive a briefing from the researcher which will include a background of the study, the purpose of the study, a description of the procedure that will be conducted, and a review of the Safety Risk Assessment conducted in accordance with the FAA-approved UND Aerospace Safety Management System.
2. If you are participating as the Pilot Flying (PF) for this procedure, you will conduct a circular landing pattern as the Pilot Flying (PF) in an aircraft during a normal standardization flight at a non-controlled airport.
3. If you are not participating as the Pilot Flying (PF) for this procedure, but will be on board the aircraft while this procedure is being conducted, you will observe the Pilot Flying (PF) conduct a circular landing pattern and will act as the Pilot Monitoring (PM) in accordance with UND Aerospace policies and procedures.
4. If you are participating as the Pilot Flying (PF) for this procedure, upon completion of the flight, you will complete a short survey indicating your perceptions of the procedure and the validity of our existing safety controls and the Safety Risk Assessment conducted in accordance with the FAA-approved UND Aerospace Safety Management System. In addition, you will be asked to indicate the date, time, and location in which you conducted the circular landing pattern for the purposes of acquiring flight data from the avionics system. In accordance with Appendix A of the UND Aerospace Safety Policies and Procedures, **no video or voice recordings will be accessed or identified except in the event of an accident, incident, or occurrence resulting in a loss of directional control, or with the direct consent and authorization by all forward seat crew members of the aircraft. All flight data will be de-identified in accordance with Appendix A of the UND Aerospace Safety Policies and Procedures. If you prefer not to release the flight data for any particular flight to the research team, you are not required to complete the survey nor should you indicate the date, time, and location in which you conducted the circular landing pattern.**
5. If you are not participating as the Pilot Flying (PF) for this procedure, you will not be asked to complete a survey. You will, however, have the ability to withdraw your consent to retrieve data from the flight.

WHAT ARE THE RISKS OF THE STUDY?

Participation in the study may involve unforeseen risks. A Safety Risk Assessment has been completed in accordance with the FAA-approved UND Aerospace Safety Management System. The level of physical risk has been determined as negligible and improbable. This Risk Assessment will be reviewed at the informational briefing. Subjects

may feel uncomfortable about the prospect of flight data being reviewed from their flight. If a subject wishes not to release flight data from any particular flight, they should avoid completing the survey and should avoid indicating the aircraft, date, time, and location of the procedure. There are no other foreseeable psychological, emotional, physical, legal, or privacy risks outside of the inherent risk encountered while operating an aircraft.

WHAT ARE THE BENEFITS OF THIS STUDY?

You may not benefit personally from being in this study. However, we hope that, in the future, other people might benefit from this study. Using the data collected by this study, we hope to introduce a new procedure to the general aviation community in an attempt to achieve a reduction in loss-of-control accidents in the traffic pattern.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not have any costs for being in this research study.

WILL I BE PAID FOR PARTICIPATING?

You will not be paid for being in this research study other than the compensation you normally receive as a UND Aerospace employee.

WHO IS FUNDING THE STUDY?

The University of North Dakota and the research team are receiving no payments from other agencies, organizations, or companies to conduct this research study.

CONFIDENTIALITY

The records of this study will be kept private to the extent permitted by law. In any report about this study that might be published, you will not be identified. Your study record may be reviewed by Government agencies, the UND Research Development and Compliance office, and the University of North Dakota Institutional Review Board.

Any information that is obtained in this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

If we write a report or article about this study, we will describe the study results in a summarized manner so that you cannot be identified.

In accordance with Appendix A of the UND Aerospace Safety Policies and Procedures, you have the right to review all audio, video, and data recordings of your flight with the direct consent and authorization by all forward seat occupants of an aircraft who are crew-members.

IS THIS STUDY VOLUNTARY?

Your participation is voluntary. You may choose not to participate or you may discontinue

your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Your decision whether or not to participate will not affect your current or future relations with the University of North Dakota or with any of the researchers on this study.

CONTACTS AND QUESTIONS?

The researchers conducting this study are **Mr. Lewis Archer, Professor Jim Higgins, Professor Kent Lovelace, Professor Gary Ullrich, Mr. Michael Lents, and Mr. John Walberg**. You may ask any questions you have now. If you later have questions, concerns, or complaints about the research please contact **Mr. Lewis Archer** at **701-777-6039** during the day and at **910-670-2893** after hours. **Mr. Lewis Archer** may also be reached at the following email address: **larcher@aero.und.edu**.

The faculty advisor for this study is **Professor Jim Higgins** who may be contacted with questions, concerns, or complaints at **701-777-6793** or **jhiggins@aero.und.edu**.

If you have questions regarding your rights as a research subject, you may contact The University of North Dakota Institutional Review Board at **(701) 777-4279** or **UND.irb@research.UND.edu**.

- You may also call this number about any problems, complaints, or concerns you have about this research study.
- You may also call this number if you cannot reach research staff, or you wish to talk with someone who is independent of the research team.
- General information about being a research subject can be found by clicking “Information for Research Participants” on the web site: <http://und.edu/research/resources/human-subjects/research-participants.cfm>

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subjects Name: _____

Signature of Subject

Date

I have discussed the above points with the subject or, where appropriate, with the subject’s legally authorized representative.

Signature of Person Who Obtained Consent

Date

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