EVALUATION OF CONTROL INPUTS ON THE SPIN RECOVERY OF THE 8KCAB SUPER DECATHLON

THESIS

Courtney Allen, Civilian

AFIT-ENV-MS-15-S-035

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENV-MS-15-S-035

EVALUATION OF CONTROL INPUTS ON THE SPIN RECOVERY OF THE 8KCAB SUPER DECATHLON

THESIS

Presented to the Faculty

Department of Systems Engineering and Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Engineering

Courtney Allen, Civilian

September 2015

AFIT-ENV-MS-15-S-035

EVALUATION OF CONTROL INPUTS ON THE SPIN RECOVERY OF THE 8KCAB SUPER DECATHLON

Courtney Allen, Civilian

Committee Membership:

John M. Colombi, Ph.D.
Chair

Lt Col Jeffrey C. Parr, USAF, Ph.D.
Member

John J. Elshaw, Ph.D.
Member

AFIT-ENV-MS-15-S-035

Abstract

The current Federal Aviation Administration (FAA) response to stall/spin related accidents is prevention through pilot awareness training and encouraging stall proof aircraft design features. Aircraft have an inherent capability to spin. The controls that influence spin recovery have yet to be quantitatively analyzed in a regression analysis. This thesis presents the regression modeling and validation process for the evaluation of control inputs on the spin recovery of the 8KCAB Super Decathlon. The regression models in this thesis explore the control inputs for factors of: rudder, elevator, and aileron. Additionally, this thesis explores the timing of the control inputs factors for sequenced as well as simultaneous application.

The research presented is of interest to general aviation pilot community with limited exposure to spins and variations of spin recovery methods. Aircraft spins have become taboo and avoided by all but the most experienced pilots and researchers. The research here is focused on the evaluation of control inputs on spin recovery qualities. While this research is limited to the 8KCAB super decathlon type aircraft, the aircraft is a good representation of the general aviation community.

To my loyal bulldog Winston, who flight after flight watched me taxi out and anxiously waited in anticipation to watch me taxi back.

Acknowledgments

The inspiration for this work was provided by one of my personal heroes, Otto Lilienthal. His words and life provide me with the greatest of inspiration. After conducting the research found within this paper; I understand why the air inspires confidence, why sacrifices must be made, and why flying is everything. Thank you for all that you have given to aviation world. I can only hope that this work may inspire a new generation of test pilots and flight test engineers.

> To invent an airplane is nothing. To build one is something. But to fly is everything. (Otto Lilienthal)

Court

Table of Contents

List of Figures

List of Tables

List of Equations

EVALUATION OF CONTROL INPUTS ON THE SPIN RECOVERY OF THE 8KCAB SUPER DECATHLON

I. Introduction

Background

The spin is an insidious and rarely understood mode of flight that has made its presence known since the dawn of human flight. The current Federal Aviation Administration (FAA) response to stall/spin related accidents is prevention through pilot awareness training and encouraging stall proof aircraft design features. There is a long history of root causes and engineering fixes to reduce the likelihood of spin occurrences; however, they are not yet completely preventable. With the search for higher performance standards from modern aircraft, the likelihood of developing stall-proof aircraft is nearly impossible. These opposing design consequences have forced an emphasis to be placed on awareness training in order to prevent accidents involving stall/spins. [1] [2]

Many in the aviation community conclude that pilot training should be based on hands-on exposure and training in spin recovery. This type of emergency training should make use of quantified data analysis of spin recovery procedures. Several aviation companies have collected spin recovery data and instruct various recovery maneuvers. However, the common practice of data collection has been without a statistical analysis of the significant control input factors that are shown to be most effective. [3] [1] [4] [5]

Problem Statement

General aviation pilots are not required to experience a spin, nor be trained in spin recovery techniques and controls. All aircraft have the inherent capability to spin and the controls that influence spin recovery have yet to be quantitatively analyzed in a regression analysis. [6]

Research Objectives/Questions

The research objective of this study is to investigate the effects of pilot control inputs on the spin recovery of an 8KCAB Super Decathlon using quantitative methods. The specific pilot inputs to be researched are the control inputs required in order to recover the aircraft to normal flight. The tasking will be to develop a spin recovery model based on pilot control inputs to the aircraft. The control inputs model will then be used to examine several popular spin recovery techniques. The intent of this research is not to provide specific procedures for recovery of an aircraft from a spin; rather, the goal is to identify the significant control inputs which should be applied during recovery to produce the least amount of average altitude loss. [7] [8]

The recovery of an aircraft from an unintentional spin poses many problems to the pilot. The majority of stall/spin accidents occur as the result of inappropriate control inputs. In this situation, a pilot's knowledge regarding how to return the aircraft to normal flight is imperative. The developed model will answer the primary research question:

1. *What control inputs are significant factors in recovery from a spin?*

The majority of the accidents resulting from an unintentional spin occur in the landing phase of flight while performing the base to final turn. The headline factor driving the question of spin recovery is a limitation on maximum altitude loss placed on the situation by a possible impact with the ground. The quantitative value of altitude loss is extremely important when faced with such a hard limit. The developed model will also answer the primary pilot's question:

2. *What control inputs produce the least amount of average altitude loss?*

Note that the question of whether or not combinations of control inputs will produce a recovery of the aircraft is not under review in this analysis. It is important to understand that particular methods that produce the least amount of altitude loss may not work under all conditions nor in all aircraft. Additionally, those methods may not produce the most desirable recovery sought out when recommending a general spin recovery procedure. [9] [7]

Hypotheses

Provided actual flight test dated using DOE methods, a spin recovery model can be developed. This model can be utilized to extract the significant control input factors affecting spin recovery. The hypothesis for the preferred recovery method is the manufacturer's prescribed recovery controls. Significant factors will include an elevator position forward of the neutral position and a rudder position full opposite the spin direction. Roll inputs will affect the spin rotational speed; however, spin recovery altitude loss will not be improved through any roll input favoring the neutral position. Potential gains through a pause of inputs will be negated through additional altitude loss during the pause.

Methodology Overview

The methodology for testing the hypothesis is to build an aircraft spin recovery model using regression based on historical data from actual flight tests. The data of interest is the flight parameters including altitude loss from spin recoveries using various control inputs. The regression model will benefit from flight test data collected using sound DOE procedures. Using this model, control inputs for pitch, roll and yaw will be analyzed and labeled significant or insignificant contributors to the positive recovery from a spin. Assumptions and limitations of the model and the flight test will be presented as part of the methodology.

Limitations

All aircraft have individualized spin recovery characteristics and no one aircraft results for spin characteristics will translate to another aircraft universally. This research was limited to the 8KCAB Super Decathlon. The 8KCAB was selected because of its availability as one on the most common aerobatic training aircraft. The Super Decathlon has an operating envelope that encompasses all types of spin modes and is certified by the FAA to perform spin maneuvers. The Super Decathlon is particularly advantageous in this research due to its commonality with the majority of the general aviation aircraft types. The Super Decathlon has a weight and balance, wing layout, and control surface plan form that closely resembles the majority of general aviation aircraft. This commonality allows the concepts developed in this research paper to be readily translated to the general aviation community. [10] [2]

Implications

The FAA has made it clear in Advisory Circular (AC) No: 61-67C that actual spin training is no longer a preference in pilot training. Stall and spin awareness training in place of demonstrated spin training has become the new requirement under Title 14 of the Code of Federal Regulations (CFR). [6] The lack of actual spin experience has left a hole in general aviation that has allowed myths and legends regarding spins to grow and prosper. When Roger Boggs, a highly regarded FAA accident investigator, testified on the subject of spin training before a congressional subcommittee he stated, "I know of only one area of ignorance which was decreed by regulation and which government has sponsored ever since – spin training". [3] This is a powerful message that highlights the need for the training material. While this paper is not a direct solution to this problem, it will provide a basis of fundamentals and development for training material to address.

Preview

The thesis research will be presented in the remaining four sections. The Literature Review section will introduce the physics of an aircraft spin, highlight relevant spin recovery research, and present currently accepted spin recovery methods. Discussions on these topics will be tailored to the development of a spin recovery model and the application of the results. Chapter III will present the flight testing performed, discuss limitations and assumptions that lead to the DOE for the spin recovery model, present popular spin recovery methods, and end with a discussion of the spin recovery model. The Analysis and Results section will present findings from the spin recovery model and present the investigative questions answered. Chapter V will finalize the presented research with conclusions, significance, and areas of future research.

II. Literature Review

Chapter Overview

The purpose of this chapter is to introduce the history of aircraft spin research, present a description of aircraft spins and phases, and provide popular spin recovery methods. The presentation of this material will provide the background material for this evaluation of control inputs on the spin recovery of the 8KCAB Super Decathlon.

Spin Background

The first recorded flight of a human being was performed by Eilmer of Malmesbury. Much of Eilmer's flight is shrouded in folklore; however, several things remain consistent in each account of the now famous flying monk's leap of faith. Eilmer of Malmesbury leaped from the tower of Abby employing a bird like glider. He encountered a directional stability problem with is flying machine and crashed into the English country side. On his own analysis of the flight, the lack of directional control could be solved with the addition of a bird like tail. Modern day analysis indicates that Eilmer most likely entered a stall spin induced by the lack of longitudinal directional stability. With no control surface (elevator) to direct pitching moments the use of Elmer's body movements to produce weight shifting, did not provide enough control input for stable flight. [11] [12]

The Wright brothers stumbled onto yet another problem with their early gliders. While developing wing warping technology, the brothers found that banking an aircraft into a turn caused an adverse yawing of the aircraft. The yawing tendency would cause the inside turning wing to lose lift often ending in a stall spin. The brothers' solution to this problem was to affix a vertical control surface (rudder) to produce a counter yawing moment, a novel solution which allowed early gliders to gain directional control. With the addition of the rudder, all three principal axes; pitch, roll and yaw, of a glider's moment of inertia could be controlled. [13] [14] [15]

The spin reemerged when the Wright brothers introduced the world to controlled flight. With an abundance of control authority, emerging pilots were expanding and testing the envelope of controlled flight. The Wright brothers were faced with an alarming number of accidents from early pilots. With increasing interest in their aircraft from the U.S. Army, the brothers were forced to investigate the problem before the aircraft could be mass produced. The brothers researched the accounts of each accident and reproduced the problems. While the conditions that caused a spin could not be designed out of the machine a novel recovery procedure was derived. Recovery from a spin was successful by moving the control stick full forward, causing the aircraft to dive into the ground. This control input was counter-intuitive to the instinctive pilot but enabled the Wright brothers to move forward with production of their aircraft. [14] [13]

During World War I, fighter pilot seeking to gain advantages over their opponents started to push the boundaries of their aircraft. Tactical spins in their aircraft became a basic fighter maneuver for the vertical fight. Early fighter pilots adopted this technique and focused on the mechanics of entering and exiting a spin safely. The earliest flight testing of spin recovery techniques were performed by Wing Commander Macmillan at the Royal Aircraft factory in Farnborough. Efforts to study the dynamics of spins became a priority as fighter aircraft advanced and fighting techniques developed. [12] [3]

Though World War II, fighter plane advancements combined with modern fighter tactics made tactical spin maneuvers obsolete. Spin recovery of advanced fighters became costly. New theories of energy management implied certain defeat or impact with the ground. Pilots were now forced to take their aircraft closer to the edges of the flight envelope. Maneuverability in dog fight became a top priority. The Battle of Brittan highlighted the link between man and machine at the edge of controlled flight. The Spitfire exhibited buffeting at high angles of attack near the critical angle of attack and warned pilots at the edge of controlled flight prior to entering a spin. This feature gave the Spitfire pilots an advantage by providing physical queues to the limits of the aircraft. Wartime development sparked the creation of modern engineering principles to improve pilot and aircraft as a system. [16]

As many veteran pilots returned home, they create a market for general aviation. The injection of surplus military aircraft flooded the marketplace with high performance airplanes. Due to their high performance designs, these planes required significantly more time to recover due to the lack of control authority during a spin. This increase in time translates to an increase in recovery altitude or altitude loss during an unintentional spin. Accidents related to stalls/spins are credited for nearly half on all general aviation fatalities from 1945 thru 1948. [3]

In 1949 the Civil Aeronautics Administration (CAA), the precursor to the FAA, passed Civil Aviation Regulation Amendment 20-3. This Regulation was a balancing act to address two concerns. The previously mandated spin training for all pilots would be replaced with stall avoidance training. This was done with the belief that teaching prevention would address the high number of stall/ spin accidents. Additionally, the CAA was forced to address general aviation in a growing light aircraft market. Amendment 20-3 moved to inspire all aircraft manufactures seeking to obtain a type certificate to include spin resistance into the design of new aircraft. The intention was to eventually achieve a spin-proof aircraft negating the need for awareness training. [3] [12]

Spins

Spin is a term which describes a flight maneuver where an aggravated stall is entered and sufficient yaw is introduced that generates autorotation. Both the stalling and yawing forces may be introduced through intentional or unintentional pilot action. The flight path of the aircraft follows a downward helical motion shown in Figure 1. The spin mode may be defined as steady, oscillatory, or cyclic. A steady spin consists of constant aircraft pitch attitude combined with a constant rotational rate. An oscillatory spin introduces a constant pitching motion where the aircrafts nose may raise and lower through a rotational period. Cyclic spins introduce a more complex combination of oscillations that occur over multiple rotations. These oscillations may increase and decrease in rate and amplitude. It is possible for a single aircraft to have multiple spin modes depending on control positions and spin entry method. There are four phases of a spin: spin entry, incipient spin, developed spin, and spin recovery. [6] [9] [5]

Figure 1: Helical Flight Path of a Spin

Spin Entry Phase

The entry phase of a spin is the initiation of pilot control which provides for the requirements of a spin. The presence of both a stalling action and a yawing action are a requirement for the development of a spin. Neither the action of stalling or yawing alone will precipitate a spin. [3] [6]

The FAA recommended procedure for entering an intentional spin is as follows:

During the entry, the power should be reduced slowly to idle, while simultaneously raising the nose to a pitch attitude that will ensure a stall. As the airplane approaches a stall, smoothly apply full rudder in the direction of the desired spin rotation while applying full back (up) elevator to the limit of travel. Always maintain the ailerons in the neutral position unless AFM/POH specifies otherwise. This recommendation produces a normal upright spin. [9] [10] [5]

Incipient Spin Phase

The incipient phase is a dynamic transition period where the aircraft moves from spin entry to a fully developed spin. Depending on the aircraft's design to resist spins and the level of pro-spin control inputs, this phase could last multiple rotational turns. This phase is pilot driven meaning that the aerodynamic and inertial forces that are driving the rotation are not enough to sustain auto rotation. Pilot control inputs are required to maintain the spinning action. During this phase the forces acting on the aircraft are unbalanced but moving toward an equilibrium that supports autorotation. [3] [1] [5] [9]

This period exhibits an input of aerodynamic forces created from the departure of normal flight. This departure could be experienced as a high energy snap roll or low energy roll. This post stall gyration input produces an oscillation with spin rotation. The incipient phase commences as the gyration energy is dissipated and the forces acting on the aircraft move to a balance state in a predictable rotational pattern. [3] [9]

Aircraft Certificated to the FAA standard for Normal and Utility category and placarded for intentional spins have successfully demonstrated spin recovery from one-turn spins. This requirement places spin recovery demonstration in the incipient spin phase which amounts to nothing more than a controllability check during an aggravated stall departure. [2]

Developed Spin Phase

The developed phase is a steady-state where the aircraft achieves a stabilized flight path with consistent vertical velocity, angular rotation, and airspeed. This consistency is achieved through a natural balancing act of the aerodynamic and inertial forces affecting the aircraft. The aerodynamically driven flight path is a sustained motion about a vertical axis that is self-propelled repetitive rotation. [3] [9] [1] [17]

The noted self-sustaining capability of the developed spin is important. If the controls were release and allowed to freely float aerodynamically the controls would remain aerodynamically load in the spin direction. For example, an intentional upright spin in the right hand direction is achieved by apply full right rudder, full aft elevator, and neutral aileron. The rolling rotation can be accelerated and decelerated by applying right and left aileron respectively. Therefore if the controls were freely released they would remain aerodynamically loaded in a right rudder, aft elevator, and right aileron position. [3] [9]

This phase is where the terms pro-spin and anti-spin are defined. While each spin orientation will very on which direction pro-spin and anti-spin controls are directed, they are all defined by the free floating control positions. The two spin orientations that will be discussed in this thesis are right and left normal upright spins. The pro-spin and anti-spin positions are defined in Table 1. [18]

Table 1: Pro-Spin and Anti-Spin Controls

SPIN ORIENTATION		CONTROL POSITION					
		Pro-Spin			Anti-Spin		
		Rudder	Elevator	Aileron	Rudder	Elevator	Aileron
Normal Upright	Right Rotating	Right	Aft	Right	Left	Forward	Left
	Left Rotating	Left	Forward	Left	Right	Aft	Right
Normal Inverted	Right Rotating	Right	Forward	Right	Left	Aft	Left
	Left Rotating	Left	Aft	Left	Right	Forward	Right

Spin Recovery Phase

As a spin is entered through the application of forces to support stall and yaw that create autorotation, recovery of a spin must provide the application of forces that oppose autorotation. The presence of a stall or yaw breaking action is required. Breaking the aerodynamically driven autorotation forces using the application of anti-spin controls is required. Because the presence of both stall and yaw is required to support a spin, removing either stall or yaw will support recovery from a spin. Rapid recovery should provide for controls to remove both stalling and yawing. As yaw is naturally coupled with roll recovery may require the forced uncoupling of these actions. [9] [3] [1] [5]

Recovery Phase is entered with the application of recovery controls and is complete when autorotation ceases. This is typically signified by a decrease in the angle of attack of both wings to less than the critical angle of attack effectively breaking the stall. The aircraft nose attitude will steepen towards the ground. Rotation and yaw may accelerate or decelerate prior to an eventual decrease to no rotation and yawing. Recovery may take several turns to recover; however, positive spin recovery can occur in as little as a quarter of a turn. It is important to note that acceleration or deceleration of autorotation or introduction of an oscillatory motion in conjunction with application of control inputs does not signify a recovery. This could be a disruption of the balance forces driving the autorotation causing a different rotational pattern. If the oscillations dampen and the spin mode becomes consistent, the spin has not recovered only enter a different mode of autorotation. [9] [3] [1] [5] [17]

Recovery Methods

The recovery methods presented here are a selection of the most popular methods published and taught within the pilot community. This selection does not encompass the entire selection of published or taught spin recovery methods.

Manufacturer-Prescribed Recovery Controls

The manufacturer-prescribed recovery controls has the most significant pedigree of any spin recovery method presented in this thesis for the 8KCAB Super Decathlon. Due to the fact that the 8KCAB is an aerobatic category type certificated aircraft there is inherently a significant amount of structured flight testing that has been performed in order to derive recommendations for flight procedures. [10] [2]

FAA spin testing for type certification in the aerobatic category is the most rigorous and demanding of the three categories: Normal, Utility and Aerobatic. Testing must be performed which explores the entire envelope of the aircraft in regards to Gross Weight (GW) and Center of Gravity (CG), moments of inertia, control surface deflection and rigging. A test spin matrix will include “the effects of gear, flaps, power, accelerated entry, and control abuse”. [2]

Significant to the testing performed in this experiment, The FAA requires the manufacturer-prescribed recovery controls to be able to recover from a fully developed 6 turn spin. Additionally, “the airplane will recover in not more than 1 1/2 turns after completing application of normal or manufacturer-prescribed recovery controls.” [2] The FAA includes additional constraints for the manufacturer-prescribed recovery method that are not addressed in other recovery methods presented in this paper. “No airplane limitations are exceeded, including positive maneuvering load factor and limit speeds.” [2] This adds an additional complexity to spin recovery development and may present problems when developing a method for the least amount of altitude loss. The FAA does not however, require a manufacture to prescribe a method for the lease amount of altitude loss.

The manufacturer-prescribed recovery controls for aircraft spin recovery is detailed as the following: [10]

Use the following procedures for a normal spin.

1) Throttle – CLOSED.
2) Ailerons – NEUTRAL POSITION.
3) Elevator – POSITIVE FORWARD TO NEUTRAL (free release of elevator control is not adequate for recovery).
4) Rudder – FULL DEFLECTION in the opposite direction to the rotation.
5) Rudder- NEUTRALIZE when rotation stops and positive control and flying speed is restored.
6) Nose Attitude – RAISE smoothly to level flight altitude.
7) Throttle – only after recovery from diving altitude, then as required.

WARNING

During the spin recovery, the airspeed will build very rapidly with a nose low altitude. Smooth but positive recovery from the dive is important to avoid an overspeed condition. Do not use full or abrupt elevator control movements after recovery to avoid secondary stall-spin.

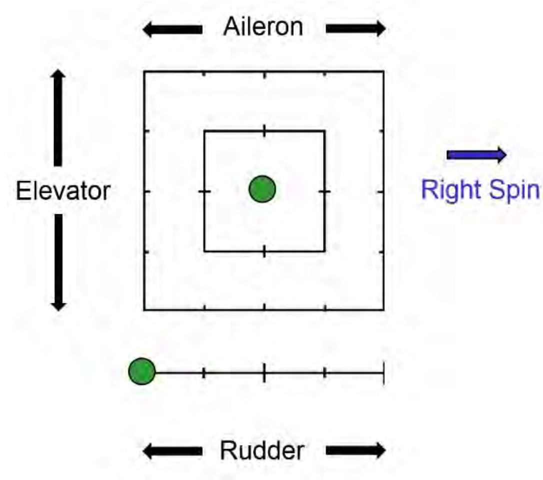


Figure 2: Manufacturer's Recovery Method

The manufacture does not discuss simultaneous or sequential application of the controls; however, the manufacture does describe the recovery control input positions as: throttle closed, ailerons neutral, elevator neutral, and rudder full opposite. As there is no specific direction to sequence the control inputs, it is logical to assume that there is no need to sequence the inputs. [10]

PARE Method

In 1936 William McAvoy published a technical paper of spin research that was accomplished while he was a National Advisory Committee for Aeronautics (NACA) test pilot at the Langley Memorial Aeronautical Laboratory. Within the research published in his paper, McAvoy details a NACA approved spin recovery procedure. [19] “The recovery actions, which assume idle power and neutral ailerons, call for full opposite rudder applied against the spin followed one quarter of a turn later with brisk forward movement of the elevator control.” [3]

In 1977 The National Aeronautics and Space Administration (former NACA) researchers sought to verify the NACA recovery procedure. Full scale spin tests are performed on four different general aviation aircraft over the next 12 years. NASA concludes that the NASA standard spin recovery procedure for typical, light, single-engine, general aviation airplanes is superior to other tested recovery methods. NASA does note the following: “spin modes do exist in the test airplanes from which recovery is impossible, regardless of the recovery actions used. Yet all of the one-turn spins investigated, only one of the spins fails to recover as required by FAR Part 23-even though some of those spins would have developed into unrecoverable flat spins if continued beyond one turn.” [3]

Following the release of the NASA spin testing, the aviation community started to adopt the NASA standard spin recovery procedure. The method becomes widely known by the mnemonic developed to remember the steps as PARE. The mnemonic shortens the steps to Power: idle, Ailerons: neutral, Rudder: full opposite, and Elevator: through neutral.

Following the 1991 FAA Advisory Circular 61-67B, *Stall and Spin Awareness Training*, the market for spin training to the new generation of pilots was created. Rich Stowell publishes his <u>Emergency Maneuver Training</u> book in 1997 to promote his EMT program which adopts the PARE spin recovery method as the heart of the program. The PARE method for aircraft spin recovery is detailed as the following: [18]

1. Power – Off.
2. Ailerons – Neutral (& flaps up).
3. Rudder – Full Opposite.
4. Elevator – Through Neutral.

Hold these inputs until spin rotation stops, then:

5. Rudder – Neutral.
6. Elevator – Recover to Straight and Level.

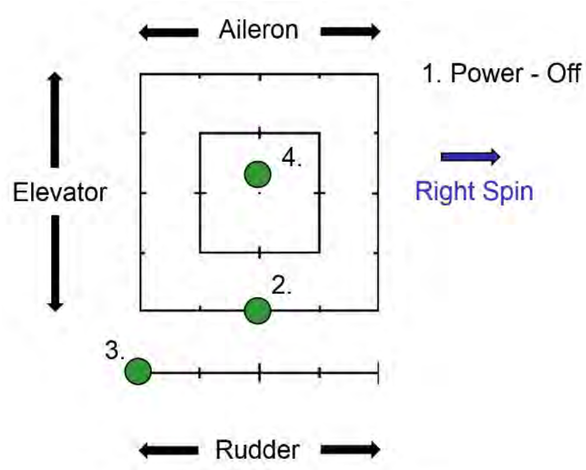


Figure 3: PARE Recovery Method

While the discussion of sequenced or simultaneous inputs is not discussed in the preceding details of the PARE spin recovery method the NASA research defines baseline Normal recovery controls as “the application of full anti-spin rudder followed by trailing-edge-down elevator/stabilator with ailerons neutralized”. [3] Additionally, NASA analysis provided “Simultaneous Recovery Controls were observed to be nearly as effective as Normal Recovery Controls for spin recovery. However, more incidences of prolonged recoveries (more than two turns) occurred with simultaneous rudder and elevator inputs versus separate inputs." [3]

Rich writes the following regarding sequencing the inputs:

Rudder-followed-by-elevator is a superior technique. Separating these two actions also makes the recovery process easier to manage for the pilot under the duress of an accidental spin. The likelihood of misapplying inputs, and thereby botching the recovery, increases when trying to apply multiple inputs simultaneously. [3]

Mueller-Beggs Method

This method has a significant pedigree as it is the very method that was made famous in 1912 by Lt. Wilfred Parke. Lt. Park a British Royal Navy entered a spin in his Avro biplane over Salisbury Plain, the incident was accounted by many observers and became famously known as Parke's Dive. Lt. Parke famously recovered from the spiraling dive by applying opposite rudder from the dominating force of the rudder during the spin. His hands were already off of the controls in order to brace himself in the cockpit. [20]

The Mueller-Beggs method was first introduced in November 1981 by Swiss Aerobatic Champion, Eric Mueller. His method debuted in an article Eric authored for *Sport Aerobatics* titled, *The Spin-Myth and Reality*. Eric Mueller described a spin recovery method in which the pilot brought the power to idle, removed hands from the stick and allowed it to freely travel, and apply full opposite rudder of the yawing direction. [4]

Gene Beggs' name was attached to this hands-off method opposite rudder method when he began experimenting and flight testing the method in his Pitts S1-S. He published his work in *Sport Aerobatics* in 1984. Now known as the Mueller-Beggs method, it was brought front and center in aerobatic instruction when Gene developed the Gene Beggs Advanced Spin Training Course. He later published a book, Spins in the Pitts Special, detailing the method and the course work. While Gene does talk about flight testing this method in his book, the author never details what experiments were flown or any results from those tests. The only significant statement of results is the following: "Flight tests in the Pitts S-2B conducted by Bob Herendeen and myself have proven there is no compromise in altitude loss using the Emergency Spin Recovery compared to the hands-on method." [4] This statement will be examined later for the 8KCAB Super Decathlon later in this paper.

It should be noted that by the Gene's own admission, this method does not work in all aircraft or in all types of spin modes. The 8KCAB Super Decathlon is widely known to discredit this recovery method, but not under all conditions. The conditional part of the 8KCAB's response to the Mueller-Beggs methods is what causes pilot so much confusion. The author clearly notes that the method will not work in an "inverted left rudder spin". [4] Additionally other aircraft have been known to experience non-recovery conditions do to entrance into fully a developed spin, CG and GW variances, and trim conditions. [4]

The Mueller-Beggs method for spin recovery is detailed as the following: [4]

1. POWER OFF
2. REMOVE YOUR HAND FROM THE STICK
3. APPLY FULL OPPOSITE RUDDER UNTIL ROTATION STOPS
4. NEUTRALIZE RUDDER AND RECOVER TO LEVEL FLIGHT

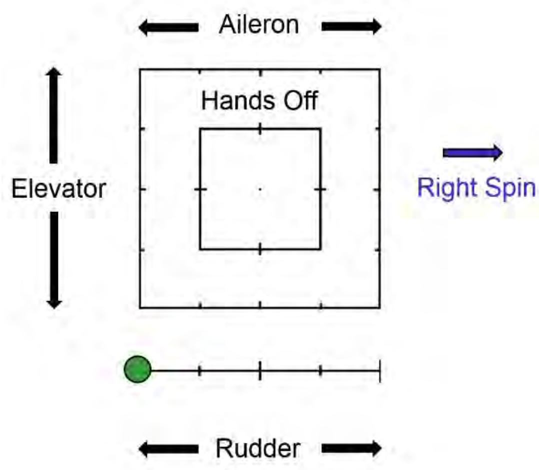


Figure 4: Mueller-Beggs Recovery Method

The method is also recommended to be performed simultaneously once full proficiency has been achieved; however, sequential application of each step is taught during initial instruction.

Summary

An aircraft enters a spin though intentional or accidental means; however, in all cases the pilot provides the critical ingredients for the spin recipe. Pilot action is required to develop a spin and pilot action is required to recover from a spin. Early pilot recognition of a spin and applying corrective controls is the key to a possible recovery. The definition of corrective controls is shown to be variable dependent upon spin mode which is highly dependent upon the design of the aircraft. Aircraft design is additionally refined by government regulation. [2] [6]

III. Methodology

Chapter Overview

The purpose of this chapter is to introduce the historical data from spin recovery testing and define the methods in which models for the spin recovery of the 8KCAB Super Decathlon are constructed. This section will define the process of the flight test experiments and how they guide the construction, assumptions, and limitations of the DOE model. Finally, the process for execution of this evaluation of control inputs will be outlined.

Flight Tests

The historical data used in this thesis is taken from a flight test program flown by Mr. Courtney Allen and Mr. Chris Olmsted. All test points flown were considered as ride along to normal aerobatic practice sessions already being flown. These practice sessions were preparation for competition aerobatics with the International Aerobatics Club (IAC). All flight activities were performed within all FAA regulations. Archival data being used was collected from the 2011 aerobatic competition season. The test plan for the historical data is found in Appendix A. Flight tests cards for the test points used in this thesis are located in Appendix B. Finally, a tabulated compilation of the flight test data used in this thesis is archived in Appendix C.

The purposes of these tests were to investigate the handling qualities of an 8KCAB Super Decathlon aircraft during the recovery phase of a spin. This directed purpose is well suited for the investigation being performed in this thesis. The historical data provides a full set of data in order to construct a full factorial analysis for all relevant control inputs. Specific handling qualities evaluated were the control inputs required in order to recover the aircraft to normal flight. The primary aircraft controls documented in testing of the 8KCAB aircraft are throttle, rudder, elevator, and aileron position. All other variables affecting the aircrafts recovery from a spin were held constant or constrained to minimize their effects. Primary variables of interest that were held constant are: the aircraft and its overall configuration, aircraft trim, and altitude. Primary variables of interest that were constrained are: CG and GW. While all of these variables minimally affect the handling qualities of the aircraft, the constraints imposed on variables during the flight test provide an excellent fit for a DOE evaluation of control inputs on the spin recovery of the 8KCAB Super Decathlon. [10] [9] [7]

Test Article

The test article for this testing was an 8KCAB Super Decathlon manufactured by American Champion Aircraft. This aircraft was chosen specifically for its physical and performance attributes. Physically it conforms to the planform of common general aviation aircraft. Figure 5 describes the planform of the 8KCAB Super Decathlon. It has a fixed high wing and an empennage with horizontal and vertical stabilizer surfaces. Primary flight controls are provided by elevator (Blue) for pitch, aileron (Red) for roll, and rudder (Green) for yaw. This planform is repeated throughout the general aviation community and lends itself well to transference of knowledge. The performance attributes of this aircraft are significant in the fact that the 8KCAB is a certificated aerobatic aircraft and certified by the FAA for spin maneuvers. [10] [7]

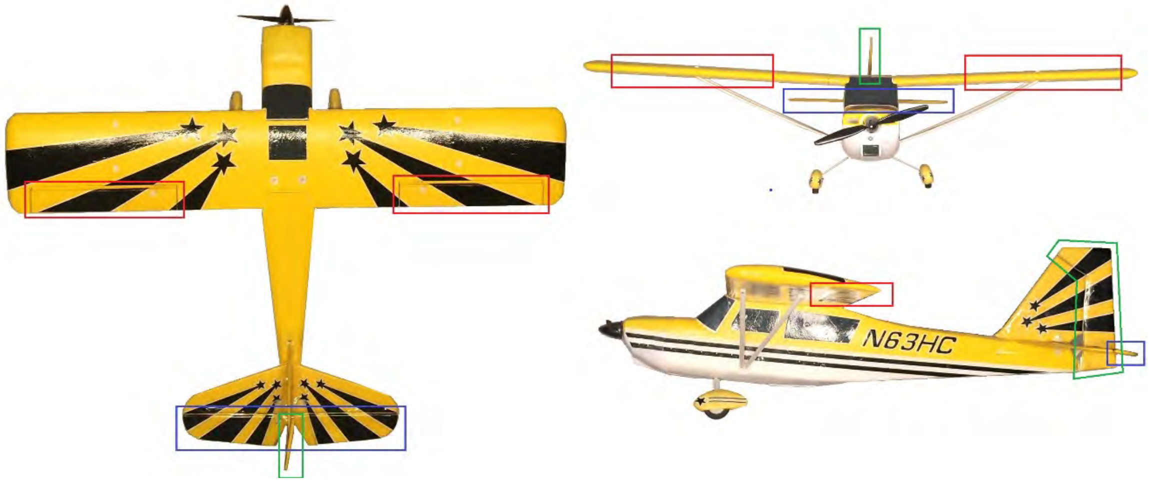


Figure 5: 8KCAB Super Decathlon Planform

Test Procedure

The procedure for replicating the same exacting flight conditions for each test run required strict procedural discipline to ensure repeatable physics. Heuristic interpretation of the aircrafts response and timing were used to verify on condition settings for each run. The procedure replicated during each run of control inputs is outline as follows:

1. All spins were performed in the normal up rite position.

2. The spin is entered from level slow flight at an altitude of 5000 ft.

3. Power is reduced to idle and level flight is maintained until just prior to stall.

4. At the moment prior to stall, the control stick is held at neutral aileron and full aft elevator. Simultaneously with the control stick movement full rudder pedal is input. The direction of the spin is directed by either left or right pedal.

5. Consistent motion of the spin is ensured by allowing the aircraft to reach a fully developed spin. In the Super Decathlon a fully developed spin is reached routinely between 1.5 to 2.25 rotations.

6. Test run controls are initiated at 3 revolutions. Controls were held in the desired position until the spin is broken and a recovery to normal flight can be made or the sequence is terminated due to safety considerations.

7. Recovery to normal flight was made with neutral rudder, a half stick roll to wings level, followed by a 3g pull-up to level attitude. The throttle remained closed for the entire recovery sequence.

This procedure is illustrated in Figure 6.

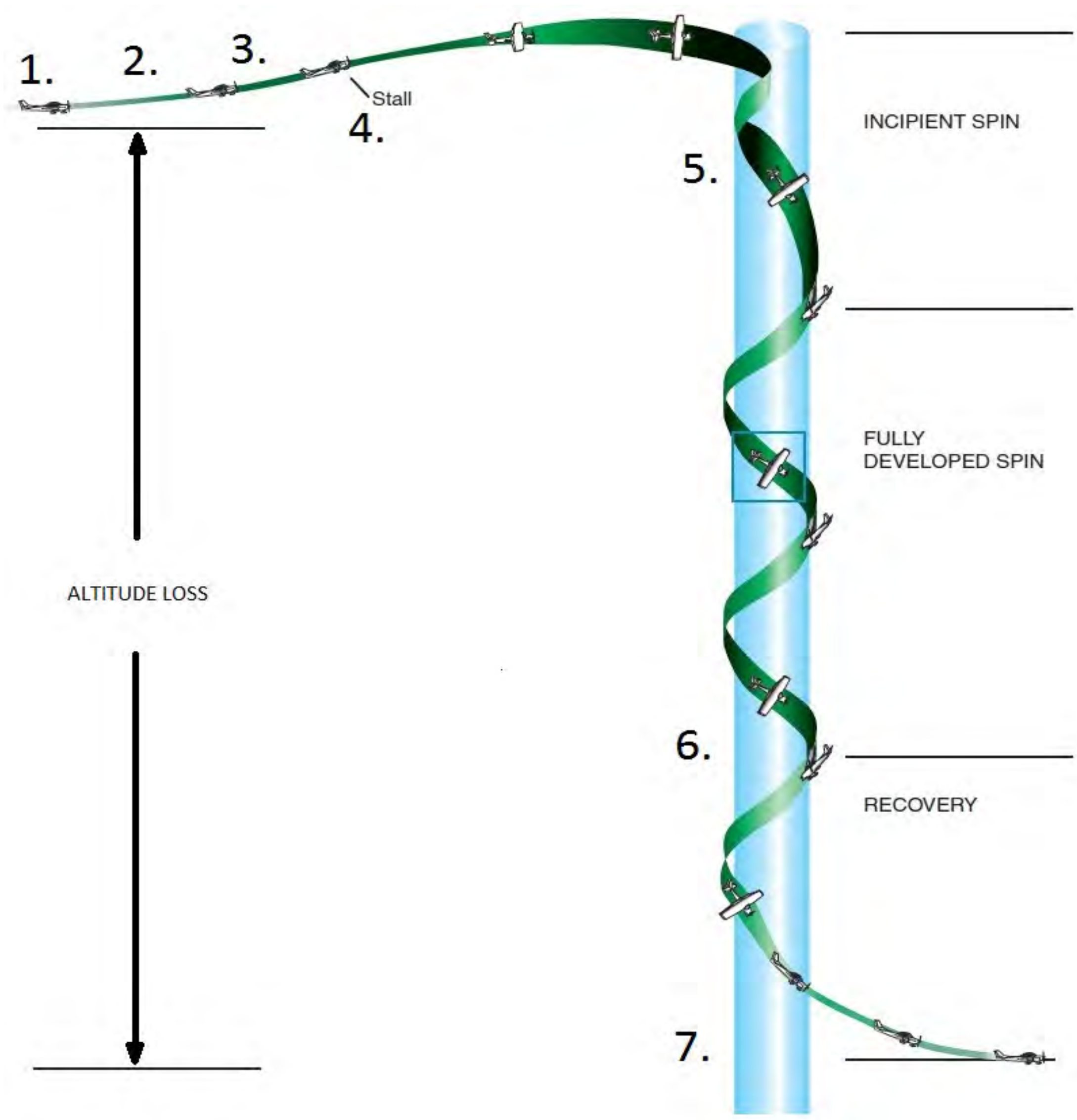


Figure 6: Test Procedure [9]

Measurements

The data collected and compiled during this flight testing effort encompassed far more data than desired to complete a full evaluation for the directed effort in this thesis. This section will introduce the measurement data primarily used in the evaluation contained within this thesis.

The primary data of interest is information regarding the recovery qualities of the spin. Table 2 compiles a listing of the measurements of interest. The response of primary concern within this evaluation is the altitude loss during the recovery.

Table 2: Primary Data of Interest

MEASUREMENT NOMENCLATURE
Beginning Altitude (ft)
Ending Altitude (ft)
Lost Altitude (ft)
Maximum Velocity (mph)
Total Time of Spin (sec)
Time to Recover (sec)
Average Vertical Velocity (ft/sec)
Revolutions to Recover
Spin Rate (RPS)

All quantitative measurements were taken from time stamped video recordings of the aircraft's flight instruments. The video recordings captured readings from the airspeed indicator and altimeter during the test maneuvers. An additional video recording captured the pilot's sight picture over the nose of the aircraft. [8] [2] [6] [12]

- Altitude: Direct readings of the altimeter produced a record of the altitude at the beginning of the spin and the altitude at the end of a spin. Altitude readings of the altimeter can be read at the nearest 50 foot increment. Lost altitude during the spin is calculated by subtracting the altitude at spin recovery from the altitude at spin initiation. [8] [10]

- Velocity: The maximum velocity during spin recovery is a direct measurement of the airspeed indicator. Airspeed indicator measurements can be read at the nearest 3 knot increment. [8] [10] [2]
- Time: Time is extracted from video editing using digital time stamps on each frame of video. Time can be measure to the nearest 0.1 second. The total time of spin from start to finish is calculated by subtracting the time of the spin initiation from the time of the recovered spin. Time to recover is calculated by subtracting the time of the spin recovery initiation from the time of the recovered spin. [8]
- Vertical Velocity: The average vertical velocity during the spin is calculated by dividing the altitude loss during the spin by the total spin time.
- Revolutions: The number of revolutions to recover can be observed from video capturing the pilot’s sight picture. This video captures the terrain directly below the spinning aircraft which contains landmarks that make angles of revolutions that are discernable to the nearest 1/8 of a revolution. [8] [2]
- Spin Rate: The spin rate then becomes a simple calculation of dividing the number of revolutions that occurred during spin recovery by the time to recover. This by definition of the calculation is an average of the spin rate over the recovery phase and not an instantaneous measurement. While the spin rate will vary dramatically the average is the best available quantifiable measurement. Further qualitative comparisons are provided in the pilot comments for acceleration of deceleration of the spin rate at the point of recovery control initiation. [8]

Factors

The first factor considered for regression is rudder. The rudder variable will be defined based on the spin's direction of rotation in yaw. For the purpose of using references known to the pilot, the position of the rudder pedal will be use to indicate the position of the rudder control surface. During a spin the rudder position for a pro-spin position depends on the direction of aircraft yawing or rotation. Again, the pilot's perspective over the nose of the aircraft for yawing direction. The pro-spin position is rudder applied with the direction of yaw. The anti-spin position is rudder applied opposite the direction of yaw. The definitions for rudder positions will be: 0 for rudder pedals to the neutral position, 1 for anti-spin (full rudder pedal opposite the direction of yaw), and -1 for pro-spin (full rudder pedal in the direction of yaw). Due to previous spin research the pro-spin rudder position can be ruled out. All available research indicates that for all aircraft, the spin becomes aggravated with pro-spin rudder pedal inputs. Free release of the rudder pedals will be defined as F. In the free release position the pilot completely removes their feet from the rudder controls and allow rudder to free float with aerodynamic forces. [18] [5] [6]

The second factor considered for regression is elevator. Due to the aerobatic performance of the 8KCAB, this aircraft has a large amount of elevator authority. While this is a highly desired capability for this test, an overabundance of control authority complicates the model definition for this variable. For the purpose of using references known to the pilot, control stick position for pitch, will be use to indicate elevator position. During a spin the elevator position for pro-spin depends on the orientation of the aircraft in either upright or inverted positions. In the upright orientation, full aft pitch stick is the pro-spin position. In the inverted orientation, full forward pitch is the pro-spin position. Given that normal spin entry and position for general aviation is upright, this thesis will only consider upright spins. More complexity is added by the fact that the Super Decathlon has enough elevator control authority to cross-over an upright spin to an inverted spin by reversing stick positions. Therefore, pitch stick inputs for forward and aft positions will be reduced to half inputs. The definitions for pitch stick positions will be: 0 for neutral (stick pitch position to the neutral position), 1 for pro-spin (stick pitch position halfway between neutral and full aft pitch stick), and -1 for anti-spin (stick pitch position halfway between neutral and full forward pitch stick). Free release of the stick will be defined as F. In the free release position the pilot completely removes their hands from the stick controls and allows elevator and ailerons to free float with aerodynamic forces. [10] [19] [2] [12] [7]

The third factor considered for regression is aileron. The aileron variable will be defined based on the spin's direction of yaw. For the purpose of using references known to the pilot, roll stick will be used to indicate aileron position. The definitions for aileron positions will be: 0 for neutral (stick roll position to the neutral position), -1 for pro-spin (stick roll position halfway between neutral and full roll stick in the direction of yaw), and 1 for anti-spin (stick roll position halfway between neutral and full roll stick in the opposite direction of yaw). While the three previous control inputs contain pro-spin and anti-spin inputs, research is indefinite for which inputs of aileron are considered pro and anti-spin. In general, the aileron to neutral is considered anti-spin while both roll stick inputs in and out of the spin's roll direction are considered pro-spin. Free release of the stick will be defined as F. In the free release position the pilot completely removes their hands from the stick controls and allows elevator and ailerons to free float with aerodynamic forces. [18] [19] [6] [20] [3]

A fourth possible factor that could be considered for regression is throttle position. This term is missing from the flight test data, the explanation for this will follow. This variable is defined as 0 for a throttle position that is closed or min power (anti-spin) and defined as 1 for open or full power (pro-spin). Due to previous spin research, the open throttle position, 1, control variable option can be eliminated from this regression. All available research indicates that for all commercially available aircraft, the spin mode becomes aggravated at higher throttle settings. Only specially built aircraft with extremely high power to weight ratios and an abundance of control authority have demonstrated the ability to recover from a spin using the application of throttle. Specifically, the 8KCAB is not recoverable at full throttle settings. In addition, all research of published spin recovery techniques requires the pilot to move the throttle to the closed position. This throttle will not be implemented as a variable factor in this model and will be held constant in the closed position. [10] [12] [19] [20] [4] [3]

Control Input Timing

The method by which control inputs are timed can be explored within this historical data. A full factorial set of flight test data is available for several varying control input sequences. This thesis will develop a model for simultaneous control inputs as the baseline product. This method is the most common procedure describe in commercial aircraft flight manuals and includes the desired treatment of variables recommend by the manufacturer of the 8KCAB Super Decathlon.

The second timing of inputs will sequence the control inputs providing a pause between the inputs of rudder first and the elevator and aileron second. This sequence is by chosen as it is the most popular alternate recovery method that involves a sequencing of control inputs. This handling sequence of flight test data includes the desired treatment of variables recommended in the NASA standard spin recovery procedure, alternatively known as PARE. [10] [19] [12] [3]

Response

The historical data provides for many possible selections for consideration of response. All of the possible selections are explained in the measurements section and in depth in the Flight Test Plan Attachment A. While all of these can support the validation of the model, loss of altitude is the pilot's primary concern. The total loss of altitude during the spin is the most immediate concern to a pilot entering an unintentional spin. Flying the base to final turn is where the majority of most spin incidents occur. Immediate corrective action from the pilot will recover the aircraft prior to impact. Continued pro-spin flight inputs from the pilot will result in an impact with the ground. This is an extremely hard limit to deal with and force loss of altitude to the number one priority for selection of a spin recovery controls. [5] [6] [1]

The response of an unrecoverable scenario is correctly interpreted as infinite altitude loss. This presents a problem in a linear model. For this reason, the model development will be limited to a controlled flight regime that will not attempt to define the nonlinearity that occurs during uncontrollable flight. Responses of unrecoverable controls will be treated outside of the model space and omitted from the analysis. This may present some problems with aliased terms in a coded design space; however, the desired model will be evaluated the in real terms. Deriving a final equation in terms of real coefficients should not pose a problem as there is enough data to provide a solution. [2] [9] [6]

Historical Data

The historical data used in this thesis is archived in Appendix B, the flight test cards and Appendix C, the tabulated flight test data. All of the presented data, in part, is used in this thesis and adds to the evaluation and interpretation of the models. The critical data used in the development of the spin recovery models is presented in the following tables: Table 3, Table 4, Table 5, and Table 6.

Table 3: Right Hand Spin, Simultaneous Input

Test Point	Rudder	Elevator	Aileron	Lost Altitude (ft)
2R	0	0	0	1300
3R	0	0	1	1350
4R	0	0	-1	1325
5R	0	1	0	1350
6R	0	-1	0	1425
7R	0	1	1	1400
8R	0	1	-1	1475
9R	0	-1	-1	X
10R	0	-1	1	1400
12R	1	0	0	1300
13R	1	0	1	1200
14R	1	0	-1	1275
15R	1	1	0	1300
16R	1	-1	0	1250
17R	1	1	1	1325
18R	1	1	-1	1350
19R	1	-1	-1	1300
20R	1	-1	1	1300

Table 4: Left Hand Spin, Simultaneous Input

Test Point	Rudder	Elevator	Aileron	Lost Altitude (ft)
2L	0	0	0	1450
3L	0	0	1	1500
4L	0	0	-1	1600
5L	0	1	0	1425
6L	0	-1	0	X
7L	0	1	1	1450
8L	0	1	-1	1650
9L	0	-1	-1	X
10L	0	-1	1	X
12L	1	0	0	1300
13L	1	0	1	1150
14L	1	0	-1	1400
15L	1	1	0	1350
16L	1	-1	0	1225
17L	1	1	1	1350
18L	1	1	-1	1325
19L	1	-1	-1	1400
20L	1	-1	1	1300

Table 5: Right Hand Spin, Sequenced Input

Test Point	Rudder	Elevator	Aileron	Lost Altitude (ft)
12R*	1	0	0	1400
13R*	1	0	1	1325
14R*	1	0	-1	1325
15R*	1	1	0	1350
16R*	1	-1	0	1275
17R*	1	1	1	1200
18R*	1	1	-1	1500
19R*	1	-1	-1	1600
20R*	1	-1	1	1300

Table 6: Left Hand Spin, Sequenced Input

Test Point	Rudder	Elevator	Aileron	Lost Altitude (ft)
12L*	1	0	0	1500
13L*	1	0	1	1500
14L*	1	0	-1	1500
15L*	1	1	0	1500
16L*	1	-1	0	1200
17L*	1	1	1	1400
18L*	1	1	-1	1400
19L*	1	-1	-1	1300
20L*	1	-1	1	1275

Design of Experiments

The spin recovery models will be based on a DOE approach to the application of recovery controls. A series of spins were flown using combinations of control inputs while the response of the aircraft is measured. The combinations of control inputs will be used in order to develop a recovery model.

Translation of Coded Factors

The provided historical data presents the aircraft's control inputs in terms of coded design space which can be confusing. In addition, this prevents the determination of final equation coefficients in real terms. For this reason, the coded terms of the historical flight test data must be translated into a real design space of physical terms. The historical data defines the rudder in coded terms of 0 and 1 which represent real terms of neutral rudder and full anti-spin rudder pedal deflection. Physically this is 0% pedal travel and 100% of the pedal travel opposite the spin direction. It is easy think of the coded term of 0 translating to the physical term of 0% rudder pedal travel, while the coded term of 1 translates to the physical term of 100% anti-spin rudder pedal travel.

The elevator term is defined in coded space as -1, 0, and 1 which represents half input stick pro-spin, neutral stick, and half anti-spin input. Physically this is 50% aft stick deflection, 0% stick deflection, and 50% forward stick deflection. Again, it is easy think of the coded term of -1 translating to the physical term of -50% aft stick deflection , the coded term 0 translating to real term 0% stick deflection, and the coded term of 1 translates to the physical term of 50% forward stick deflection.

The aileron term is defined in coded space as -1, 0, and 1 which represents full input stick pro-spin, neutral stick, and full anti-spin input. Physically this is 100% spin direction stick deflection, 0% stick deflection, and 100% opposing spin direction stick deflection. Again, it is easy think of the coded term of -1 translating to the physical term of -100% pro-spin deflection, the coded term 0 translating to real term 0% stick deflection, and the coded term of 1 translates to the physical term of 100% anti-spin stick deflection. [21] [22] [23]

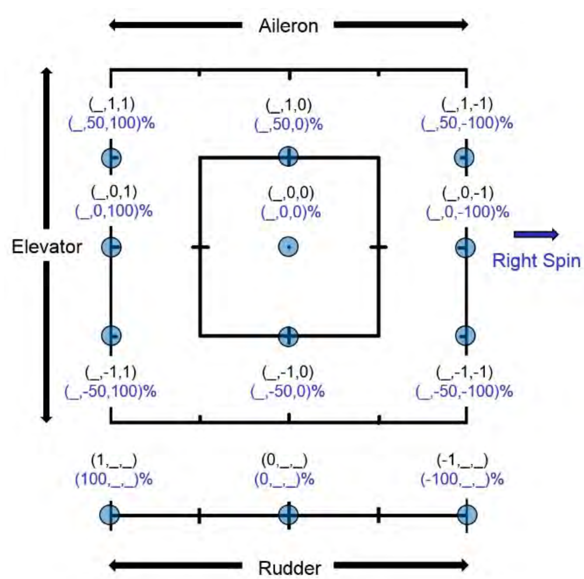


Figure 7: Coding of Model Factors

Blocking

There is an additional variable of the direction of spin rotation. There are two possible spin directions. For the purpose of using references known to the pilot, spin directions will be labeled left and right based on the orientation of the pilot. Spins with references moving horizontally right to left over the pilot's view of the aircraft cowling will be labeled right hand spins. Spins with references moving horizontally left to right over the pilot's view of the aircraft cowling will be labeled left hand spins. While spin direction is not a pilot control, the response of the aircraft to pilot's inputs may be affected by the spin direction as explained in the literature review section. [21] [24]

Model Data

The historical data presented has been translated into a real design space and appropriately blocked in the following tables: Table 7 and Table 8.

Table 7: Simultaneous Input

Block	Rudder Deflection (%)	Elevator Deflection (%)	Aileron Deflection (%)	Lost Altitude (ft)
Right	0%	0%	0%	1300
Right	0%	0%	100%	1350
Right	0%	0%	-100%	1325
Right	0%	50%	0%	1350
Right	0%	-50%	0%	1425
Right	0%	50%	100%	1400
Right	0%	50%	-100%	1475
Right	0%	-50%	-100%	X
Right	0%	-50%	100%	1400
Right	100%	0%	0%	1300
Right	100%	0%	100%	1200
Right	100%	0%	-100%	1275
Right	100%	50%	0%	1300
Right	100%	-50%	0%	1250
Right	100%	50%	100%	1325
Right	100%	50%	-100%	1350
Right	100%	-50%	-100%	1300
Right	100%	-50%	100%	1300

Left	0%	0%	0%	1450
Left	0%	0%	100%	1500
Left	0%	0%	-100%	1600
Left	0%	50%	0%	1425
Left	0%	-50%	0%	X
Left	0%	50%	100%	1450
Left	0%	50%	-100%	1650
Left	0%	-50%	-100%	X
Left	0%	-50%	100%	X
Left	100%	0%	0%	1300
Left	100%	0%	100%	1150
Left	100%	0%	-100%	1400
Left	100%	50%	0%	1350
Left	100%	-50%	0%	1225
Left	100%	50%	100%	1350
Left	100%	50%	-100%	1325
Left	100%	-50%	-100%	1400
Left	100%	-50%	100%	1300

Table 8: Sequenced Input

Block	Rudder Deflection (%)	Elevator Deflection (%)	Aileron Deflection (%)	Lost Altitude (ft)
Right	100%	0%	0%	1400
Right	100%	0%	100%	1325
Right	100%	0%	-100%	1325
Right	100%	50%	0%	1350
Right	100%	-50%	0%	1275
Right	100%	50%	100%	1200
Right	100%	50%	-100%	1500
Right	100%	-50%	-100%	1600
Right	100%	-50%	100%	1300
Left	100%	0%	0%	1500
Left	100%	0%	100%	1500
Left	100%	0%	-100%	1500
Left	100%	50%	0%	1500
Left	100%	-50%	0	1200
Left	100%	50%	100%	1400
Left	100%	50%	-100%	1400
Left	100%	-50%	-100%	1300
Left	100%	-50%	100%	1275

Model Selection

The selection of models to be developed must answer the questions regarding the inputs of recovery controls and the desired response for the least amount of altitude loss. In order to answer this question completely, several models will be completed in order to compare and contrast varying effects.

The analysis will start with a model selection that presents simultaneous control inputs. This model will be developed with both left and right hand spin directions to include appropriate blocking controls. The model will undergo and analysis of several types to determine the suitability of the model. The first statistical test will be an Analysis of Variance (ANOVA) which will provide a statistical significance of the model and individual treatments through the F-test. Following analysis will look at the residuals using varying methods. Factor selection will use as many main effects and interacting terms as possible that provide a significant model. Follow on models may reduce these variables as appropriate to the analysis. [21] [25] [26] [22]

Finally, an analysis of a model selection that presents sequenced control inputs. This model will be developed with both left and right hand spin directions to include appropriate blocking controls. The model will undergo and analysis of several types to determine the suitability of the model. The first statistical test will be an analysis of variance (ANOVA) which will provide a statistical significance of the model and [23] individual treatments through the F-test. Following analysis will look at the residuals using varying methods. Factor selection will only include many main effects in order to directly compare the results from models develop with simultaneous control inputs and sequenced control inputs. [21] [25] [26] [22]

The selected models will be analyzed for statistical significance using an F-test. The alternative or research hypothesis that the model is significant can be accepted if the null hypothesis that there is no significance is rejected. This will be done by comparing the F statistic for the model and individual factors with the critical value. The critical value is calculated by choosing an alpha value which determines the level of significance for the F test. The probability of Type I error is determined by the alpha value that is chosen for this test. This test is being performed on a relatively small population of experimental results. The population is small due to the large expense and time effort required to gain such a wealth of information regarding spin recovery. Given the resources required in obtaining this information, the value of alpha that will be used is $\alpha = 0.1$. This selected value allows for a higher level of Type I error than contemporarily accepted with large sample sizes; however, the selection does fall within traditionally acceptable values. [25]

Summary

The historical data was selectively chosen in order to support development of two models. The flight test methodology supports the DOE approach to analysis and regression modeling. The first model to be analyzed is a procedure of spin recovery control inputs that are simultaneously applied. This type of application is fundamentally similar to the aircraft manufacturer’s recommendation for spin recovery. The second model analyzed is a procedure of spin recovery control inputs that are sequentially applied. The type of sequence application that will modeled is fundamentally similar to the NASA standard spin recovery procedure.

IV. Analysis and Results

Chapter Overview

The purpose of this chapter is to introduce the analysis and results from the evaluation of control inputs on the spin recovery of the 8KCAB Super Decathlon. Analysis will include historical data taken from actual flight experiments presented in the methodology section. Results will be presented in a forum of handling qualities from a number of different viewpoints including modeling of key spin characteristics, discussion of pilot vehicle interface characteristics, and a dissection of the anatomy behind principle test points.

REA.sim Model

The REA.sim model represents spin recovery control inputs with simultaneous inputs for all three treatments of Rudder, Elevator, and Aileron. The REA.sim model will block the left and right spin directions in order to evaluate this effect on spin recovery. Some of the runs in the REA.sim model contain unrecoverable spin recovery controls and will be omitted from the model. A discussion of unrecoverable spin data and the validity of removing this data was presented in the methodology section. The unrecoverable runs represent run 8, 23, 26, and 27 from Table 9 and correspond to test points 9R, 6L, 9L, and 10L from Table 3 and Table 4 respectively.

Design

The design of the REA.sim model is a 3 factorial experiment with factors of rudder, elevator, and aileron. It will use numeric factors of A, B, and C to represent rudder, elevator, and aileron respectively. The rudder factor will consist of 2 treatment levels. This factor will contain coded variables of -1, 1 and be defined in actual terms as neutral rudder and full anti-spin rudder respectively. Neutral rudder will be defined as 0% deflection of the pedal while full anti-spin rudder will be defined as 100% deflection opposite the spin direction. The elevator factor will consist of 3 treatment levels. The factor will contain coded variables of -1, 0, 1 and be defined in actual terms as pro-spin elevator, neutral elevator, and anti-spin elevator respectively. Full elevator inputs will not be used for the reasons described previously in the methodology section. Pro-spin elevator will be defined in actual terms as -50% deflection of the control stick aft, neutral elevator defined as 0% deflection, and anti-spin elevator defined as 50% deflection forward. The aileron factor will consist of 3 treatment levels. The factor will contain coded variables of -1, 0, 1 and be define in actual terms as full pro-spin aileron, neutral aileron, and full anti-spin aileron respectively. Full pro-spin Aileron will be defined in actual terms as -100% deflection of the control stick into the spin direction, neutral aileron defined as 0% deflection, and anti-spin aileron defined as 100% deflection out of spin direction. The response variable will be defined in actual terms as the altitude loss in feet during the spin and recovery. These details are highlighted in Table 9. The REA.sim model contains both left and right spin data which is broken into two blocks with no replicates. Block 1 contains a full factorial design for right hand spins while block 2 contains a full factorial design for left hand spins. The data for unrecoverable runs is struck through and will be ignored in the analysis for the reasons described in the methodology section. With this missing data the model is not orthogonal which means the coefficients be dependent on other model terms. This is acceptable for this model as all terms will be defined. The design of the model is shown in Table 9. [21] [25] [23] [26]

Table 9: REA.sim Model Design and Test Results

Block	Run	Factor 1 A:Rudder % Deflection	Factor 2 B:Elevator % Deflection	Factor 3 C:Aileron % Deflection	Response 1 Altitude Loss ft
Right Spins	1	0	0	0	1300
Right Spins	2	0	0	100	1350
Right Spins	3	0	0	-100	1325
Right Spins	4	0	50	0	1350
Right Spins	5	0	-50	0	1425
Right Spins	6	0	50	100	1400
Right Spins	7	0	50	-100	1475
~~Right Spins~~	~~{8}~~	~~0~~	~~-50~~	~~-100~~	~~0~~
Right Spins	9	0	-50	100	1400
Right Spins	10	100	0	0	1300
Right Spins	11	100	0	100	1200
Right Spins	12	100	0	-100	1275
Right Spins	13	100	50	0	1300
Right Spins	14	100	-50	0	1250
Right Spins	15	100	50	100	1325
Right Spins	16	100	50	-100	1350
Right Spins	17	100	-50	-100	1300
Right Spins	18	100	-50	100	1300
Left Spins	19	0	0	0	1450
Left Spins	20	0	0	100	1500
Left Spins	21	0	0	-100	1600
Left Spins	22	0	50	0	1425
~~Left Spins~~	~~{23}~~	~~0~~	~~-50~~	~~0~~	~~0~~
Left Spins	24	0	50	100	1450
Left Spins	25	0	50	-100	1650
~~Left Spins~~	~~{26}~~	~~0~~	~~-50~~	~~-100~~	~~0~~
~~Left Spins~~	~~{27}~~	~~0~~	~~-50~~	~~100~~	~~0~~
Left Spins	28	100	0	0	1300
Left Spins	29	100	0	100	1150
Left Spins	30	100	0	-100	1400
Left Spins	31	100	50	0	1350
Left Spins	32	100	-50	0	1225
Left Spins	33	100	50	100	1350
Left Spins	34	100	50	-100	1325
Left Spins	35	100	-50	-100	1400
Left Spins	36	100	-50	100	1300

A summary of the REA.sim model design is shown in Table 10. Statistics are shown for the entire data set of actual responses including both blocks for right and left hand spins. The minimum and maximum responses are 1150ft and 1650ft respectively with a mean of 1359ft. The standard deviation for the entire data set is 105ft. Note in the Table 10, the regression model chosen is a 3 main factor influence model with no transformations.

Table 10: REA.sim Model Data Statistics

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.	
A	Rudder	% Deflection	Numeric	Continuous	0	100	-1.000=0	1.000=100	50	50.7093	
B	Elevator	% Deflection	Numeric	Continuous	-50	50	-1.000=-50	1.000=50	0	41.4039	
C	Aileron	% Deflection	Numeric	Continuous	-100	100	-1.000=-100	1.000=100	0	82.8079	
Response	**Name**	**Units**	**Obs**	**Analysis**	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**	**Ratio**	**Trans**	**Model**
R1	Altitude Loss	ft	32	Factorial	1150	1650	1359.38	105.063	1.43478	None	3FI

Figure 8 displays the data points which are graphed for rudder pedal deflection verses altitude loss. Note that the number beside points in the graph represent multiple points that overlap each other at that response. The data spread for 0% rudder pedal deflection overlaps with the data spread for 100% rudder pedal deflection. It can be seen that a 100% rudder pedal deflection provides a significantly lower average than that for 0% rudder pedal deflection. 100% rudder pedal deflection or anti-spin rudder provides the least average altitude lost for spin recovery. Calculated values are 1300ft and 1435ft respectively, which differentiates the two by an average of 135ft. This is a large difference which implies it will be a large contributor to the model. Additionally, within this graph the variation within the data blocks for right and left spins can be seen. Right spin runs are colored in black while left spin runs are colored in red. It is visually evident that the standard deviation for right spins is significantly smaller than the standard deviation for left spins. Calculated values are 67ft and 131ft respectively. Right hand spins deviations are nearly half of the deviations found in left hand spins. This difference is expected due to propeller effects and aerodynamically balanced trim surfaces. It is important to evaluated this difference as many airplanes will not be suitable to model left and right hand spins together. The analysis for 8KCAB shows a high degree of balance for both left and right spins and allows for a combined analysis.

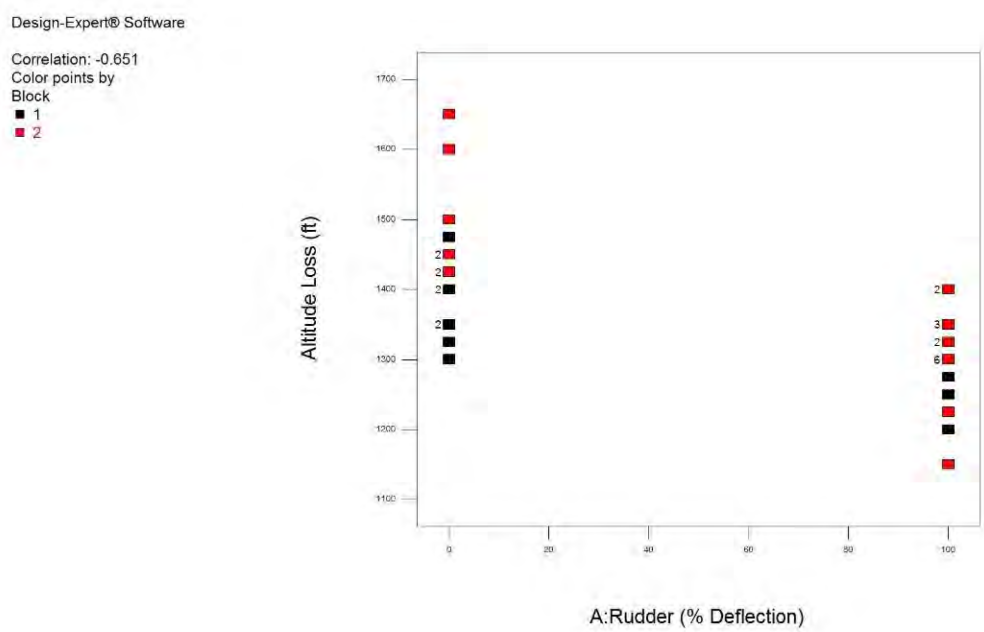


Figure 8: REA.sim Model: Rudder vs. Altitude Loss (Actual)

Figure 9 displays the data points which are graphed for elevator control stick deflection verses altitude loss. The data spread for the three elevator treatments (-50%, 0%, and 50% deflection of the control stick) overlaps with one another. A calculation of the three averages for altitude loss, 1325ft, 1345ft, and 1395ft respectively reveals that -50% control stick deflections or pro-spin elevator provides the least altitude loss for spin recovery. The largest difference between these averages is 70ft. It is likely this factor will not be a large contributor to this model. It should be noted that the total change in elevator stick deflection is only half of the control range. The methodology section explains the need to limit the authority of this factor in order to best ensure recovery. Additionally, within this graph the variation within the data blocks for right and left spins can be seen. Right spin runs are colored in black while left spin runs are colored in red. Noteworthy is the difference in standard deviation between neutral elevator runs for right and left spins. Deviations are 51ft and 151ft respectively. This difference accounts for a majority portion of the overall deviation between right and left spins.

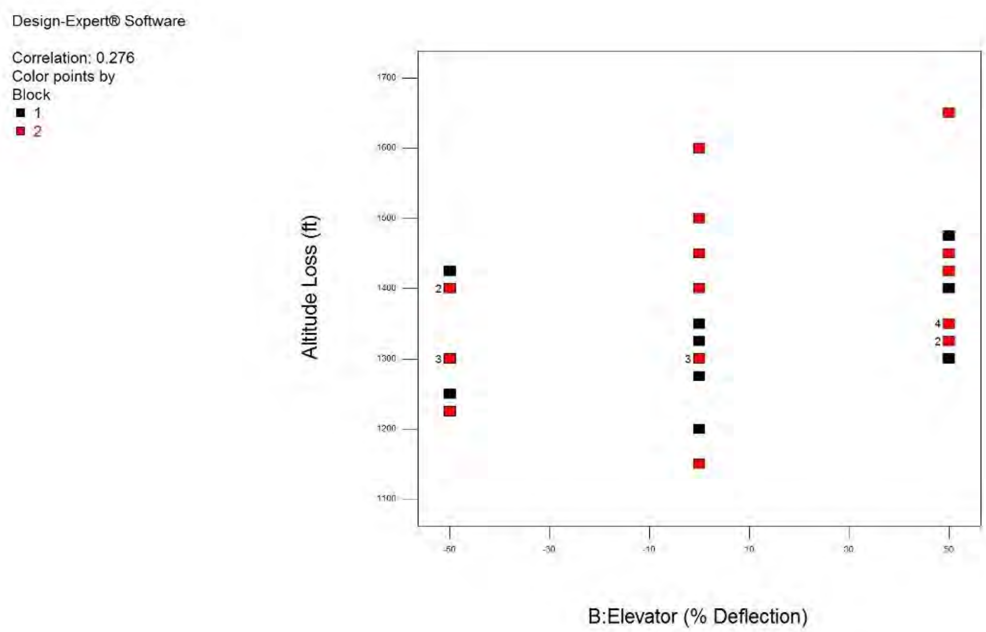


Figure 9: REA.sim Model: Elevator vs. Altitude Loss (Actual)

Figure 10 displays the data points which are graphed for aileron control stick deflection verses altitude loss. The data spread for the three aileron treatments (-100%, 0%, and 100% deflection of the control stick) overlaps one another. A calculation of the three averages for altitude loss, 1410ft, 1334ft, and 1338ft respectively, reveals that 0% control stick deflection or neutral aileron provides the least altitude loss for spin recovery. The largest difference between these averages is 76ft. It is likely this factor will not be a large contributor to the REA.sim model. Additionally, within this graph the variation within the data blocks for right and left spins can be seen. Right spin runs are colored in black while left spin runs are colored in red.

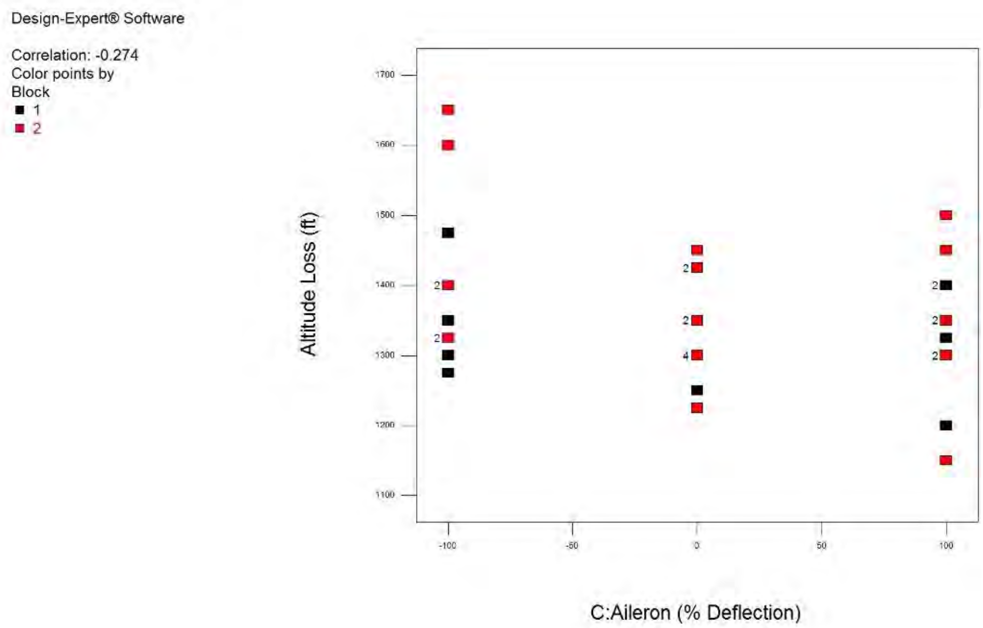


Figure 10: REA.sim Model: Aileron vs. Altitude Loss (Actual)

Factor Selection and Significance

The ANOVA for the REA.sim Model is shown in Table 11. Using $\alpha = 0.1$ the calculated critical value of the F statistic is $F_{0.10,7,23} = 2.00$. The F statistic for the model provided in the ANOVA is 5.63 and greater than the critical value. Applying this F test, the null hypothesis can be rejected and a conclusion can be drawn that the model selected is significant. Analyzing the first treatment in the experiment, A-Rudder, the critical value of $F_{0.1,1,23} = 2.93$ is calculated. The F statistic for the rudder treatment provided in the ANOVA is 23.62 and greater than the critical value. Therefore, a conclusion is made that rudder treatment is significant for the REA.sim model. Moving onto the second treatment in the model, B-Elevator, the critical value of the F statistic is repeated as $F_{0.1,1,23} = 2.93$. The F statistic for the elevator treatment provided in the ANOVA is 1.06 and less than the critical value. Therefore, the conclusion that the elevator treatment is not significant for the REA.sim model is made. Finally, the third treatment in the model, C-Aileron, the critical value of the F statistic is repeated as $F_{0.1,1,23} = 2.93$. The F statistic for the aileron treatment provided in the ANOVA is 2.68 and less than the critical value. Therefore, the conclusion is made that the aileron treatment is not significant for the REA.sim model. A review of all the interaction terms shows that all interactions were not significant for the REA.sim model. [25]

The ANOVA analysis provides that a regression model with selections including all the main effects and interacting terms of A, B, C, AB, AC, BC, and ABC is significant. The A-Rudder term is demonstrated to be the only significant term. The B-Elevator, C-Aileron, and the ABC interaction terms provide near significant influence over the model; however, these two main factors are dominated by the A-Rudder term. [25]

Table 11: REA.sim Model ANOVA

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Block	29442.40	1	29442.40			
Model	1.974E+005	7	28206.79	5.63	0.0007	significant
A-Rudder	*1.184E+005*	*1*	*1.184E+005*	*23.62*	*< 0.0001*	
B-Elevator	*5325.40*	*1*	*5325.40*	*1.06*	*0.3134*	
C-Aileron	*13412.16*	*1*	*13412.16*	*2.68*	*0.1155*	
AB	*1.20*	*1*	*1.20*	*2.398E-004*	*0.9878*	
AC	*807.05*	*1*	*807.05*	*0.16*	*0.6919*	
BC	*2675.00*	*1*	*2675.00*	*0.53*	*0.4725*	
ABC	*8172.05*	*1*	*8172.05*	*1.63*	*0.2144*	
Residual	1.153E+005	23	5012.94			
Cor Total	3.422E+005	31				

The Half Normal plot for the REA.sim model is shown in Figure 11. The plot shows all the main effects and interacting terms selected for inclusion in the model. The plot shows a desirable highly linear relation for the error estimates indicating there are no departures from a normal distribution. Using the estimated parameters in the regression model no transformations are required for the REA.sim model.

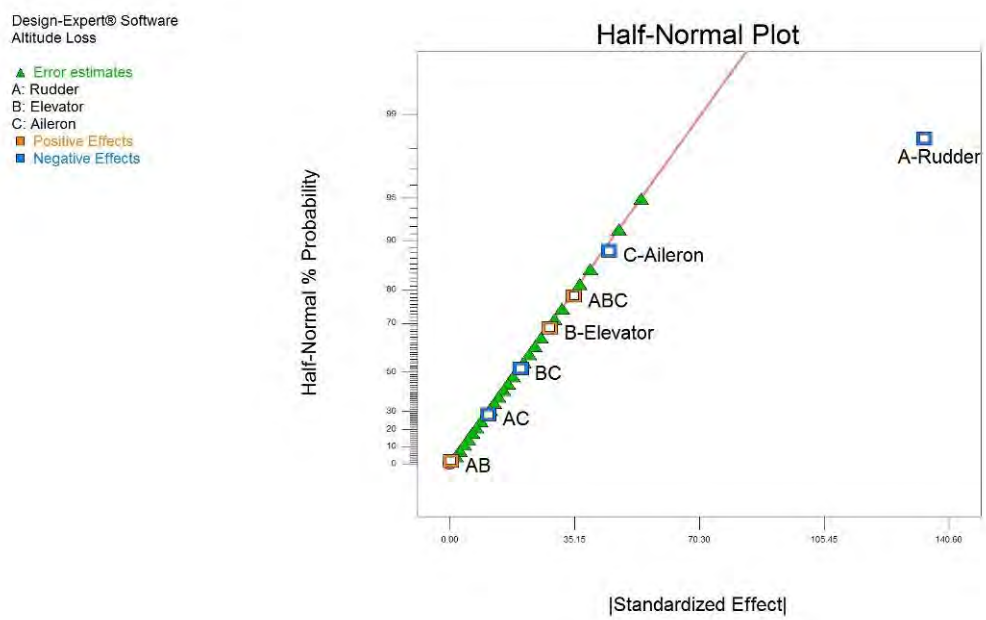


Figure 11: REA.sim Model Half-Normal Plot

Checking the REA.sim model assumptions, a review of the Normal Plot of Residuals in Figure 12 is performed. The plot is used to check the assumption that the error distribution is normal. The plot should resemble a straight line where more emphasis is place on central values rather than extreme values. The plot shows a high structure of linearity for all values. Some variation is seen as points straddle a linear estimate. However, all of the points show a high degree of linearity.

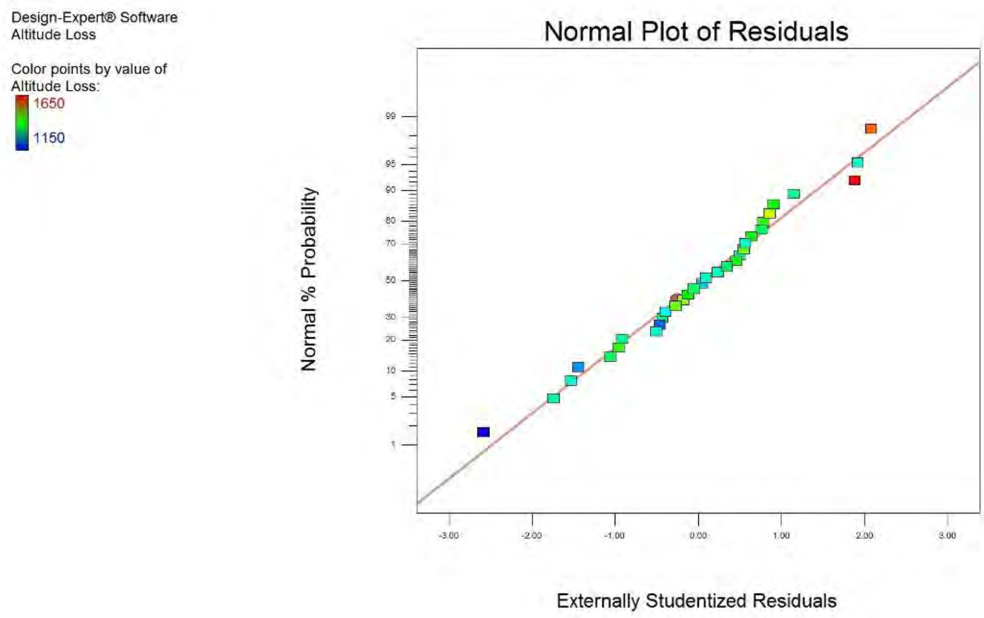


Figure 12: REA.sim Model Normal Plot of Residuals

A review of non-constant variance is shown in the Residual Plots and Summary of Residuals table in Appendix D. A quick review of the residuals table shows that all residuals are acceptable, except for runs 3, 18, 21, 25 and 29 for the DFFITS residual. All of these points are dynamic at the edge of the control envelope, This examination of the physical points leads to a conclusion that these are high influence points. Additionally the distribution and size of influence for these points is not large enough for concern and likely due to missing data from points that were unrecoverable control inputs.

Results

The final equation for REA.sim model is shown in Equation 1. Using this equation, two contour plots to graphically show response of the REA.sim model can be produced.

Equation 1: REA.sim Model Equation (Actual Factors)

Final Equation in Terms of Actual Factors:

$$
\begin{aligned}
\text{Altitude Loss} = \; & +1433.70340 \\
& -1.33703 \; * \text{Rudder} \\
& +0.36390 \; * \text{Elevator} \\
& -0.21464 \; * \text{Aileron} \\
& +1.11020\text{E-}004 \; * \text{Rudder} * \text{Elevator} \\
& -1.39529\text{E-}003 \; * \text{Rudder} * \text{Aileron} \\
& -9.18586\text{E-}003 \; * \text{Elevator} * \text{Aileron} \\
& +1.16859\text{E-}004 \; * \text{Rudder} * \text{Elevator} * \text{Aileron}
\end{aligned}
$$

Figure 13 represents a plot of Aileron vs Elevator vs Altitude Loss for 0% rudder deflections while Figure 14 represents a plot of Aileron vs Elevator vs Altitude Loss for 100% anti-spin rudder deflections. As expected from the significance of the rudder treatment, 100% anti-spin rudder provides significantly less altitude loss during spin recovery. The least amount of altitude loss predicted for a point is (100%, -50%, 100%) which does not correspond to the lowest actual point recorded in flight test. The lowest actual point recorded was for (100%, 0%, 100%), this corresponds well with the low significance of the elevator factor as the model puts little significance between -50% elevator deflection and 0% elevator deflection.

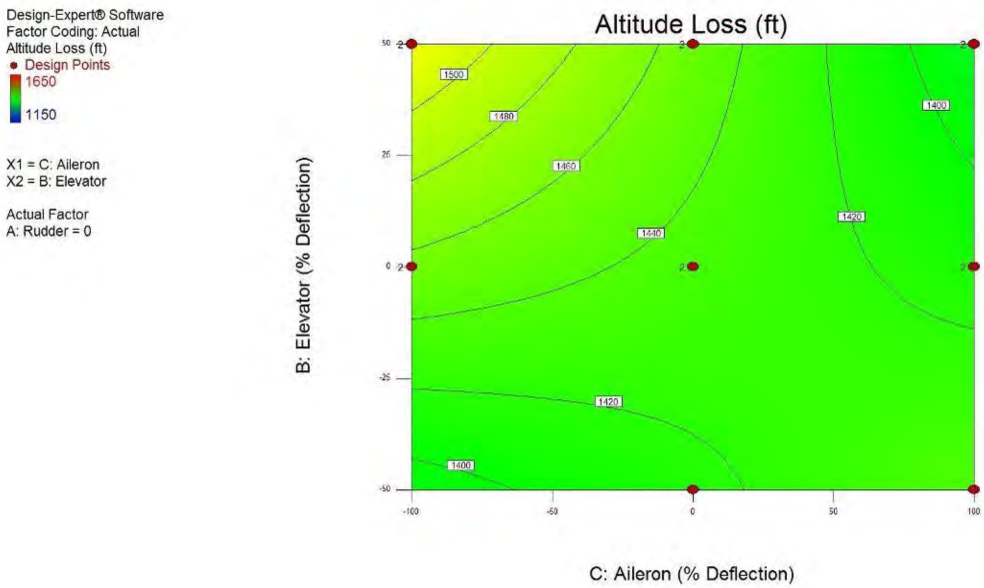


Figure 13: REA.sim Model Contour Plot; Altitude Loss, Rudder=0

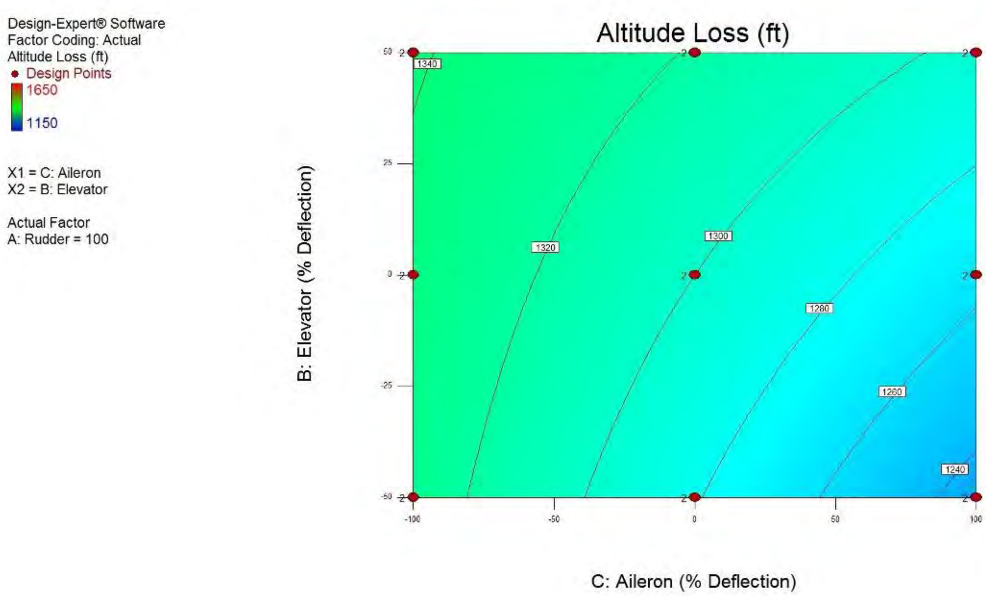


Figure 14: REA.sim Model Contour Plot; Altitude Loss, Rudder=100

This outcome is in large part due to several factors. The first factor effecting the significance of the elevator is the selection of only using 50% deflection in either direction from the neutral elevator position. Full forward or full aft elevator conditions will only change the upright or inverted aircraft position within the spin and must be limited in order to produce a recoverable condition. Moreover, there is now substantial evidence to say that the elevator is highly significant over the full travel range. Within 50% travel from neutral position of the elevator is relatively insignificant. Elevator control favors a more aft or -50% pro-spin position. The aileron is more significant than the positioning of the elevator (noting that the elevator be positioned within 50% travel from neutral) and favors 100% anti-spin inputs.

EA.sim Model

The EA.sim represents spin recovery control inputs with Simultaneous inputs for two treatments of Elevator, and Aileron. This model is a reduction of the REA.sim in order to make a direct comparison of simultaneous and sequential recovery control inputs. The EA.sim model removes the treatment of rudder as described in the analysis of the REA.sim model. This model will only use treatments of 100% anti-spin rudder as the REA.sim model shows that the 0% neutral rudder position is an overwhelmingly poor selection for the goal of least amount of altitude loss. The EA.sim will be blocked for left and right spin directions in order to evaluate the spin direction effect on spin recovery.

Design

The EA.sim model under investigation is a 2 factorial experiment with factors of elevator and aileron. The model will use numeric factors of A and B to represent elevator and aileron respectively. Similar to the REA.sim model, the elevator factor will consist of 3 treatment levels. The factor will contain coded variables of -1, 0, 1 and be defined in actual terms as pro-spin elevator, neutral elevator, and anti-spin elevator respectively. Full elevator inputs will not be used for the reasons described previously in the methodology section. Pro-spin elevator will be defined in actual terms as -50% deflection of the control stick aft, neutral elevator defined as 0% deflection, and anti-spin elevator defined as 50% deflection forward. The aileron factor will again consist of 3 treatment levels. The factor will contain coded variables of -1, 0, 1 and be define in actual terms as full pro-spin aileron, neutral aileron, and full anti-spin aileron respectively. Full pro-spin aileron will be defined in actual terms as -100% deflection of the control stick into the spin direction, neutral aileron defined as 0% deflection, and anti-spin aileron defined as 100% deflection out of the spin direction. The response variable will be defined in actual terms as the altitude loss in feet during the spin and recovery. These keying details are highlighted in Table 12. The EA.sim model contains both left and right spin data which is broken into two blocks with no replicates. Block 1 contains a full factorial design for right hand spins while block 2 contains a full factorial design for left hand spins. The design of the EA.sim model is shown in Table 12. [21] [25] [23] [26]

Table 12: EA.sim Model Design and Test Results

Block	Run	Factor 1 A:Elevator % Deflection	Factor 2 B:Aileron % Delfection	Response 1 Altitude Loss ft
Right Spins	1	0	0	1300
Right Spins	2	0	100	1200
Right Spins	3	0	-100	1275
Right Spins	4	50	0	1300
Right Spins	5	-50	0	1250
Right Spins	6	50	100	1325
Right Spins	7	50	-100	1350
Right Spins	8	-50	-100	1300
Right Spins	9	-50	100	1300
Left Spins	10	0	0	1300
Left Spins	11	0	100	1150
Left Spins	12	0	-100	1400
Left Spins	13	50	0	1350
Left Spins	14	-50	0	1225
Left Spins	15	50	100	1350
Left Spins	16	50	-100	1325
Left Spins	17	-50	-100	1400
Left Spins	18	-50	100	1300

A summary of the model design is shown in Table 13. Statistics are shown for the entire data set of actual responses including both blocks for right and left hand spins. The minimum and maximum responses are 1150ft and 1400ft respectively with an average of 1300ft. The standard deviation for the entire data set is 64ft. Note, the regression model is based on only main effects for the model are chosen with no transformations.

Table 13: EA.sim Model Data Statistics (Actual)

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Elevator	% Deflection	Numeric	Continuous	-50	50	-1.000=-50	1.000=50	0	42.0084
B	Aileron	% Delfection	Numeric	Continuous	-100	100	-1.000=-100	1.000=100	0	84.0168

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Altitude Loss	ft	18	Factorial	1150	1400	1300	64.1689	1.21739	None	Main effects

Figure 15 displays the data points which are graphed for elevator control stick deflection verses altitude loss. The data spread for the three elevator treatments of (-50%, 0%, and 50% deflection of the control stick) overlaps with one another. A calculation of the three averages for altitude loss result in, 1296ft, 1271ft, and 1333ft respectively. These figures reveal that 0% control stick deflections or neutral elevator provides the least altitude loss for spin recovery. The largest different between these averages is 37ft. It is likely this factor will not be a large contributor to this model. It should be noted that the total change in elevator stick deflection is only half of the control range. The methodology section explain the need to limit the authority of this factor in order to reasonably ensure spin recovery. Additionally, within this graph the variation within the data blocks for right and left spins can be seen. Right spin runs are colored in black while left spin runs are colored in red. Noteworthy is the largest deviation in response occurs at the neutral elevator position which produces the lowest average altitude loss.

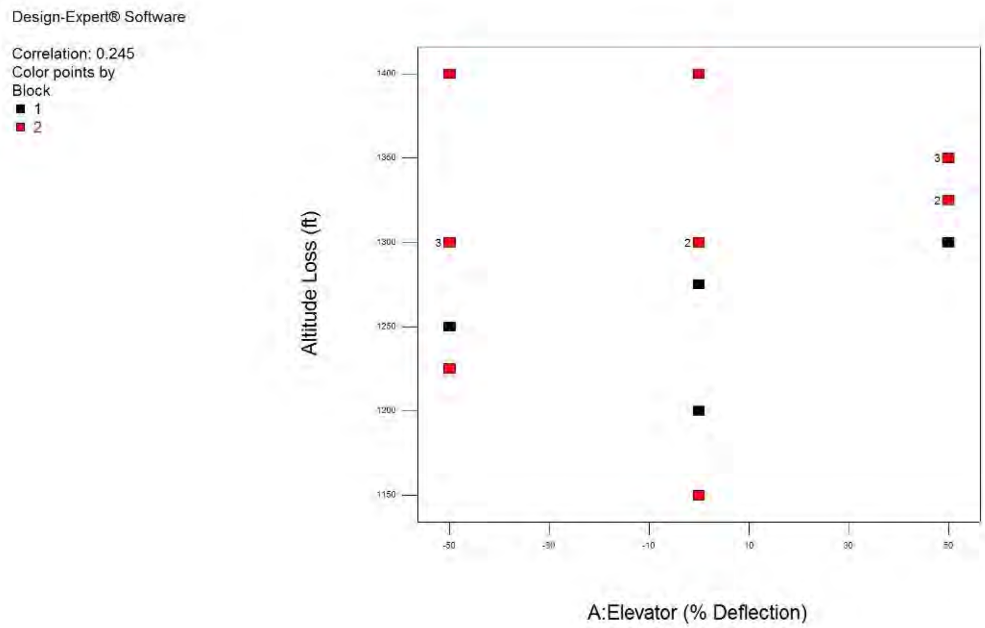


Figure 15: EA.sim Model: Elevator vs. Altitude Loss (Actual)

Figure 16 displays the data points which are graphed for aileron control stick deflection verses altitude loss. Note, the number beside the points in the graph represent multiple points that overlap each other at that response. The data spread for the three aileron treatments (-100%, 0%, and 100% deflection of the control stick) overlaps with one another. A calculation of the three averages for altitude loss, 1342ft, 1225ft, and 1300ft respectively reveals that 0% control stick deflection or neutral aileron provides the least altitude loss for spin recovery. The largest difference between these averages is 75ft. It is likely this factor will not be a large contributor to the EA.sim model. Additionally, within this graph the variation within the data blocks for right and left spins can be seen. Right spin runs are colored in black while left spin runs are colored in red.

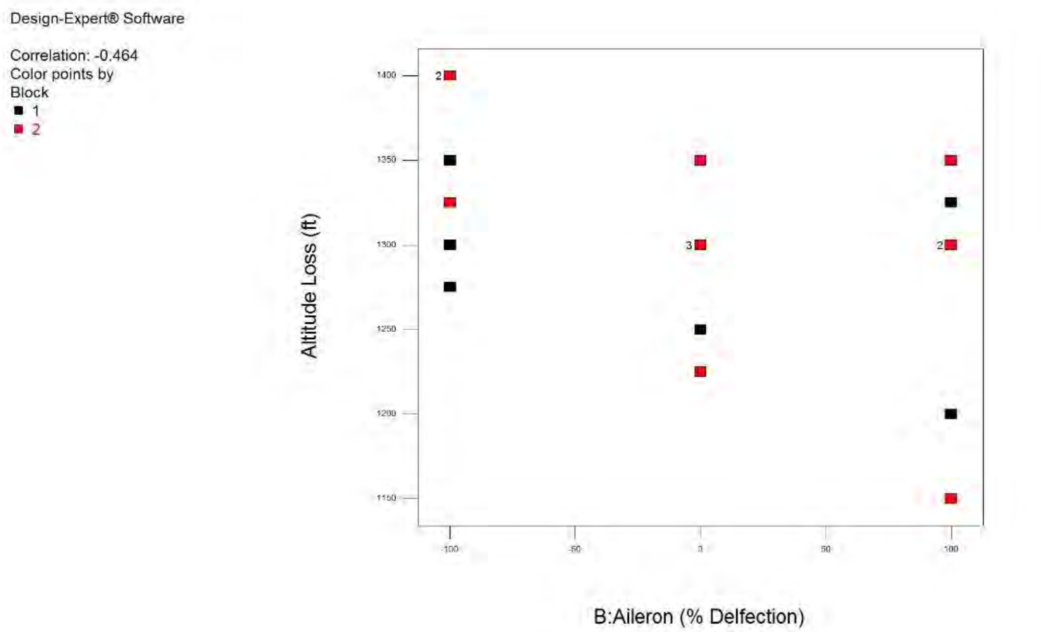


Figure 16: EA.sim Model: Aileron vs. Altitude Loss (Actual)

Factor Selection and Significance

The ANOVA for the EA.sim model is shown in Table 14. Using $\alpha = 0.1$ the calculated critical value of the F statistic is $F_{0.10,2,14} = 2.73$. The F statistic for the model provided in the ANOVA is 2.78 and greater than the critical value. Applying this F test, the null hypothesis can be rejected and the conclusion that the EA.sim model is significant is drawn. Analyzing the first treatment in the experiment, A-Elevator, the critical value of $F_{0.1,1,14} = 3.10$ is calculated. The F statistic for the elevator treatment provided in the ANOVA is 1.22 and less than the critical value. Therefore, a conclusion that the elevator treatment is not significant for the EA.sim model is made. Moving onto the second treatment in the model, B-Aileron, the critical value of the F statistic is repeated as $F_{0.1,1,14} = 3.10$. The F statistic for the aileron treatment provided in the

ANOVA is 4.34 and greater than the critical value. Therefore, the conclusion that the aileron treatment is significant for the EA.sim model is made. [25]

The ANOVA analysis provides the EA.sim model including the main effects of A-Elevator and B-Aileron is significant. The B-Aileron term is demonstrated as the only significant term in the EA.sim model. The A-Elevator provide a near significant influence over the model; however, is dominated by the B-Aileron term. [25]

Table 14: EA.sim Model ANOVA

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Block	2222.22	1	2222.22			
Model	19270.83	2	9635.42	2.78	0.0962	significant
A-Elevator	*4218.75*	*1*	*4218.75*	*1.22*	*0.2884*	
B-Aileron	*15052.08*	*1*	*15052.08*	*4.34*	*0.0559*	
Residual	48506.94	14	3464.78			
Cor Total	70000.00	17				

The Half Normal plot for the EA.sim is shown in Figure 17. The plot shows only the main effects selected for inclusion in the EA.sim model. The plot shows a desirable highly linear relation for the error estimates indicating there are no departures from a normal distribution. Using the estimated parameters for the regression model no transformations are required for the EA.sim model.

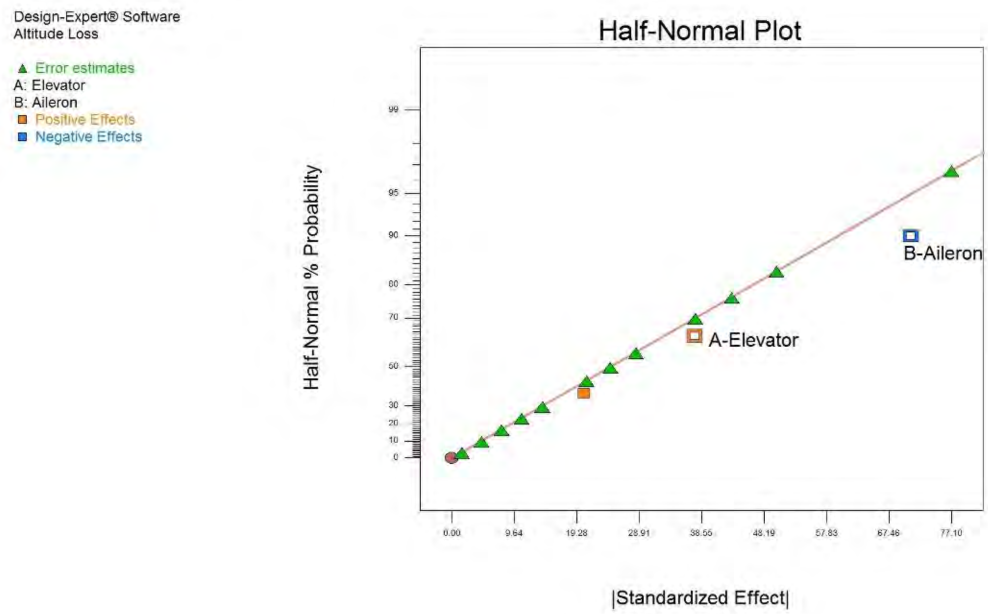


Figure 17: EA.sim Model Half-Normal Plot

Checking the EA.sim model assumptions a review of the Normal Plot of Residuals in Figure 18 is performed. The plot is used to check the assumption that the error distribution is normal. The plot should resemble a straight line where more emphasis is place on central values rather than extreme values. The plot shown in Figure 18 shows a high structure of linearity for all values. Some variation is seen as points straddle a linear estimate. However, all of the points show a high degree of linearity.

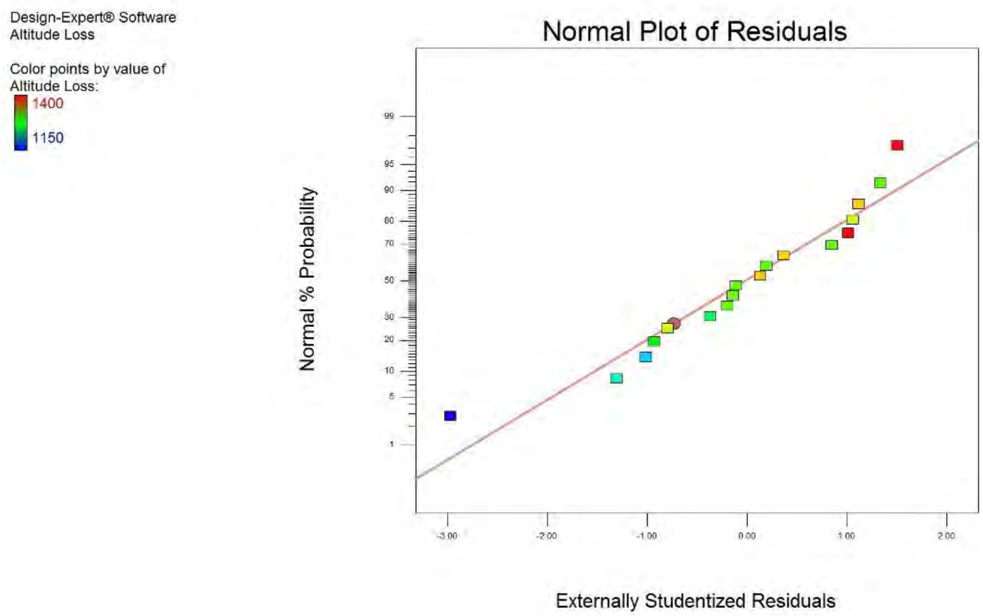


Figure 18: EA.sim Model Normal Plot of Residuals

A review of for non-constant variance is shown in the Residual Plots and Summary of Residual table in Appendix D. A quick review of the residual table shows that all residuals are acceptable except for point for run 11 for the DFFITS residual. This point is (100, 0, 100) which is the lowest lost altitude and leads us to believe this point is highly influential.

Results

The final equation for the EA.sim model is shown in Equation 2. Using this equation, a contour plot to graphically show response of the EA.sim model can be produced.

Equation 2: EA.sim Model Equation (Actual Factors)

Final Equation in Terms of Actual Factors:

$$
\begin{aligned}
\text{Altitude Loss} &= \\
&+1300.00000 \\
&+0.37500 \ * \text{ Elevator} \\
&-0.35417 \ * \text{ Aileron}
\end{aligned}
$$

Figure 19 represents a contour plot of Aileron vs Elevator vs Altitude Loss. As the EA.sim model is a reduced set of data from the REA.sim model the contour plot for model two is nearly identical to the contour plot for model on with 100% rudder pedal deflection. The least amount of altitude loss is predicted for (100%, -50%, 100%) which again does not correspond to the lowest actual point recorded during flight testing. With the rudder treatment removed from the model the treatment for aileron predictably becomes the most significant factor in the EA.sim model with the elevator factor again not showing significance given that the control is place in within the bounds of ±50% of the neutral position. The contour lines the contour plot are angled more vertically such that they favor significance with the aileron treatment. This plot show an even higher indifference to a -50% or 0% elevator deflection than the REA.sim model.

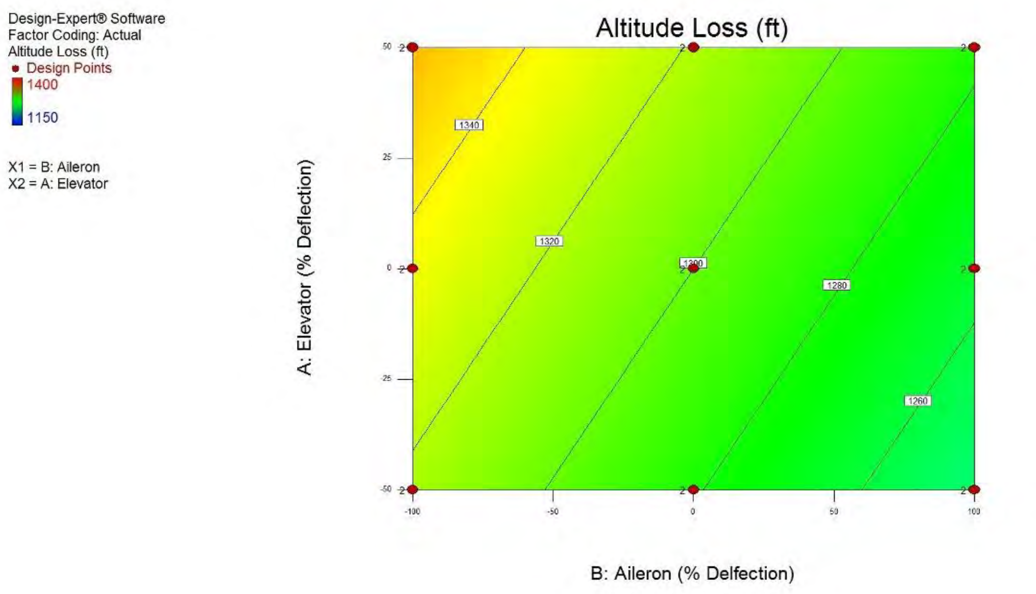


Figure 19: EA.sim Model Contour Plot; Aileron, Elevator, Altitude Loss

EA.seq Model

The EA.seq model represents spin recovery control inputs with Sequenced inputs for two treatments of Elevator, and Aileron. The EA.seq model represents a pause between the inputs of rudder first and the elevator and aileron second. The EA.seq model removes the treatment of rudder as described in the analysis of the REA.sim model. The EA.seq model will block the left and right spin directions in order to evaluate this effect on spin recovery. Note that Run 8 which is defined as (100%, -50%, -100%) was removed from the model as in early analysis, this point was found to be an outliner that was largely influential. This influenced caused the build-up in residual errors that made the model insignificant. The residual figures and summary table of residuals shows for this analysis in Appendix F.

Design

The EA.seq model is a 2 factorial experiment with factors of elevator, and aileron. The EA.seq model will use numeric factors of A and B to represent elevator and aileron respectively. As in the REA.sim and EA.sim models, the elevator factor will consist of 3 treatment levels. The factor will contain coded variables of -1, 0, 1 and will be defined in actual terms as pro-spin elevator, neutral elevator, and anti-spin elevator respectively. Full elevator inputs will not be used for the reasons described in previously in the methodology section. Pro-spin elevator will be defined in actual terms as -50% deflection of the control stick aft, neutral elevator defined as 0% deflection, and anti-spin elevator defined as 50% deflection of the control stick forward. The aileron factor will again consist of 3 treatment levels. The factor will contain coded variables of -1, 0, 1 and be define in actual terms as full pro-spin aileron, neutral aileron, and full anti-spin aileron respectively. Full pro-spin Aileron will be defined in actual terms as -100% deflection of the control stick into the spin, neutral aileron defined as 0% deflection, and anti-spin aileron defined as 100% deflection out of the spin. The response variable will be defined in actual terms as the altitude loss in feet during the spin and recovery. These details are highlighted in Table 15. The EA.seq model contains both left and right spin data which is broken into two blocks with no replicates. Block 1 contains a full factorial design for right hand spins while block 2 contains a full factorial design for left hand spins. The design of the EA.seq model is shown in Table 15. [21] [25] [23] [26]

Table 15: EA.seq Model Design and Test Results

Block	Run	Factor 1 A:Elevator % Deflection	Factor 2 B:Aileron % Delfection	Response 1 Altitude Loss ft
Right Spins	1	0	0	1400
Right Spins	2	0	100	1325
Right Spins	3	0	-100	1325
Right Spins	4	50	0	1350
Right Spins	5	-50	0	1275
Right Spins	6	50	100	1200
Right Spins	7	50	-100	1500
~~Right Spins~~	~~{8}~~	~~-50~~	~~-100~~	~~1600~~
Right Spins	9	-50	100	1300
Left Spins	10	0	0	1500
Left Spins	11	0	100	1500
Left Spins	12	0	-100	1500
Left Spins	13	50	0	1500
Left Spins	14	-50	0	1200
Left Spins	15	50	100	1400
Left Spins	16	50	-100	1400
Left Spins	17	-50	-100	1300
Left Spins	18	-50	100	1275

A summary of the EA.seq model design is shown in Table 16. Statistics are shown for the entire data set of actual responses including both blocks for right and left hand spins. The minimum and maximum responses are 1200ft and 1500ft respectively with a Mean of 1368ft. The standard deviation for the entire data set is 105ft. Note in the table, only main effects for the EA.seq model are chosen with no transformations.

Table 16: EA.seq Model Data Statistics (Actual)

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Elevator	% Deflection	Numeric	Continuous	-50	50	-1.000=-50	1.000=50	0	42.0084
B	Aileron	% Delfection	Numeric	Continuous	-100	100	-1.000=-100	1.000=100	0	84.0168

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Altitude Loss	ft	17	Factorial	1200	1500	1367.65	105.24	1.25	None	Main effects

Figure 20 displays the actual data points for the EA.seq model. Actual data points are graphed for elevator control stick deflection verses altitude loss. The data spread for the three elevator treatments (-50%, 0%, and 50% deflection of the control stick) overlap with one another. A calculation of the three averages for altitude loss, 1325ft, 1425ft, and 1391ft respectively. This result reveals that -50% control stick deflections or pro-spin elevator provides the least altitude loss for spin recovery. The largest difference between these averages is 100ft. It is likely this factor will be a contributor to the EA.seq model. It should be noted that the total change in elevator stick deflection is only half of the control range. The methodology section explain the need to limit the authority of this factor in order to reasonably ensure spin recovery. Additionally, within this graph the variation within the data blocks for right and left spins can be seen. Right spin runs are colored in black while left spin runs are colored in red. Noteworthy is the largest deviation for elevator positions occurs at the neutral position which is produces the lowest average altitudes.

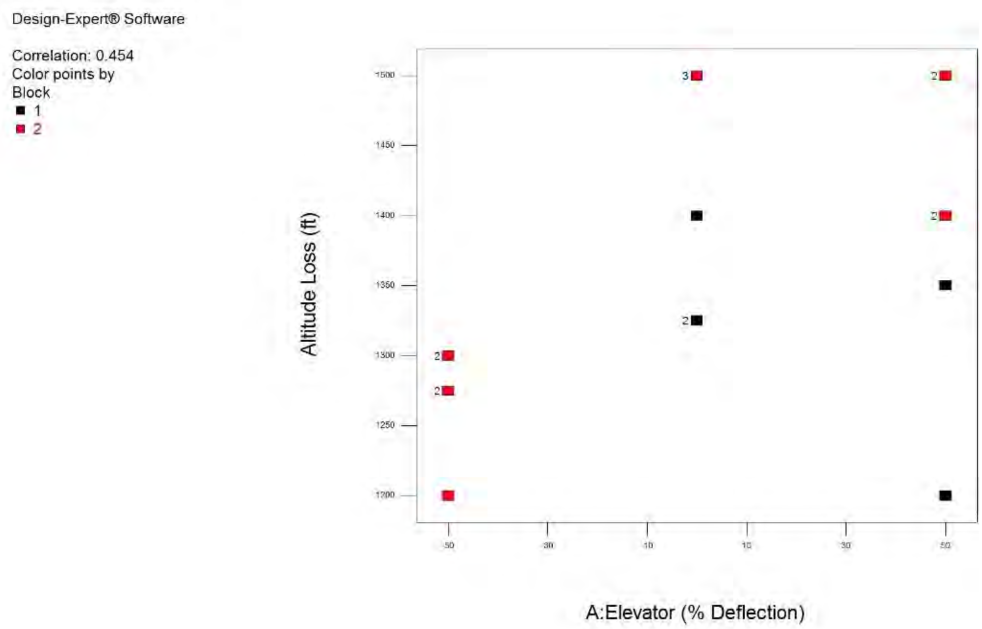


Figure 20: EA.seq Model: Elevator vs. Altitude Loss (Actual)

Figure 21 displays the data points for the EA.seq model. The data points are graphed for aileron control stick deflection verses altitude loss. Note that the number beside points represent multiple points that overlap each other at that response. The data spread for the three aileron treatments (-100%, 0%, and 100% deflection of the control stick) overlap with one another. A calculation of the three averages for altitude loss are, 1438ft, 1371ft, and 1333ft respectively. These results reveals that 100% control stick deflection or full anti-spin aileron provides the least altitude loss for spin recovery. The largest different between these averages is 105ft. It is likely this factor will be a contributor to the EA.seq model. Additionally, within this graph the variation within the data blocks for right and left spins can be seen. Right spin runs are colored in black while left spin runs are colored in red.

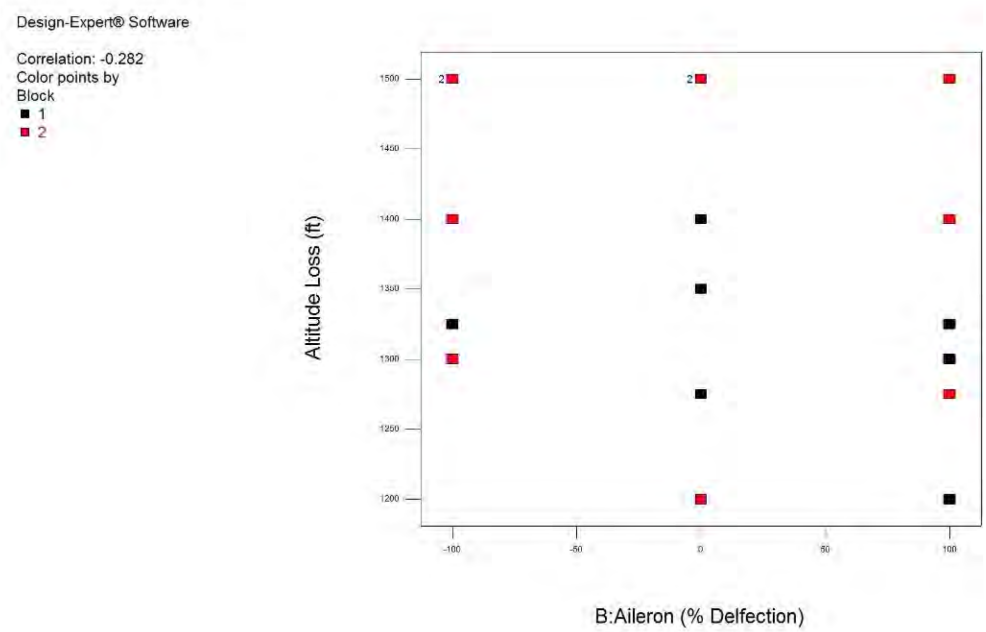


Figure 21: EA.seq Model: Aileron vs. Altitude Loss (Actual)

Factor Selection and Significance

The ANOVA for the EA.seq Model is shown in Table 17. Using $\alpha = 0.1$ the calculated critical value of the F statistic is $F_{0.10,2,13} = 2.76$. The F statistic for the EA.seq model provided in the ANOVA is 2.82 and greater than the critical value. Applying this F test, the null hypothesis can be rejected and the conclusion that the EA.seq model is significant is made. Analyzing the first treatment in the experiment, A-Elevator, the critical value of $F_{0.1,1,13} = 3.14$ is calculated. The F statistic for the elevator treatment provided in the ANOVA is 4.27 and greater than the critical value. Therefore, the conclusion is made that the elevator treatment is significant for the EA.seq model. Moving onto the second treatment in the model, B-Aileron, the critical value of the F statistic is repeated as $F_{0.1,1,13} = 3.14$. The F statistic for the aileron treatment provided in the ANOVA is 0.91 and less than the critical value. Therefore, the conclusion that the aileron treatment is not significant is made for the EA.seq model. [25]

The ANOVA analysis provides the EA.seq model selection including the main effects of A-Elevator and B-Aileron are significant. The A-Elevator term is demonstrated as the only significant term. The B-Aileron provides a near significant influence over the model; however, is dominated by the A-Elevator term. [25]

Table 17: EA.seq Model ANOVA

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Block	16728.45	1	16728.45			
Model	48585.74	2	24292.87	2.82	0.0959	significant
A-Elevator	*36709.84*	*1*	*36709.84*	*4.27*	*0.0594*	
B-Aileron	*7844.90*	*1*	*7844.90*	*0.91*	*0.3571*	
Residual	1.119E+005	13	8607.05			
Cor Total	1.772E+005	16				

The Half Normal plot for this experiment is shown in Figure 22. The plot shows only the main effects selected for inclusion in the EA.seq model. The plot shows a desirable highly linear relation for the error estimates indicating there are no departures from a normal distribution. Using the estimated parameters no transformations are required in the model.

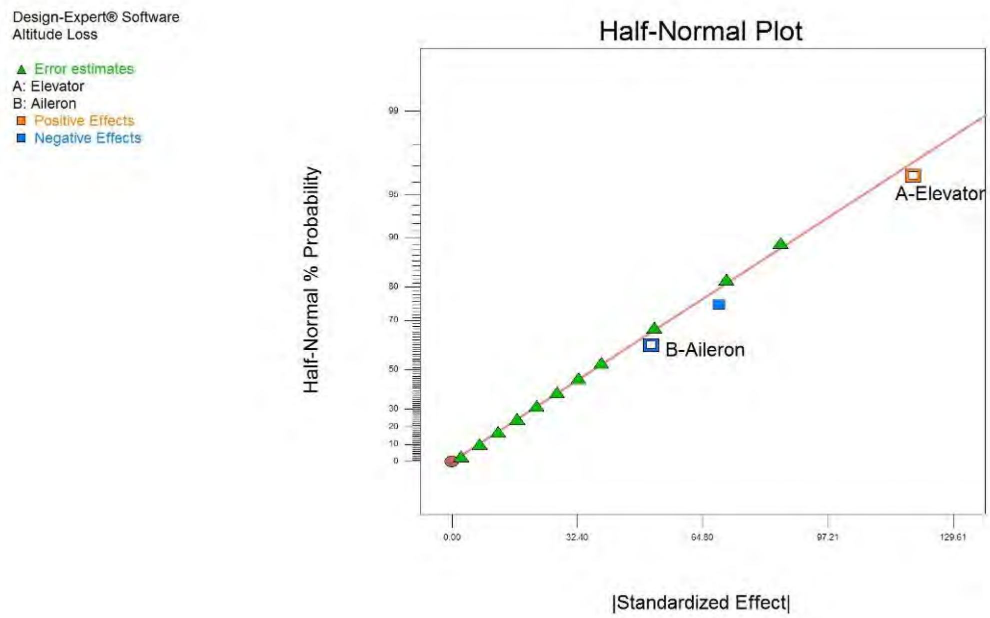


Figure 22: EA.seq Model Half-Normal Plot

Checking the EA.seq model assumptions a review the Normal Plot of Residuals in Figure 23 is performed. The plot is used to check the assumption that the error distribution is normal. The plot should resemble a straight line where more emphasis is place on central values rather than extreme values. The plot shows a high structure of linearity for all values. Some variation is seen as points straddle a linear estimate. However, all of the points show a high degree of linearity.

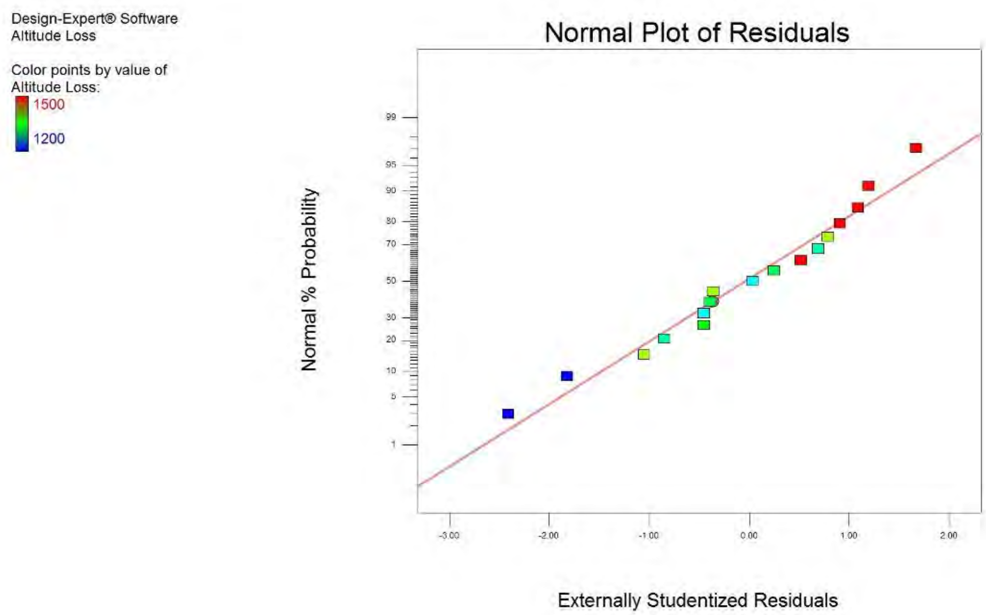


Figure 23: EA.seq Model Normal Plot of Residuals

A review of for non-constant variance is shown in the Residual Plots and Summary of Residual table in Appendix D. A quick review of the residual table shows that all residuals are acceptable except for point for run 6 for the DFFITS residual. This point is (100, 50, 100) which is the lowest lost altitude and leads us to believe this point is highly influential.

Results

The final equation for the EA.seq model is shown in Equation 3. Using this equation, a contour plot to graphically show response of the EA.seq model can be produced.

Equation 3: EA.seq Model Equation (Actual Factors)

Final Equation in Terms of Actual Factors:

$$
\begin{aligned}
\text{Altitude Loss} &= \\
&+1363.83547 \\
&+1.16827 \ * \text{Elevator} \\
&-0.27003 \ * \text{Aileron}
\end{aligned}
$$

Figure 24 represents a contour plot of Aileron vs. Elevator vs. Altitude Loss. The least amount of altitude loss is predicted for (100%, -50%, 100%) which again does not correspond to the lowest actual point recorded in flight test. With the rudder treatment removed from the model the treatment for elevator becomes the most significant factor in the model with the aileron factor not showing significance. This is a variance from model two. When comparing the contour plots for model two and three a great deal of similarity can be seen with the most dramatic difference being the angle of the contour lines. The contour lines in model three are angled more horizontal such that they favor significance with the elevator treatment.

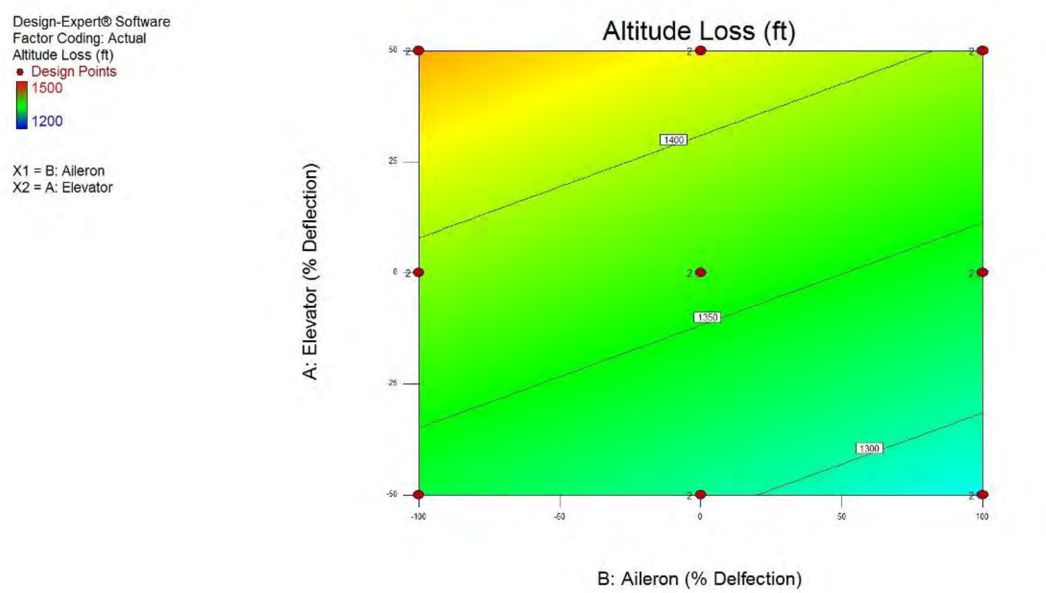


Figure 24: EA.seq Model Contour Plot; Aileron, Elevator, Altitude Loss

Summary

A summary of the models investigated shows that in the control inputs, the least amount of altitude loss during spin recovery is 100% rudder input opposing the direction of spin rotation (right rudder pedal for left to right spinning from pilot over the nose perspective), -50% elevator deflection in the pro-spin direction (aft stick for upright spins), and 100% aileron deflection in the anti-spin direction (right stick for left to right spinning from pilot over the nose perspective). This varies dramatically from the selected popular spin recovery methods for several reasons, highlighted in the analysis and results section. The most pointed reason discussed, is the models goals where to seek the least amount of altitude loss. This is the determined goal regardless of pilot feedback and workload, aircraft handling, and risk of damage to the aircraft. The Manufacturers Method, in terms of control inputs, most closely matches the models prediction for least amount of altitude loss. The significant variation is the addition of anti-spin aileron. The manufacturer is justified in not including this as part of the recovery sequence as it would produce asymmetric loading of the aircraft and likely to cause secondary stalling if the pull to level flight were too aggressive.

The sequenced approached to control inputs was found to perform significantly worse than simultaneous control inputs in regards to producing the least amount of altitude loss. The PARE method of spin recovery performed far worse than the manufacturer's recommended method in actual results and modeled results. The Beggs-Mueller method which was not modeled additionally performed worse than the manufacturer's recommended method in actual test results. The actual results for these popular methods are shown in Table 18.

Table 18: Popular Spin Recovery Method Results

	PARE	Manufacturer	Beggs -Mueller
Right Spin	1400 ft	1300 ft	1350 ft
Left Spin	1500 ft	1300 ft	1525 ft

V. Conclusions and Recommendations

Chapter Overview

The purpose of this chapter is to present answers to investigative questions, solidify conclusions, and layout recommendations from this evaluation of control inputs on the spin recovery of the 8KCAB Super Decathlon.

Investigative Questions Answered

1. *What control inputs are significant factors in recovery from a spin?*

Reviewing the results for all three models the significance of each input treatment varies depending on the bounds of the selected input and the order in which those inputs are chosen. All of the models chosen have the elevator bounded to inputs of ±50% of travel from the neutral position. This was done as the information provided from the presented research material concludes that inputs of -100% deflections of the elevator create an upright spin and any combination of controls that include -100% deflections only slow or accelerate a the spin. For the control inputs with 100% deflection of the elevator, the presented research material concludes that this will create an inverted spin. Additionally, during an upright spin, control combinations that include 100% deflections will cross-over the spin from the upright to inverted position and vice versa. The conclusion that elevator position between -50% and 50% is significant can be made without analyzing the models presented here. Examining the bounds of the rudder, a determination that -100 rudder defection can excluded from the regression. This input is combined with 100% travel of the elevator in order to create and upright spin. Rudder pedal controls from 0% to 100% rudder deflection are the only acceptable choices and the rudder is a significant factor under this boundary condition. Once this is established the regression model factors can be explored for significance.

The REA.sim model explores the conditions where inputs are made simultaneously. Under this selected condition the only significant input is rudder. This determination becomes clear when the test runs are reviewed. It can be seen that all the control inputs combinations that include 100% rudder pedal input were recoverable, while 4 test runs that included 0% rudder were unrecoverable. The REA.sim model remains significant when including all of the treatments for control inputs for rudder, elevator, and aileron; however, the model can be reduced to rudder alone.

Rudder is the most significant treatment factor in the EA.sim model. This model includes a bounded condition that only 100% rudder pedal is used in the recovery. This condition reduces the possible control inputs to elevator and aileron. Under this selected condition the only significant input is aileron. This determination is less clear and requires some further examination. After a spin breaks, the orientation of the aircraft is not in a position of straight and level flight. Generally the aircraft is in a nose down attitude in a spiraling turn into the spin direction. Proper recovery requires the pilot to roll the aircraft to wings level and pull to a level flight attitude. Remember that under our definition the total altitude loss is determined at the level flight attitude. The conclusion that by initiating the roll during spin recovery, an allowance is made for less time spent performing a roll to wings level during the final recovery sequence. It should noted that performing this combined input produces a high degree of asymmetric loading of the aircraft. This type of loading is the reason the final recovery is commonly split into two movements, roll to wings level and pull to a level flight attitude. The asymmetric loading build up during the pull to a level flight attitude is more stressing on the aircraft then when performed at slower airspeeds during initial spin break. However, the loading condition should be noted when referring to individual types of aircraft as the type of maneuver could permanently damage the aircraft structure if not properly rated for these types of maneuvers.

Exploring the EA.seq model, sequencing the control inputs is introduced. The EA.seq represents 100% rudder pedal input with a pause between inputs for a sequence of 100% rudder, elevator, and aileron. Recovery was bounded to 100% rudder pedal deflection. This condition reduces the possible control inputs to elevator and aileron. Under these select conditions the only significant input is elevator. This is a departure from the control inputs found to be significant in the EA.sim model, some further examination is required. Remembering that rudder is input prior to aileron and that rudder and aileron are coupled inputs, it can determined that the delayed input of aileron is less effective in the control scheme do to early input of the rudder. Additionally, for most test runs the spin break was occurring prior to or at the input of the aileron as the early effects of rudder and elevator provided enough control authority to break the spin without aileron input. This role reversal of significance in factors from EA.sim and EA.seq models highlights the damaging effects of delaying any control inputs on the timeliness of the recovery resulting in significantly lower recovery altitudes.

2. *What control inputs produce the least amount of altitude loss?*

The control input that provides the least amount of altitude loss is a simultaneous input of 100% deflection of rudder, -50% to 0% Elevator, and 100% aileron. This can be seen in the contour plot in Figure 14. This is a departure from all known popular spin recovery methods. As this is a departure from common wisdom, an explanation is warranted.

100% rudder input is consistent will all popular spin recovery methods and comes as no surprise. It is also the most significant factor in this research.

Moving on to dissecting the elevator movement, note that the bounds of the research were defined as ±50% of travel from the neutral position. After a spin breaks the orientation of the aircraft is in a nose down attitude. The more nose down the attitude of the aircraft the faster the aircraft will accelerate towards the ground causing higher recovery speeds and lower recovery altitudes. It would lead us to conclude that the position of the elevator that would break the stall while respecting the need to recover at the highest possible altitude would be somewhere between -50% and 0% elevator deflection. While all popular spin recovery methods recommend neutral elevator, it stands to reason that a more effective position for optimizing recovery altitude is possible. This optimization would have to consider the aircrafts stall breaking attitude. Note that neutral elevator produces a highly desirable clean stall break while -50% elevator deflections lends itself to secondary stalling and would not be desirable for manufacturers recommendations. The workload is high with undesirable handling qualities. Additionally, actual results for 100%, 0, 100% produced lower altitude losses than the actual results for 100%, -50%, 100%.

The use of 100% aileron input is likely the most controversial outcome of the spin recovery model. This is due to the fact that the combined input produces a high degree of asymmetric loading of the aircraft, this loading condition would never be accepted by a manufacturer as a recommended recovery method. The actual data shows that the treatment for aileron does not always produce the least amount of altitude loss on a point by point basis and is effected by the spin direction. Moreover, combining elevator and aileron inputs that are not neutral or full stick deflection produce a very high workload and can cause the pilot to start dropping tasks in order to perform the maneuver. With a complete review of the conclusions, one fact cannot be ignored. Initiating the roll during the spin recovery produces less time spent performing the final recovery sequence of rolling to wings level and the pulling to a level flight attitude.

Simultaneous inputs produce the least amount of altitude loss. This can be verified in a comparison of the mean values for the EA.sim and EA.seq models, seen in Table 19 and Table 20 respectively. The mean actual altitude loss for simultaneous inputs of the EA.sim model is 1300ft. This is 83ft less than the mean altitude loss for sequenced inputs of the EA.seq model. A review of the actual individual points shows that a simultaneous approach to control inputs produces a lower altitude loss for spin recovery for all points but three. Those three points vary by less than 50ft which is smaller than the standard deviation of both models. The modeled effect of this can be seen by comparing the contour plots for EA.sim and EA.seq models shown in Figure 19 and Figure 24 respectively. Figure 19 for the EA.sim model with simultaneous inputs displays contour ranges from 1260- to 1340+. Figure 24 for the EA.seq model with sequenced inputs displays contour ranges from 1300- to 1400+.

Table 19: EA.sim Model Fit Statistics

Std. Dev.	58.86	R-Squared	0.2843
Mean	1300.00	Adj R-Squared	0.1821
C.V. %	4.53	Pred R-Square	-0.2068
PRESS	81792.92	Adeq Precisior	4.705

Table 20: EA.seq Model Fit Statistics

Std. Dev.	112.54	R-Squared	0.2056
Mean	1380.56	Adj R-Squared	0.0921
C.V. %	8.15	Pred R-Square	-0.3670
PRESS	3.051E+005	Adeq Precisior	3.848

Conclusions of Research

In conclusion, the effects of pilot control inputs on recovery from a spin can be modeled using regression with statistically significant results. The factors that were deemed significant in this analysis of historical data were: rudder, elevator and aileron. A regression model can be used to determine the control inputs to provide the least amount of average altitude drop when recovering from a spin. The concluded method differs from both the manufacturer's recommended method and other popular methods; however, the variation in this model does not account for any factors other than the least amount of altitude loss and control inputs. Recovery under all conditions, specific loading conditions, pilot workload, and pilot feedback were not of consideration. The developed model does provide specific handling quality characteristics that can be applied in pilot instruction for stall and spin awareness training.

Significance of Research

The research presented here is most significant to general aviation pilots with limited exposure to spins and variations of spin recovery methods. Additionally, aerobatic pilots that routinely spin their aircraft into fully developed spins will benefit from this research. The aviation community is a highly diverse community with broad ranges of experience level. While there exists many within the community that focus on expanding the knowledge of every pilot, some areas have become taboo and avoided all but the most experienced pilots and researchers. This leads to much misinformation bordering on myth and legend. The research here is focused on scientific methodology and factual presentation for evaluation of control inputs on spin recovery qualities. While this research is limited to the 8KCAB super decathlon type aircraft, the aircraft is a good representation of the general aviation community. [6]

Recommendations for Future Research

The future potential research of the historical data alone is very broad. The flight test program developed by the author of this paper provided more available information than which could be presented in this thesis. As the author is also partial owner of an aerobatic airplane which is routinely used for aerobatic flight instruction and emergency maneuver training, future research will focus on training and demonstration material to student pilots, general aviation pilots, and aerobatic pilots. Areas of particular interest are: data collected for Bedford workload and Cooper-Harper rating; developing finer treatment levels for rudder, elevator, and aileron; and further expansion of the developed limited bounds of both rudder and elevator. While further development of the topic with more representative general aviation aircraft would be desired, more research must be conducted in order to safely test on aircraft with limited operating envelopes. This testing would require a more significant financial contribution. [2] [8]

Summary

The research objective of this study was to investigate the effects of pilot control inputs on the spin recovery of an 8KCAB Super Decathlon using quantitative methods.

This investigation was performed by using historical data from actual flight testing to develop a regression model of the control inputs. The specific pilot inputs studied were control inputs required in order to recover the aircraft to normal flight. The modeled treatments include rudder, elevator, and aileron. The developed model was statistically significant and provides an understanding of the controls involved in spin recovery. The intent of this research was not to provide specific procedures for recovery of an aircraft from a spin; however, to provide a basic understanding of the handling qualities observed during recovery from a spinning aircraft. This goal was accomplished.

Appendix A: Flight Test Plan

Flight Test Evaluation
of
Spin Recovery Handling Qualities

Evaluation of the 8KCAB Super Decathlon

Version 4.0 Dated 29 MAY 2011

Authored by
Courtney Allen

SIGNATURE PAGE

Flight Test Evaluation of Spin Recovery Handling Qualities
Evaluation of the 8KCAB Super Decathlon

Flight Test Engineer ________________________________

Flying Qualities ________________________________

Performance ________________________________

Human Factors ________________________________

Test Safety ________________________________

Project Pilot ________________________________

Background

This flight test program will be flown in support of Mr. Courtney Allen's Master's thesis at the Air Force Institute of Technology (AFIT). All test points to be flown are considered ride along to aerobatic practice sessions already being flown by Mr. Courtney Allen and Mr. Chris Olmsted. These practice sessions are being flown as preparation for competition aerobatics with the International Aerobatics Club (IAC). All flight activities are performed within all Federal Aviation Administration regulations. In addition, all CP Aviation's procedures and practices for safe spin training will be followed. The spin practice portions of the aerobatic sessions will be flown to include this flight test program.

The Idea for Mr. Courtney Allen's Master's thesis spawned from his recent flight training at CP Aviation. CP Aviation is home to Master Flight Instructor Rich Stowell. Mr. Rich Stowell developed the (Emergency Maneuver Training) EMT program in order to provide a type of training that was lacking within the general aviation community. Myths about spins have been promoted and wide spread throughout the aviation community. Even the fathers of human flight, the Wright Brothers, have done their share of promoting myths of the stall/spin. In 1991 the Federal Aviation Administration changed the Federal Aviation Regulations (FAR) regarding actual spin training in an airplane for recreational, private, and commercial pilots. FAR 61.97, 61.105 and FAR 61.125 currently require that pilots only have knowledge of "stall awareness, spin entry, spins, and recovery techniques." The effect of these changes in the FARs has only provided a vehicle for the myths surrounding spins to grow and inspire fear within the pilot community.

Mr. Courtney Allen would like to break out of the veil of ignorance and explore the handling qualities of the 8KCAB Super Decathlon during spin recovery. The 8KCAB Super Decathlon is the primary aircraft of choice for beginner aerobatics training. The knowledge gained by performing this flight test program will benefit Mr. Courtney Allen while performing competition spins in the 8KCAB Super Decathlon. Competition spins are an example of extreme precision, flown during aerobatic maneuvers. At the most basic level of competition, the pilot is required to enter and exit the spin at given headings and number of turns. At the highest level of competition, the pilot must manipulate nearly every aspect of the spin including roll rate, yaw rate, and pitch attitude.

Purpose of the Tests

The purpose of these tests is to investigate the handling qualities of an 8KCAB Super Decathlon aircraft during the recovery phase of a spin. Specific handling qualities to be researched are the control inputs required in order to recover the aircraft to normal flight. The tests will document the pilots control inputs upon initiation of recovery controls in order to develop a model of spin recovery handling qualities. The model will use control inputs as a variables in order to predict the most preferred spin recovery technique for the 8KCAB Super Decathlon. Using the model, a comparison will be made of several spin recovery techniques currently promoted within the aviation community.

Scope of Tests

The scope of these tests will be limited to the pilot's control inputs and how they affect the recovery of the spin. The primary aircraft controls of interest for the 8KCAB aircraft are throttle, rudder, elevator, and aileron position. All other variables affecting the aircrafts recovery from a spin will be held constant or constrained to minimize their effects. Primary variables of interest to be held constant or constrained are altitude, Center of Gravity (CG), Gross Weight (GW) in addition to the overall configuration of the aircraft. While all of these variables are likely to change the handling qualities of the aircraft, due to limited resources a full evaluation under all conditions is not feasible.

The response of each spin recovery will be measured by both quantitative and qualitative data. Qualitatively, the test pilot will rate the recovery controls based on the Cooper-Harper rating scale. The pilot will be asked to comment on the response of the aircraft though out the spin recovery sequence. In addition the test pilot will rate the workload of the control inputs based on the Bedford workload scale. The pilot will be asked to comment on the individual taskings that were given though out the spin recovery sequence.

Quantitatively there are several variables to consider. The total loss of altitude during the spin is an immediate concern to a pilot entering an unintentional spin while flying the a base to final turn. This insidious maneuver is where the majority of spin incidents occur. Immediate corrective action from the pilot will recover the aircraft prior to impact. Continued uncoordinated flight inputs from the pilot well result in impact with the ground. The maximum indicated air speed at the exit of the recovery is also a valuable piece of knowledge to all pilots. A pilot maneuvering an aircraft at its maximum control deflection never wants to exceed the maneuvering speed of the aircraft. For non-aerobatic aircraft this limit is extremely important to the structural integrity of the aircraft. A count of the number of turns required to stop the rotation of the spin is a useful tool to the aerobatic pilot. In addition, a non-aerobatic pilot may prefer a recovery technique that provides the least number of turns or the quickest aircraft response to control inputs. In addition the vertical velocity and spin rate are key characteristics of the spin mode and will be measured for comparison of effects the controls have on manipulating the spin characteristics.

Tests and Test Conditions

Each test flown under this program is designed to provide specific data in order to evaluate the handling qualities of an 8KCAB Super Decathlon aircraft during the recovery phase of a spin. The scope of the testing has been limited to the primary aircraft controls: throttle, rudder, elevator, and aileron. The measured response of the aircraft will be altitude loss, number turns to recovery, exit speed, vertical velocity and spin rate. The foundation of the testing will be performed in order to develop and validate a spin recovery model. The spin recovery model will be developed by Mr. Courtney Allen in order to investigate and predict the response of the aircraft to various pilot inputs for throttle, rudder, elevator, and aileron. Using the predictions from the model, several validation tests will be performed using several types of spin recovery techniques currently promoted within the aviation community.

Model Development Testing

The spin recovery model will be based on a design of experiments of approach the application of recovery controls. A series of spins will be flown using combinations of control inputs while the response of the aircraft is measured. The combinations of control inputs will be used in order to develop a recovery model.

The first control variable is throttle position. This variable will be defined as 0 for a throttle position that is closed or min power (anti-spin) and defined as 1 for open or full power (pro-spin). Due to previous spin research we eliminate the control variable option for 1 or open throttle position from this testing. All available research indicates that for all aircraft, the spin mode becomes aggravated at higher throttle settings. Specifically, the 8KCAB is not recoverable at full throttle settings. In addition, all research of published spin recovery techniques requires the pilot to move the throttle to the closed position. All testing will be performed for minimum throttle at 0 or the closed position.

The second control variable is rudder. The rudder variable will be defined based on the spin's direction of rotation in yaw. For the purpose of using references known to the pilot, the position of the rudder pedal will be use to indicate rudder position. During a spin the rudder position for pro-spin depends on the direction of rotation in yaw of the aircraft. The anti-spin position is opposite the direction of yaw. The pro-spin position is in the direction of yaw. The definitions for rudder positions will be: 0 for rudder pedals to the neutral position, 1 for full rudder pedal opposite the direction of yaw (anti-spin), and -1 for full rudder pedal in the direction of yaw (pro-spin). Due to previous spin research we can rule out the -1 or full rudder pedal in the direction of yaw (pro-spin). All available research indicates that for all aircraft, the spin becomes aggravated with rudder pedal inputs in the direction of yaw (pro-spin). Free release of the rudder pedals will be defined as F.

The third control variable is the elevator. Due to the aerobatic qualities of the 8KCAB, the aircraft has a large amount of elevator authority. While this is a highly desired feature for this test, it does complicate the definition for the control. For the purpose of using references known to the pilot, pitch stick will be use to indicate elevator position. During a spin the elevator position for pro-spin depends on the orientation of the aircraft in either upright or inverted positions. In the upright orientation, full aft pitch stick is the pro-spin position. In the inverted orientation, full forward pitch is the pro-spin position. More complexity is added by the fact that the Super Decathlon has enough elevator control authority to cross-over an upright spin to an inverted spin by reversing stick positions. Therefore, pitch stick inputs for forward and aft positions will be reduced to half inputs. The definitions for pitch stick positions will be: 0 for stick to the neutral position, 1 for ½ aft pitch stick position (pro-spin in an upright spin), and -1 for ½ forward pitch stick position (anti-spin in an upright spin). Free release of the stick will be defined as F.

The fourth control variable is aileron. The aileron variable will be defined based on the spin's direction of roll. For the purpose of using references known to the pilot, roll stick will be used to indicate aileron position. The definitions for aileron positions will be: 0 for neutral stick, 1 for roll stick opposite the direction of roll, and -1 for full roll stick in the direction of roll. While the three previous control inputs contain pro-spin and anti-spin inputs, research is indefinite for which inputs of aileron are considered pro and anti spin. In general, the aileron to neutral is considered anti-spin while both roll stick inputs in and out of the spin's roll direction are considered pro-spin. Free release of the stick will be defined as F.

Using these defined control inputs a basic matrix of test points can be developed. The developed matrix in Table 3.1.1 1 highlights all possible configurations that may be tested for each handling sequence to be tested.

Table 3.1.1 1

Spin Recovery Control Inputs				
Test Point	Throttle	Rudder	Elevator	Aileron
1	0	F	F	F
2	0	0	0	0
3	0	0	0	1
4	0	0	0	-1
5	0	0	1	0
6	0	0	-1	0
7	0	0	1	1
8	0	0	1	-1
9	0	0	-1	-1
10	0	0	-1	1
11	0	1	F	F
12	0	1	0	0
13	0	1	0	1
14	0	1	0	-1
15	0	1	1	0
16	0	1	-1	0
17	0	1	1	1
18	0	1	1	-1
19	0	1	-1	-1
20	0	1	-1	1

Simultaneous Control Inputs

The first handling sequence to be tested is simultaneous control inputs at the point of recovery initiation. This sequence is the most logical sequence to obtain the desired responses due to time delay penalties incurred while the pilot is initiating the required controls. The control inputs for each test point will be applied once a fully developed spin is achieved (3 turns). The inputs to the control surfaces are to be applied in one rapid movement not to exceed 1 second for full desired input. Controls will be held in the desired position until the spin is broken and a recovery to normal flight can be made or the sequence is terminated due to safety considerations. Recovery shall be made with neutral rudder, a half stick roll to wings level, followed by a 3g pull-up to level attitude. The throttle shall remain closed for the entire recovery sequence. These points may be flown multiple times in either left or right spin directions in order to more accurately define the model.

Sequenced Control Inputs

The second handling sequence to be tested is sequencing the control inputs the point of recovery initiation. Previous research has shown the order in which the controls are applied may affect the response of the aircraft. The most prominent control inputs will be selected and have their control inputs varied.

Selection of the most prominent control inputs will be made based on statistical significance within the model. The same responses as the original model development points will be measured. Variation of the control inputs to be flown is shown in Table 3.1.1.2 1.

Spin Recovery Control Inputs	
Sequence 1	Rudder - Pitch Stick- Roll Stick
Sequence 2	Rudder - Roll Stick - Pitch
Sequence 3	Pitch Stick - Rudder - Roll Stick
Sequence 4	Pitch Stick - Roll Stick - Rudder
Sequence 5	Roll Stick - Rudder - Pitch Stick
Sequence 6	Roll Stick - Pitch Stick - Rudder
Sequence 7	Rudder - (Pitch and Roll) Stick
Sequence 8	(Pitch and Roll) Stick - Rudder

Table 3.1.1.2 1

The control inputs for each test point will be applied once a fully developed spin is achieved (3 turns). The inputs to the control surfaces are to be applied in sequence. As an example, sequence 7 will have the test pilot initiate rudder controls at the point of recovery initiation, pause a yaw reaction, and the apply stick inputs. Upon the completed sequence, controls will be held in the desired position until the spin is broken and a recovery to normal flight can be made or the sequence is terminated due to safety considerations. Recovery shall be made with neutral rudder, a half stick roll to wings level, followed by a 3g pull-up to level attitude. The throttle shall remain closed for the entire recovery sequence. These points may be flown multiple times in either left or right spin directions in order to more accurately define the model.

Only the most prominent controls will be tested, test points may be excluded if the control input is not desirable.

Model Validation Testing

Model Validation testing will be performed as a series of test to compare and contrast the results obtained in the model with various spin recovery methods and techniques found in general aviation. The Beggs-Mueller technique and the PARE technique are both popular universal spin recovery techniques, yet approach the spin from dramatically different approaches. Both the Beggs-Mueller and PARE technique spins will be flown in order to compare and contrast those spin recovery techniques with the results from the model development testing.

Test Envelope

Flight operations specified within this test plan will be in performed in accordance with Federal Aviation Regulations (FARs). Flight test maneuvers that are considered aerobatic will adhere to FAR part 91.303 Aerobatic Flight. An aerobatic maneuver is defined as “an intentional maneuver involving an abrupt change in an aircraft’s attitude, an abnormal attitude, or an abnormal acceleration, not necessary for normal flight”. Regulations regarding flight testing of experimental aircraft are not applicable to this flight test program. The aircraft that will be flown in this flight test program is a certificated aircraft flown within the manufacturers approved envelope and is considered to be a proven aircraft by the Federal Aviation Administration (FAA).

Refer to the FAA Approved Airplane Flight Manual for aircraft limitations.

The aircraft to be flown in this flight test program will be operated in accordance with the restrictions specified by the FAA Type Certificate and the FAA Approved Airplane Flight Manual. The aircraft will be restricted to the aerobatic category for all flight operations.

The following table highlights important test envelope limitations:

Table 3.2 1

Airspeed Limitations	
Normal Operating Range	54-160 CAS MPH
Never Exceed V_{NE}	200 CAS MPH
Maneuvering V_A	132 CAS MPH
Weight and Balance Limitations	
Maximum Gross Weight	1800 Lbs
CG Min/Max (at 1800 Lbs)	+13.5 to +18.5
CG Min/Max (< 1550 Lbs)	+11.5 to +18.6
Load Factor Limitations	
Aerobatic Positive	+6 g
Aerobatic Negative	-5 g
Powerplant Limitations	
Avoid Aerobatic Operation	2600-2700 RPM
Maximum	2700 RPM

Flight Clearance

The aircraft that will be flown in this flight test program is a certificated aircraft and is considered to be a proven aircraft by the Aviation Administration (FAA). No experimental type certificate or clearance will be required. The aircraft to be flown in this flight test program will be operated in accordance with the restrictions specified by the FAA Type Certificate and the FAA Approved Airplane Flight Manual. The aircraft will be restricted to the aerobatic category for all flight operations.

Test Loadings

The aircraft to be flown in this flight test program will be operated in accordance with the restrictions specified by the FAA Type Certificate and the FAA Approved Airplane Flight Manual. The aircraft will be restricted to the aerobatic category for all flight operations. Gross Weight (GW) is limited to 1800 lbs. The Center of Gravity (CG) will be limited to the region shown below in Figure 3.4.1. The Aerobatic region of the aircraft is contained inside the area enclosed by the blue lines.

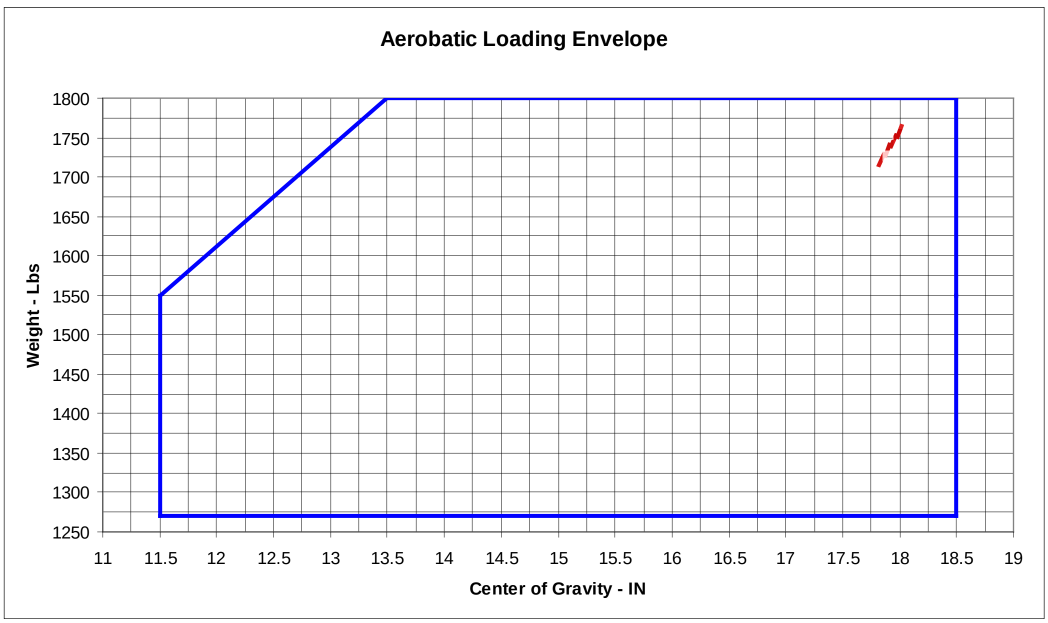


Figure 3.4 1

For test planning purposes the initial loading of the aircraft at take off with both test pilot, flight test engineer, 20 gallons of fuel and 2 lbs of instrumentation is GW is 1775 lbs and a CG of 18.08 in. The fuel burn rate with engine settings of 2500 rpm and 25 inches of manifold pressure is approximated at 12 gallons/hour. A ten minute flight is required to ferry the aircraft to and from the aerobatic box. The aircraft calculated loading of the aircraft at the start of testing is a GW of

1763 lbs and a CG of 18.02in. Changes in gross weight from the start of testing to the end of testing will be limited to 50 lbs. This limitation will be monitored based on flight time and fuel burn rate. Testing time will be limited to 0.66 hours (40 minutes). The aircraft loading at the end of testing will be a GW of 1715 lbs and a CG of 17.80. The loading curve of the aircraft during testing is highlighted in the figure 3.4.1 by a red line.

Test Configurations

The configuration of the aircraft will remain in a constant FAA approved configuration though out the test program with allowances for routine maintenance. The test pilot will remain constant for the entire flight test program and will sit in the front seat of the aircraft. The flight test engineer will remain constant for the entire flight test program and will sit in the rear seat of the aircraft. Two cameras will be placed in the aircraft during flight testing and will be mounted in the same approximate locations for all flight testing. Refer to section 3.4 for aircraft loading configuration.

Method of Tests

The requirement of this flight testing is to collect quantitative and qualitative data for handling qualities of the 8KCAB Super Decathlon aircraft during spin recovery. The variables of interest for handling qualities are the primary aircraft controls. The desired response of the aircraft during recovery from a spin is based on several factors.

Test Methods and Procedures

The first factor to consider in this test program is the pilot’s rating for handling qualities of the recovery controls. The Method for gathering this qualitative data will be the Cooper-Harper rating scale.

The Cooper-Harper rating scale is the current standard for rating aircraft flying qualities. The scale is a subjective rating scale due to a set of criteria that must be evaluated from a hierarchical decision tree. The pilot evaluation criteria are designed to lead the pilot to handling quality rating based on a ten point rating scale. The Cooper-Harper rating scale is shown in Figure 4.1 1.

Decision Tree		Aircraft Characteristics	Workload Description	Rating
Is it satisfactory without improvement?	Yes	Excellent Highly desirable	Pilot compensation not a factor for desired performance	1
		Good Negligible deficiencies	Pilot compensation not a factor for desired performance	2
		Fair - Some mildly unpleasent deficiencies	Minimal pilot compensation required for desired performance	3
	No	Minor but annoying deficiencies	Desired performance requires moderate pilot compensation	4
		Moderately objectionable but tolerable deficiencies	adequate performance requires considerable pilot compensation	5
		Very objectionable but tolerable deficiencies	Adequate performance requires extensive pilot compensation	6
Yes				
Is adequate performance attainable with a tolerable pilot workload?	No	Major deficiencies	adequate performance not attainable with maximum tolerable pilot compensation	7
		Major deficiencies	Considerable pilot compensation is required for control	8
		Major deficiencies	Intense pilot compensation is required to retain control	9
Yes				
Is it controllable?	No	Major deficiencies	Control will be lost during some portion of required operation	10

Figure 4.1 1

The second factor to consider in this test program is the pilot's workload during the application of recovery controls. The Method for gathering this qualitative data will be the Bedford workload scale.

The Bedford workload scale is the current standard for rating the pilots workload. Modified from the Cooper-Harper rating scale, the Bedford workload scale is a subjective rating scale due to a set of criteria that must be evaluated from a hierarchical decision tree. The pilot evaluation criteria are designed to lead the pilot to a handling quality rating based on a ten point rating scale. The Bedford workload scale is shown in Figure 4.1 2.

Decision Tree		Workload Description	Rating
Was the workload satisfactory without reduction?	Yes	Workload insignificant.	1
		Workload low.	2
		Enough spare capacity for all desirable additional tasks.	3
	No	Insufficient spare capacity for easy attention to additional tasks.	4
		Reduced spare capacity. Additional tasks cannot be given the desired amount of attention.	5
		Little spare capacity. Level of effort allows little attention to additional tasks.	6
Yes			
Was the workload tolerable for the task?	No	Very little spare capacity, but maintenance of effort in the primary task not in question.	7
		Very high workload with almost no spare capacity. Difficulty in maintaining level of effort.	8
		Extremely high workload. No spare capacity. Serious doubts as to ability to maintain level of effort.	9
Yes			
Was it possible to complete the task?	No	Task abandoned. Pilot unable to apply sufficient effort.	10

Figure 4.1 2

The third factor considered in this test program is the loss of altitude during the recovery phase of the aircraft. The method for gathering this quantitative data will be measurements taken from the aircraft's altitude indicator at starting and ending altitudes of the spin. The start altitude will be defined as the altitude at which the spin was initiated. The end altitude will be defined as lowest altitude reached during the recovery from a spin.

The fourth factor considered in this test program is the maximum velocity of the aircraft exiting the spin. The method for gathering this quantitative data will be measurements taken from the aircraft's airspeed indicator. The maximum velocity will be defined as the maximum reading of the airspeed indicator from spin initiation through recovery.

The fifth factor considered in this test program is the number of revolutions of the aircraft prior to recovery. The revolutions of the turn shall be delineated to 1/8th of a revolution and will be determined by the pilot, flight test engineer, and video playback of the spin recovery. Recovery of the spin shall be initiated upon the third turn where 0 revolutions will be indicated for the recovery.

Quantitative values for the sixth and seventh factor, vertical velocity and spin rate, will only be obtainable through video playback of the spin recovery. Vertical velocity will be measure by delta altitude as read from the aircraft's altimeter divided by the delta time as logged by the video camera. The spin rate will be measured by the delta revolutions of the aircraft divided by the delta time as logged by the video camera. The delta revolutions shall be no less than ½ of a revolution for any measurement of spin rate providing the video footage contains a land mark that is identifiable at 180 degree segments. Otherwise one full revolution is required for a spin rate measurement. Pilot's comments on the spin rate acceleration or deceleration in roll and yaw will be noted. All spins shall be flown over the visual references in order to use fixed objects as heading references. The pilot may choose any reference that he deems provides the greatest acuity (recommended road intersections). The pilot will note the spin entry heading and recovery heading.

Due to the high variability of a spin maneuver, an high order of consistency when flying this maneuver must be maintained. For this reason the procedure for flying this maneuver is as follows:

The spin will be initiated using the normal spin procedure outlined in the Pilot's Operating handbook. At the top of the aerobatic box (5000' MSL) the test pilot will enter a normal upright power off stall. While maintaining an upright straight and level flight attitude, the throttle will be retarded to idle. Aft pitch stick will be applied to maintain level flight. Rudder pedals will be used to maintain wings level. 3-5 knots prior to stall speed, a combination of full aft pitch stick and full rudder pedal in the direction of desired spin direction will be applied (spin direction is pilots choice, all spins must be performed in the same direction). The control inputs for each test point will be applied once a fully developed spin is achieved (3 turns). Controls will be held in the desired position until the spin is broken and a recovery to normal flight can be made or the sequence is terminated due to safety considerations. Recovery shall be made with a half stick roll to wings level followed by a 3g pull-up to level attitude. The throttle shall remained closed for the entire recovery sequence.

Instrumentation and Data Processing

No flight test specific instrumentation will be require for this flight test program. All measurements will be taken from aircraft flight instruments. All measurements taken will be used on a comparison basis with other readings within this test. No calibration of the flight instruments will be required beyond the Federal Aviation Administration's regulations for flight equipment. Video recordings will be taken of the airspeed indicator and altimeter flight instruments during the test point maneuvers. An additional video recording will be taken of the pilot's sight picture over the nose of the aircraft. The camera requirements for these recordings are provided in the resources section of this test plan (section 6.1.2.4). Audio overlay if the video recording is not required.

Data Analysis

Data analysis will be performed by Mr. Courtney Allen. Deliverable items will be limited to measured data specified within this test plan and edited video recordings. The deliverables will be provided to Mr. Courtney Allen for further analysis and report generation as part of his Master's thesis.

This flight test program does not have a requirement for an official report. All requests for flight test data will be addressed through Mr. Courtney Allen.

Exit Criteria

Exit of the flight test program will be based on Mr. Courtney Allen's approval.

Management

Management of this flight test program will be provided by Mr. Courtney Allen. Management responsibilities include: manage funding and resources, provide scheduling and milestone actions, and delegate personal assignments. Miscellaneous management activities, as required by flight test program, will be addressed on an as required basis.

Funding and Resource Requirement

All funding and resources required for this flight test program will be provided by Mr. Courtney Allen.

Funding

Funding of all flight test program activities will be provided by Mr. Courtney Allen. All capital investments used in this flight test program are the personal property of Mr. Courtney Allen and will be retained by him upon completion of the flight test program. All rights to intellectual property gained in the flight test program will be retained by Mr. Courtney Allen. This includes but is not limited to video taken during flight test operations.

Resources

Procurement of all resources will be provided by Mr. Courtney Allen. All capital investments used in this flight test program are the personal property of Mr. Courtney Allen and will be retained by him upon completion of the flight test program. All rights to intellectual property gained in the flight test program will be retained by Mr. Courtney Allen. This includes but is not limited to video taken during flight test operations.

Aircraft

The aircraft to be flown is a American Champion Aircraft 8KCAB Super Decathlon. The same aircraft will be flown for all if the test points under this test plan.

Airspace

This flight test program will be flown out of the Santa Paula Airport (KSZP). All flight operations will not exceed a 50 mile radius from KSZP. All maneuvers requiring aerobatic flight (spins) will be performed over non populated areas of the Santa Paula Aerobatic Box. The Santa Paula aerobatic box designated as an aerobatics area granted to CP Aviation by the Federal Aviation Administration through the Van Nuys Flight Standards District Offices (FSDO) under Federal Aviation Regulation part 91.305. The aerobatic box encloses an area contain within the blue box highlighted on the sectional shown below. The aerobatic box contains the airspace from 1500 ft MSL to 5000 ft MSL. The aerobatic box is active from sunrise to sunset during Visual Meteorological Conditions (VMC).

Figure 6.1.2.2 1

Test Pilot

The test pilot will be Mr. Chris Olmsted. Mr. Olmsted is a Certified Flight Instructor (CFI) with CP Aviation. He has been trained and authorized to teach the Emergency Maneuver Training (EMT) course developed by Rich Stowell. The course includes stall/spin training and unusual attitude recovery. In addition, Mr. Olmsted is an accomplished aerobatic pilot who has flown both competition and air show aerobatics.

Instrumentation and Data Analysis

Altitude measurements will be taken from the aircraft's altimeter. The altimeter shall be set to field elevation (MSL) prior to take off. No calibration of the pitot static system (PSS) is required beyond Federal Aviation Administration regulations.

Airspeed measurements will be taken from the aircraft's airspeed indicator (ASI). No calibration of measurement equipment (ASI) is required beyond Federal Aviation Administration regulations.

Video recording of the test activities shall be taken with two cameras. The first camera shall record the pilot's instrument panel. The camera shall provide enough definition to determine a 3 knot indicated increment from the airspeed indicator and a 50 foot increment from the altimeter. The second camera shall record the pilot's sight picture over the nose of the aircraft. The sight picture shall include the top of the cowling, the spinner, and a view of the terrain in front of the aircraft. The camera shall provide enough definition to determine physical features of the terrain in front of the aircraft. Both video shall be recorded at a rate of no less than 25 frames per second and a resolution of no less than 720p. Video recording shall be in the native format of the camera. Mounting of the camera shall be non-permanent and able to withstand +5g/-5g.

Playback and editing of video will be performed using Sony Vegas Movie Studio. Video from each test point will be edited to include a minimum of 5 seconds prior to the initiation of the spin and a minimum of 5 seconds after recovery of the aircraft to a level flight attitude. Video shall be rendered in a .WMV file format.

All flight test program records will be digitalized and stored in a dual redundant storage device. Two separate hard drives are preferred.

Safety Equipment

Federal Aviation Administration regulation part 91.307 requires that all persons on board an aircraft performing spin maneuvers wear an approved parachute manufactured under a type certificate or technical standard order. Both test pilot and flight test engineer will wear an emergency parachute complying with this regulation.

Both test pilot and flight test engineer will wear head sets recommended for aerobatic flight.

Both Test pilot and flight test engineer will have reviewed the Pilots Operating Manual and the FAA Approved Airplane Flight Manual prior to the start of testing.

Schedule and Milestones

This flight test program will be managed based on both fixed timelines and event driven milestones. Due to the flight test program's support of Mr. Courtney Allen's Master's thesis all thesis timeline requirements are strict deadlines and are to be observed as key project success criteria. The remainder of the flight test activities will be event driven and scheduled tasks will be performed on a floating timeline. The following table identifies key time driven and event driven milestones. A full fight test schedule is provided in attachment A.

Personal Assignments

Personal will be assigned on an as required basis. All assignments will be subject to the approval of Mr. Courtney Allen. The following are personal assignments that have been identified as required for the execution of this flight test program:

Test Pilot – Mr. Chris Olmsted, Flight Test Engineer – Mr. Courtney Allen

Reports

This flight test program does not have a requirement for an official report. All requests for flight test data will be addressed through Mr. Courtney Allen.

Deliverable items will be limited to raw data and edited video recordings. The deliverables will be provided to Mr. Courtney Allen for further analysis and report generation as part of his Master's thesis.

Safety Plan

All testing is part of normal flight operations currently being flown by Mr. Courtney Allen and Mr. Chris Olmsted. All flight activities are performed within all Federal Aviation Administration regulations. In addition, all CP Aviation's procedures and practices for safe spin training (Rich Stowell's Emergency Maneuver Training Program) will be followed. The safety planning presented here is not to call into question the regulations provided by the Federal Aviation Regulations for safe execution of aerobatic flight. As the test maneuvers presented within this test plan are currently being flown within all Federal Aviation Regulations with a certificated aircraft within the demonstrated aerobatic flight envelope, no test specific hazards exists.

Special Precautions

While safety planning requirements do not require planning for test unique hazards, special precautions will be taken to reduce the risk associated with aerobatic flight operations and the associated spin maneuvers. The following rules for aerobatic flight during these training/test operations will be followed:

All Federal Aviation Regulations (FARs) will be followed. Specific FAR to be highlighted is FAR Part 91.303 regarding aerobatic flight.

All CP Aviation's procedures and practices will be followed. Specific procedure to be highlighted is the use of the Santa Paula Aerobatic Box.

All aerobatic maneuvers will be flown in the Santa Paula Aerobatic Box. Refer to section 6.1.2.2 for aerobatic box description.

All occupants of the aircraft will wear an emergency parachute per FAR.

All flight maneuvers will be flown in the aerobatic loading region of the aircraft flight envelope. Refer to section 3.4 for information regarding specific loading configurations.

No test points will be considered that have not already been performed by Mr. Courtney Allen and Mr. Chris Olmsted in previous flight training.

All spins will be initiated from a normal upright spin as outlined in the manufacturer's Pilot's Operating Manual. No inverted or aggravated spins will be performed in pursuit of these test points.

A control ability check will be performed prior to any aerobatic flight to ensure control surfaces are working properly.

An aerobatic control ability check will be performed in order to ensure full stick deflection in roll, half stick deflection in pitch and full rudder deflection in yaw.

All items in the cabin shall be secured prior to all aerobatic maneuvers.

All spins will be initiated at the top of the aerobatic box (5000 ft MSL) allowing the maximum amount of time for recovery.

Normal spin recovery as demonstrated by the manufacture will be initiated prior to the sixth complete turn if no recovery from the spin is immanent using the test control inputs. Note: the aircraft has been demonstrated to the Federal Aviation Administration by the manufacturer to recover from a six turn spin. Previous training flights performed by Mr. Courtney Allen and Mr. Chris Olmsted have demonstrated safe recovery of the aircraft in excess of 6 turns using normal spin recovery procedures. These maneuvers were performed with similar aircraft loadings in multiple spin modes including upright, inverted, crossover, accelerated, and aggravated.

Normal spin recovery as demonstrated by the manufacture will be initiated prior to 2000 ft MSL regardless of where the aircraft is in the recovery phase or the number of turns that has occurred. Recovery of aircraft using normal spin recovery controls has been demonstrated at less than 500 ft from the initiation of the recovery controls. Full recovery of the aircraft is expected prior to 1500 ft MSL if initiated at 2000 ft MSL. At 2000 ft MSL a “recover recover recover” call will be made by the flight test engineer and echo by the test pilot.

Bail out will be initiated at 1500 ft MSL if no recovery is immanent. The parachutes being used are demonstrated to provide safe landings from openings lower than 500 ft AGL. At an average vertical decent rate of 2000 ft/min in a spin, the occupants will have 22.5 seconds to clear the aircraft. Demonstrated bailout times are less than 15 seconds. The “bail out” call will be made by the test pilot and echo by the flight test engineer.

A preflight briefing will be performed prior to all test flights. Preflight briefing shall include a review of all special precautions, review of all planned test points, and a review to the entire flight.

A post flight briefing will be performed after each test flight to review the flight test procedures and explore any required changes to safety planning.

High Risk Points

All of the points flown within this test program are considered low risk points. All flight activities are performed within all Federal Aviation Administration regulations. The aircraft is a certificated aerobatic airplane with demonstrated spin recovery qualities. The aircraft will be flown within the limits specified by the Manufacturer’s Pilot’s Operating Manual and the FAA Approved Airplane Flight Manual.

Checklists

Both Test pilot and flight test engineer will have reviewed the Pilots Operating Manual and the FAA Approved Airplane Flight Manual prior to the start of testing. All non test specific procedures will be address using these documents. All test specific procedures will be addressed within this test plan and the safety planning. Test Cards will be developed from this test plan for each test maneuver.

Data Management

Flight test program data will be managed by Mr. Courtney Allen. All requests for flight test data will be addressed through Mr. Courtney Allen.

All flight test program records will be digitalized and stored in a dual redundant storage device. Two separate hard drives are preferred.

Security Considerations

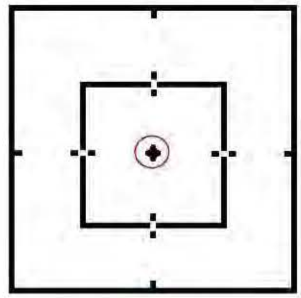
This flight test program is publicly releasable; distribution of all flight test information is unlimited.

Appendix B: Flight Test Cards

FLIGHT TEST CARD 0001

01 R	**Test Point: 0001** Neut Rud, Free Stick – R Throttle: **0** Rudder: **0** Elevator: **F** Aileron: **F**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Free – release after fully developed

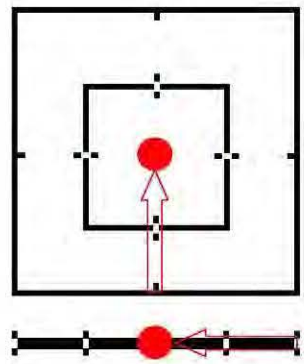
Recovery Altitude:	**3250**	Recovery Velocity:	**135**	Recovery Revolutions:	**3 1/8**
Cooper-Harper Rating:	**10**		Bedford Rating:	**2**	

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3250' MSL. Total altitude loss during maneuver was calculated to be 1750'. The Maximum indicated speed during spin recovery was 135 mph. Recorded time from stall to spin recovery was 19.2 sec. Calculated average vertical velocity during maneuver was 91 ft/sec. Aircraft continued to spin for 3.125 rev after initiation of recovery controls. Recovery time was 5.2 sec with a calculated average spin rate of 0.60 rev/sec. Comparing the 00FF methods (01R vs 01L), for left and right spins reveals that the aircraft has significantly higher spin rates for right spiraling spins. Regardless of this favoritism, recovery altitudes end in the same result. This illustrates an important reality that the min recovery altitude is determined by both recovery velocity and the shape of the flight path during spin recovery. In this study, the spin rate is the primary indicator of the flight path shape.
Pilot noted the aircraft provided no feedback during recovery. This sensation loss could be the result of not having a hand on the control stick. The mechanical connections to the control surfaces provide a conscious sense of a control feedback loop. The stall break upon recovery was noted as dirty and added a concern that positive breaking response to control inputs took longer than expected. Pilot noted that the addition of rudder input to neutral from a true free condition where all controls are released was favorable. A true free condition was not included in this study as the test maneuver could not be completed within provided airspace and test safety guidelines. Pilot noted 3 revolutions with a minimum recovery altitude of 3300. While this is only a small variation from video playback the difference does illustrate how indecisive the break occurred. Higher workload to regrab stick.

FLIGHT TEST CARD 0002

02 R	**Test Point: 0002** Neut Rud, Neut Stick – R Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Neutral, Neutral – push after fully developed

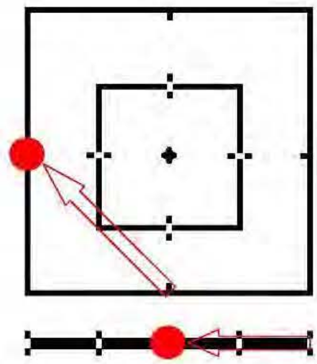
Recovery Altitude:	**3700**	Recovery Velocity:	**120**	Recovery Revolutions:	**1 1/4**
Cooper-Harper Rating:	**3**	Bedford Rating:	**1**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 80 ft/sec. Aircraft continued to spin for 1.250 rev after initiation of recovery controls. Recovery time was 3.0 sec with a calculated average spin rate of 0.42 rev/sec. Comparing the 0000 methods (02R vs 02L) for left and right spins reveals that the aircraft has similar spin rates for right spiraling spins, 0.42 vs 0.43 rev/sec. This indicates that the shape of the recovery spin was similar. Maximum recovery velocity and average vertical velocity for 02L was slightly higher which predictably summed into a lower minimum recovery altitude, 3550' vs 3700'. Surprisingly the recovery time for 02L was 0.7sec quicker than 02R indicating that higher indicated velocities aid recovery time.
Pilot noted positive control with ample feedback throughout the spin recovery. Stall break was clean and distinguishable. Pilot was able to accurately recall all three prime test parameters; recovery altitude, recovery speed, and revolutions. Workload was found to almost non-existent. Neutral position for both rudder pedal and stick was easily located. Video playback of controls showed neutral position was correct. Pilot noted that the addition of stick inputs added stability to the recovery and there was less pitching and yaw rate changes. Video playback confirmed this observation.

FLIGHT TEST CARD 0003

03 R	**Test Point: 0003** Neut Rud, Neut Elv, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Neutral, Left – push after fully developed

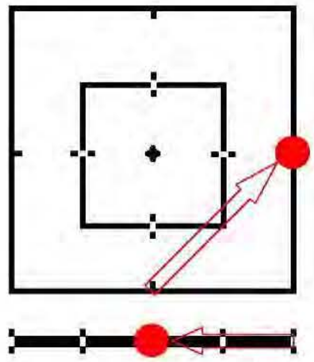
Recovery Altitude:	**3650**	Recovery Speed:	**120**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**4**	Bedford Rating:	**2**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3650' MSL. Total altitude loss during maneuver was calculated to be 1350'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 83 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 3.2 sec with a calculated average spin rate of 0.35 rev/sec. Comparing the 02R, 03R, and 04R methods reveal all three with neutral elevator, regardless of aileron input, result in similar spin recovery characteristics. Maximum indicated recovery speed was the same on all three test cases 120 mph. 0000 with neutral aileron input did produced the quickest recovery time and least altitude lost by slim margins indicating preference to neutral aileron. Predictably, the anti-spin aileron did produce a slower spin rate while pro-spin aileron produced higher spin rates. Interestingly this acceleration and deceleration had marginal effects on recovery altitude but gave preference to pro-spin aileron.
Pilot noted less control with 03R than with 02R indicating that the additional input of anti-spin aileron added some instability to the system aggravating the return to controlled flight. This can be seen in the video playback with a dirtier stall break. Pilot additionally noted a flatter spin attitude then seen in 02R. This phenomenon is noticeable in video playback as well indicating the addition of anti-spin aileron produces a slower flatter spiral.

FLIGHT TEST CARD 0004

04 R	**Test Point: 0004** Neut Rud, Neut Elv, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Neutral, Right – push after fully developed

Recovery Altitude:	**3675**	Recovery Speed:	**120**	Recovery Revolutions:	**1 1/2**
Cooper-Harper Rating:	**4**	Bedford Rating:	**2**		

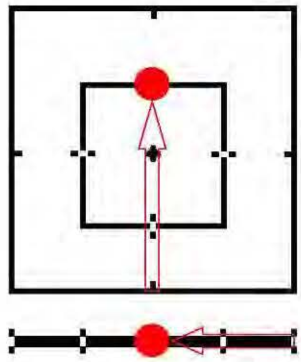
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3675' MSL. Total altitude loss during maneuver was calculated to be 1325'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 16.0 sec. Calculated average vertical velocity during maneuver was 83 ft/sec. Aircraft continued to spin for 1.500 rev after initiation of recovery controls. Recovery time was 3.1 sec with a calculated average spin rate of 0.31 rev/sec. Comparing the 02R, 03R, and 04R methods reveal all three with neutral elevator, regardless of aileron input, result in similar spin recovery characteristics. Maximum indicated recovery speed was the same on all three test cases 120 mph. 0000 with neutral aileron input did produced the quickest recovery time and least altitude lost by slim margins indicating preference to neutral aileron. Predictably, the anti-spin aileron did produce a slower spin rate while pro-spin aileron produced higher spin rates. Interestingly this acceleration and deceleration had marginal effects on recovery altitude but gave preference to pro-spin aileron.
Pilot noted less control with 04R than with 02R indicating that the additional input of pro-spin aileron added some instability to the system aggravating the return to controlled flight. This can be seen in the video playback with a dirtier stall break. Pilot additionally noted an more agitated nose down spin attitude then seen in 02R. This phenomenon is noticeable in video playback as well indicating the addition of pro-spin aileron produces a faster deeper spiral.

FLIGHT TEST CARD 0005

05 R	**Test Point: 0005** Neut Rud, Pitch Down, Neut Aileron – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **0**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Fwd, Neutral – push after fully developed

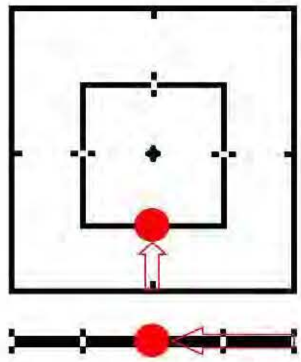
Recovery Altitude:	**3650**	Recovery Speed:	**130**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**3**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3650' MSL. Total altitude loss during maneuver was calculated to be 1350'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 15.2 sec. Calculated average vertical velocity during maneuver was 89 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.54 rev/sec. Comparing the 02R, 05R, and 06R methods reveal all three with neutral aileron, with variation of elevator input, result in different spin recovery characteristics. These results indicate that elevator input will be a significant factor in the development of a spin recovery model. The data indicates the there is a relationship between elevator input and spin recovery time & altitude. There exists a sweet spot in elevator deflection that will produce the highest recovery altitudes along with fastest recovery times. This is predictable as we understood that full elevator down deflection (Stick AFT) produces a spin and full elevator up deflection (Stick FWD) will crossover to an inverted spin.
Pilot noted a severe pitch down during recovery resulting in a negative g experience. The sharp pitch down created an acceleration of rotation rate. This can be seen in video playback and a results in higher average spin rate during recovery. Upon recovery, the pilot again noted that the recovery speed was undesirable similar to note in 05L. Pilot noted maximum indicated velocity was 135 mph. Video play back reveals that maximum recovery indicated velocity was 130 mph; however, the buildup of speed was more rapid during the recovery dive. This may have led to the perception of higher exit velocities.

FLIGHT TEST CARD 0006

06 R	**Test Point: 0006** Neut Rud, Pitch Up, Neut Aileron – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Aft, Neutral – push after fully developed

Recovery Altitude:	**3575**	Recovery Speed:	**125**	Recovery Revolutions:	**1 3/4**
Cooper-Harper Rating:	**2**	Bedford Rating:	**2**		

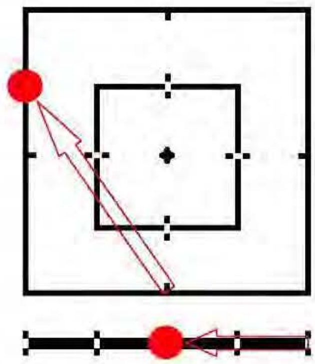
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3675' MSL. Total altitude loss during maneuver was calculated to be 1325'. The Maximum indicated speed during spin recovery was 125 mph. Recorded time from stall to spin recovery was 16.3 sec. Calculated average vertical velocity during maneuver was 87 ft/sec. Aircraft continued to spin for 1.750 rev after initiation of recovery controls. Recovery time was 4.1 sec with a calculated average spin rate of 0.43 rev/sec. Comparing the 02R, 05R, and 06R methods reveal all three with neutral aileron, with variation of elevator input, result in different spin recovery characteristics. These results indicate that elevator input will be a significant factor in the development of a spin recovery model. The data indicates the there is a relationship between elevator input and spin recovery time & altitude. There exists a sweet spot in elevator deflection that will produce the highest recovery altitudes along with fastest recovery times. This is predictable as we understood that full elevator down deflection (Stick AFT) produces a spin and full elevator up deflection (Stick FWD) will crossover to an inverted spin.
Pilot noted a significant lack of stability. While the feedback of the spin was noticeably better than 01R, the stability was nearly identical. There seemed to be no acceleration in the direction of acting controls resulting from the inputs, conversely more rotation was noticed in the recovery.

FLIGHT TEST CARD 0007

07 R	**Test Point: 0007** Neut Rud, Pitch Down, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Fwd, Left – push after fully developed

Recovery Altitude:	**3600**	Recovery Speed:	**130**	Recovery Revolutions:	**0 7/8**
Cooper-Harper Rating:	**6**	Bedford Rating:	**6**		

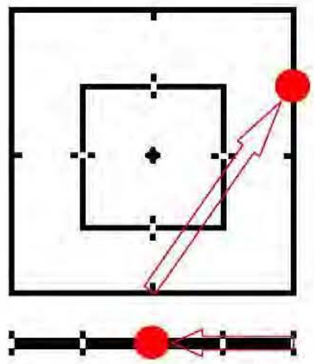
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3600' MSL. Total altitude loss during maneuver was calculated to be 1400'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 87 ft/sec. Aircraft continued to spin for 0.875 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.42 rev/sec. Comparing the 05R, 07R, and 08R methods reveal all three with elevator down combined with various aileron input methods result in different spin recovery characteristics. This result differs from the relative indifference in aileron position found when comparing methods 02R, 03R, and 04R. In the cases of elevator down controls anti spin roll input produced a significantly higher recovery altitude than pro spin aileron 3600ft versus 3525ft. While the spin revolutions were the similar between 07R and 08R anti spin roll input again produces a better result with 1.125 versus 1.625 revolutions. Neutral aileron 05R predictably produced the best result of the three. These results indicate that elevator input will be a significant factor in the development of a spin recovery model.
Pilot noted this method was a higher than normal workload caused by searching for the correct stick position. The extreme flatness of the spin attitude produced no rotational acceleration out of the spin during stall break. Stability suffered but added elevator down control provided better stability than 03R. Pilot noted all recovery methods with stick forward 05R, 07R, and 08R of neutral produced clean stall breaks.

FLIGHT TEST CARD 0008

08 R	**Test Point: 0008** Neut Rud, Pitch Down, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Fwd, Right – push after fully developed

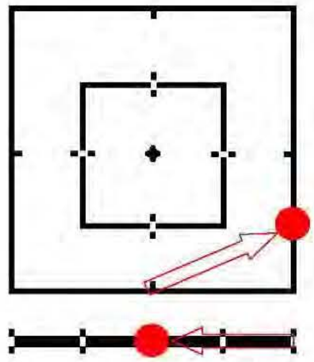
Recovery Altitude:	**3525**	Recovery Speed:	**127**	Recovery Revolutions:	**1 5/8**
Cooper-Harper Rating:	**6**	Bedford Rating:	**6**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3525' MSL. Total altitude loss during maneuver was calculated to be 1475'. The Maximum indicated speed during spin recovery was 127 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 91 ft/sec. Aircraft continued to spin for 1.625 rev after initiation of recovery controls. Recovery time was 3.1 sec with a calculated average spin rate of 0.52 rev/sec. Comparing the 05R, 07R, and 08R methods reveal all three with elevator down combined with various aileron input methods result in different spin recovery characteristics. This result differs from the relative indifference in aileron position found when comparing methods 02R, 03R, and 04R. In the cases of elevator down controls anti spin roll input produced a significantly higher recovery altitude than pro spin aileron 3600ft versus 3525ft. While the spin revolutons were the similar between 07R and 08R anti spin roll input again produces a better result with 1.125 versus 1.625 revolutions. Neutral aileron 05R predictably produced the best result of the three. These results indicate that elevator input will be a significant factor in the development of a spin recovery model.
Pilot noted this method was a higher than normal workload caused by searching for the correct stick position. Spin rotation rate accelerated and nose dug in with a steeper spin attitude with input of controls. Stability was reduced producing worst gyrations of all three methods, similar to 08L. Pilot noted all recovery methods with stick forward 05R, 07R, and 08R of neutral produced clean stall breaks.

FLIGHT TEST CARD 0009

09 R	**Test Point: 0009** Neut Rud, Pitch Down, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Aft, Right – push after fully developed

Recovery Altitude:	XXXX	Recovery Speed:	XXX	Recovery Revolutions:	X
Cooper-Harper Rating:	10	Bedford Rating:	4		

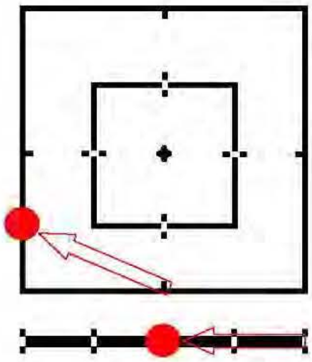
Notes:
Stall was initiated at 5000' MSL. Spin was unrecoverable prior to minimum recovery altitude.
Pilot noted the control inputs caused a deep aggravated spin with an oscillatory motion. No feeling of recovery was indicated. Pilot correctly indicated upon initiation of recovery controls that no recovery was possible.

FLIGHT TEST CARD 0010

10 R	**Test Point: 0010** Neut Rud, Pitch up, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **1**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Aft, Left – push after fully developed

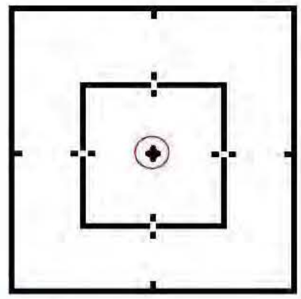
Recovery Altitude:	**3600**	Recovery Speed:	**125**	Recovery Revolutions:	**1 1/2**
Cooper-Harper Rating:	**5**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3600' MSL. Total altitude loss during maneuver was calculated to be 1400'. The Maximum indicated speed during spin recovery was 125 mph. Recorded time from stall to spin recovery was 18.2 sec. Calculated average vertical velocity during maneuver was 77 ft/sec. Aircraft continued to spin for 1.500 rev after initiation of recovery controls. Recovery time was 4.2 sec with a calculated average spin rate of 0.36 rev/sec. Comparing methods 06R, 09R, and 10R reveals all three with elevator up combined with various aileron input methods result in different spin recovery characteristics. These results are similar when comparing methods 05R, 07R, and 08R, elevator down control. In the cases of elevator up controls anti spin roll and neutral aileron input produced significantly higher recovery altitudes than pro spin aileron 3600ft and 3575ft versus 3100ft. Neutral aileron 07R did not produced the best result of the three but the difference in 07R and 09R is negligible. A review of all the aileron variations shows that avoiding pro-spin aileron controls will be significant; however, the difference in neutral and anti-spin controls will need to be explored during modeling.
Pilot noted a deceleration in the rotation rate with input of recovery controls. Stall Break was undesirable with no positive feedback of breaking. Recovery was slow in to return to normal flight. Stability during recovery is undesirable as control inputs were slow to provide any noticeable effect. While there was no feeling of control return to positive rate was quick.

FLIGHT TEST CARD 0011

11 R	**Test Point: 0011** Opp Rud, Free Stick – R Throttle: **0** Rudder: **F** Elevator: **F** Aileron: **F**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Free – release after fully developed

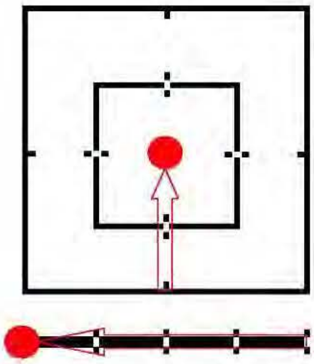
Recovery Altitude:	3650	Recovery Speed:	130	Recovery Revolutions:	1 1/8
Cooper-Harper Rating:	10	Bedford Rating:	2		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3650' MSL. Total altitude loss during maneuver was calculated to be 1350'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 84 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 2.3 sec with a calculated average spin rate of 0.49 rev/sec. Comparing 01R to 11R we see a dramatic improvement in both recovery altitude and yaw rate shown in decrease of recovery revolutions. This response to rudder control indicates that rudder input will be a significant factor in the development of a spin recovery model. Comparing the 01FF methods (11R vs 11L) for left and right spins reveals that the aircraft has similar spin rates for right and left spiraling spins while 11L displays both a larger maximum velocity and vertical velocity, 140 versus 130 and 96 versus 84. Recovery altitude loss ends with different results, 1350ft versus 1525ft. This illustrates an important reality that the min recovery altitude is determined by both recovery velocity and the shape of the flight path during spin recovery. In this study, the spin rate is the primary indicator of the flight path shape.
Pilot noted slight zero g sensation of the body during stall break. The aircraft provided little feedback during recovery. Feedback varied based on pedal pressure against the pedal stop. The stall break upon recovery was noted as dirty and added a concern that positive breaking response to control inputs took longer than expected. Pilot noted that the addition of rudder input to full input from a neutral position was favorable.

FLIGHT TEST CARD 0012

12 R	**Test Point: 0012** Opp Rud, Neut Stick – R Throttle: **0** Rudder: **1** Elevator: **0** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Neutral, Neutral – push after fully developed

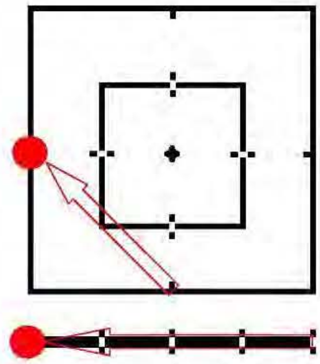
Recovery Altitude:	**3700**	Recovery Speed:	**123**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**2**	Bedford Rating:	**1**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 123 mph. Recorded time from stall to spin recovery was 15.4 sec. Calculated average vertical velocity during maneuver was 84 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.36 rev/sec. Comparing methods 02R and 12R we can directly show the impacts of neutral rudder and full control of anti-spin rudder. A comparison of the recovery altitudes shows no noticeable difference between the methods as both arrive at a recovery altitude of 3700ft. Looking at the number of revolutions occurring during the spin we see that 12R dramatically reduces the yaw rate with ¾ of a revolution while 02R results in 1¼ revolutions. While the end results are the same we can see that positive yaw control of the aircraft was achieved earlier with the use of anti-spin rudder. This result highlights that while rudder may in fact be a significant factor in spin recovery, rudder is not dominate. This also illustrate why many sources dissect the spin recovery into two components: breaking the stall and breaking the yaw.
Pilot noted positive control from both stick and rudder pedals. Control inputs provided effective and positive control over the entire recovery phase. Stability was excellent with quick response to control inputs. No acceleration was feel in yaw or pitching moments in response to recovery controls. Workload was extremely low with the rudder pedal on the stops and stick in a familiar neutral position.

FLIGHT TEST CARD 0013

13 R	**Test Point: 0013** Opp Rud, Neut Elv, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Neutral, Left – push after fully developed

Recovery Altitude:	**3800**	Recovery Speed:	**120**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**3**	Bedford Rating:	**2**		

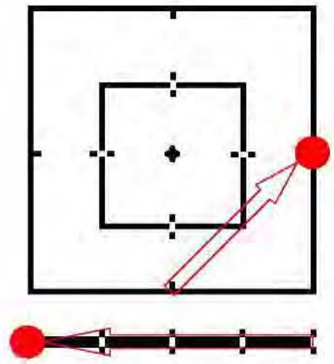
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3800' MSL. Total altitude loss during maneuver was calculated to be 1200'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 15.3 sec. Calculated average vertical velocity during maneuver was 78 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.36 rev/sec. Comparing the four results for 02R, 03R, 04R, 12R, 13R, and 14R we can dive deeper into the effects that rudder has on spin recovery by adding aileron inputs. We know that mixed aileron inputs can result in aggravated spins. We can see that this is the case for 03R, 04R, and 14R as these conditions result in similar of worse recovery altitudes as the conditions found for no aileron input. The exception is 13R which shows dramatic improvement in both recovery altitude and recovery revolutions when compared to 12R. Note this example best demonstrates a coordinated roll maneuver of the aircraft. All other inputs contain an adverse yaw component.
Pilot noted that feeling of response to the controls was positive Stability was similar to 12R with a slower rotation rate. Actual measurements reveal that both were the same; however, 13R did produce a slightly slower vertical velocity which may have caused a perception of slower yaw rates. Workload was noticeably higher as ensure neutral pitch with full roll inputs required more attention to control positioning.

FLIGHT TEST CARD 0014

14 R	**Test Point: 0014** Opp Rud, Neut Elv, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Neutral, Right – push after fully developed

Recovery Altitude:	**3725**	Recovery Speed:	**120**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**3**	Bedford Rating:	**2**		

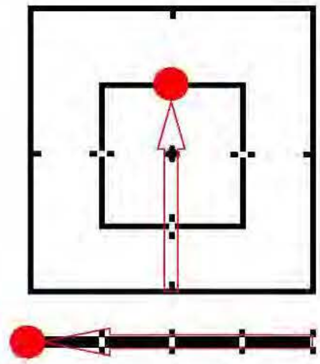
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3725' MSL. Total altitude loss during maneuver was calculated to be 1275'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 15.2 sec. Calculated average vertical velocity during maneuver was 84 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.54 rev/sec. Comparing the four results for 02R, 03R, 04R, 12R, 13R, and 14R we can dive deeper into the effects that rudder has on spin recovery by adding aileron inputs. We know that mixed aileron inputs can result in aggravated spins. We can see that this is the case for 03R, 04R, and 14R as these conditions result in similar of worse recovery altitudes as the conditions found for no aileron input. The exception is 13R which shows dramatic improvement in both recovery altitude and recovery revolutions when compared to 12R. Note this example best demonstrates a coordinated roll maneuver of the aircraft. All other inputs contain an adverse yaw component.
Pilot noted a 0g sensation during initiation of controls which provided good feedback that controls were responsive. Upon full control input the spin rate accelerated which can be seen in video playback. This acceleration and positive control made pilot initially think that spin would not break and be recoverable with the applied inputs. Stall break was clean and responsive. Pilot workload was higher than 13R due to pulling stick away from the neutral position in lieu of pushing as pilot was flying with right hand with throttle controls in the left hand.

FLIGHT TEST CARD 0015

15 R	**Test Point: 0015** Opp Rud, Pitch Down, Neut Aileron – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **0**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Mid Fwd, Neutral – push after fully developed

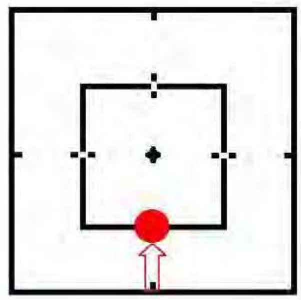
Recovery Altitude:	**3700**	Recovery Speed:	**120**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**2**	Bedford Rating:	**3**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 15.1 sec. Calculated average vertical velocity during maneuver was 86 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.0 sec with a calculated average spin rate of 0.38 rev/sec. Comparing the four results for 02R, 05R, 06R, 12R, 15R, and 16R we can dive deeper into the effects that rudder has on spin recovery by adding elevator inputs. We know that both elevator and rudder input will be a significant factor in the development of a spin recovery model. We can quickly point out that 16R produces the best result with a recovery altitude of 3725ft. We can also cite that all of the methods with full rudder input, 12R, 15R, and 16R, produce better results than methods with neutral input. Additionally, when reviewing 12R, 15R, and 16R there exists a sweet spot in elevator deflection that will produce the highest recovery altitudes along with fastest recovery times.
Pilot noted a clean stall break with great response to control inputs. Desired response was quickly achieved with good stability while holding input. Desired control inputs were low work load to obtain and maintain positioning. There was no acceleration from spin recovery inputs.

FLIGHT TEST CARD 0016

16 R	**Test Point: 0016** Opp Rud, Pitch Up, Neut Aileron – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Mid Aft, Neutral – push after fully developed

Recovery Altitude:	**3750**	Recovery Speed:	**115**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**1**	Bedford Rating:	**1**		

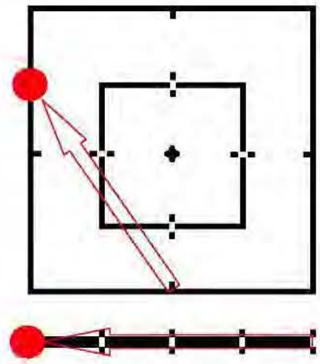
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3750' MSL. Total altitude loss during maneuver was calculated to be 1250'. The Maximum indicated speed during spin recovery was 115 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 78 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 3.0 sec with a calculated average spin rate of 0.38 rev/sec. Comparing the four results for 02R, 05R, 06R, 12R, 15R, and 16R we can dive deeper into the effects that rudder has on spin recovery by adding elevator inputs. We know that both elevator and rudder input will be a significant factor in the development of a spin recovery model. We can quickly point out that 16R produces the best result with a recovery altitude of 3725ft. We can also cite that all of the methods with full rudder input, 12R, 15R, and 16R, produce better results than methods with neutral input. Additionally, when reviewing 12R, 15R, and 16R there exists a sweet spot in elevator deflection that will produce the highest recovery altitudes along with fastest recovery times.
Pilot noted poor feedback from the controls as they provided little control which cause the stability of the aircraft to suffer as control surfaces provided little control power in the desired recovery controls. Response time to stall break suffered as there was clear evidence of momentum in the right direction from control inputs but very little response. Additionally stall break was poor and too slow.

FLIGHT TEST CARD 0017

17 R	**Test Point: 0017** Opp Rud, Pitch Down, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **1**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Mid Fwd, Left – push after fully developed

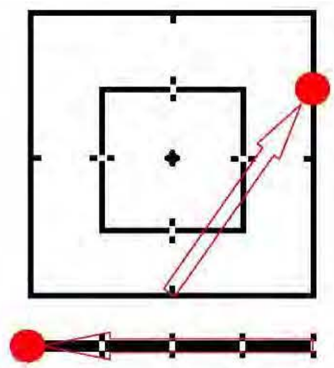
Recovery Altitude:	**3675**	Recovery Speed:	**130**	Recovery Revolutions:	**0 5/8**
Cooper-Harper Rating:	**6**	Bedford Rating:	**5**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3675' MSL. Total altitude loss during maneuver was calculated to be 1325'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 15.0 sec. Calculated average vertical velocity during maneuver was 88 ft/sec. Aircraft continued to spin for 0.625 rev after initiation of recovery controls. Recovery time was 1.2 sec with a calculated average spin rate of 0.52 rev/sec. Comparing the 15R, 17R, and 18R methods reveal all three with elevator down combined with various aileron input methods result in different spin recovery characteristics. In the cases of elevator down controls anti spin roll input produced a marginally higher recovery altitude than pro spin aileron 3675ft versus 3650ft. While the spin rates were the similar between 07R and 08R anti spin roll input again produces a better overall revolution count with 0.625 versus 1.250 revolutions. When comparing 05R, 07R, 08R, 15R, 17R, and 18R we again see that all of the methods with full rudder input, 15R, 17R, and 18R, produce better results than methods with neutral input.
Pilot noted a clean stall break with adequate stability from control inputs. No noticeable acceleration in the spin recovery however video playback showed evidence of slowed rotation. Pilot workload was higher that with all previous recovery methods as the forward and left stick position was difficult to find and maintain position. Video playback confirmed slight unloading to 1/4g during initiation of controls.

FLIGHT TEST CARD 0018

18 R	**Test Point: 0018** Opp Rud, Pitch Down, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Mid Fwd, Right – push after fully developed

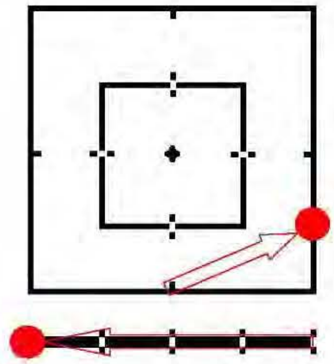
Recovery Altitude:	**3650**	Recovery Speed:	**133**	Recovery Revolutions:	**1 1/4**
Cooper-Harper Rating:	**6**	Bedford Rating:	**5**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3650' MSL. Total altitude loss during maneuver was calculated to be 1350'. The Maximum indicated speed during spin recovery was 133 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 84 ft/sec. Aircraft continued to spin for 1.250 rev after initiation of recovery controls. Recovery time was 2.5 sec with a calculated average spin rate of 0.50 rev/sec. Comparing the 15R, 17R, and 18R methods reveal all three with elevator down combined with various aileron input methods result in different spin recovery characteristics. In the cases of elevator down controls anti spin roll input produced a marginally higher recovery altitude than pro spin aileron 3675ft versus 3650ft. While the spin rates were the similar between 07R and 08R anti spin roll input again produces a better overall revolution count with 0.625 versus 1.250 revolutions. When comparing 05R, 07R, 08R, 15R, 17R, and 18R we again see that all of the methods with full rudder input, 15R, 17R, and 18R, produce better results than methods with neutral input.
Pilot noted acceleration of the spin rate during initiation of recovery controls. Acceleration did not affect the clean break that was exhibited. Stability felt lower than 12R but difficulty in ranking other that it was not the worst. Workload was highest yet due to pulling stick away from the neutral position in lieu of pushing as pilot was flying with right hand with throttle controls in the left hand.

FLIGHT TEST CARD 0019

19 R	**Test Point: 0019** Opp Rud, Pitch Down, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Mid Aft, Right – push after fully developed

Recovery Altitude:	**3700**	Recovery Speed:	**127**	Recovery Revolutions:	**1 1/2**
Cooper-Harper Rating:	**5**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 127 mph. Recorded time from stall to spin recovery was 16.0 sec. Calculated average vertical velocity during maneuver was 81 ft/sec. Aircraft continued to spin for 1.500 rev after initiation of recovery controls. Recovery time was 2.3 sec with a calculated average spin rate of 0.65 rev/sec. Comparing the 16R, 19R, and 20R methods reveal all three with elevator up combined with various aileron input methods result in different spin recovery characteristics. In the cases of elevator up controls neutral aileron input produced a significantly higher recovery altitude than pro/ant-spin aileron 3750ft versus 3700ft and 3700ft. Pro/Anti-spin inputs result in similar recovery altitudes, although with slightly different flight path characteristics. When comparing 06R, 09R, 10R, 16R, 19R, and 20R we see that all of the methods with full rudder input, 16R, 19R, and 20R, produce better results than methods with neutral input. This indicates that rudder input will be a significant factor in determining a spin recovery model.
Pilot noted a dramatic yaw during control input and stall break. Control inputs provided little control which cause the stability of the aircraft to suffer as control surfaces provided little control power in the desired recovery controls. Workload was high due to pulling stick away from the neutral position in lieu of pushing as pilot was flying with right hand with throttle controls in the left hand. Pilot made multiple attempts to get stick position correct.

FLIGHT TEST CARD 0020

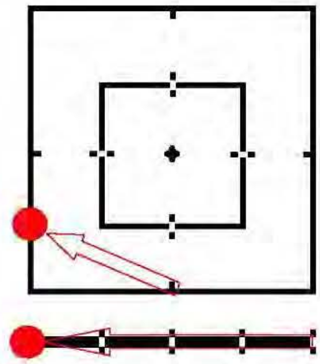
20 R	**Test Point: 0020** Opp Rud, Pitch up, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **1**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right



Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
    Stick- Mid Aft, Left – push after fully developed

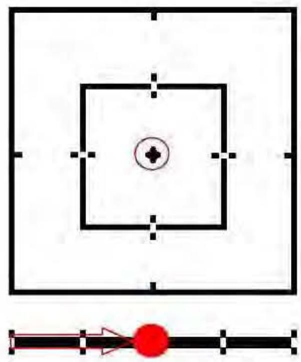
Recovery Altitude:	**3700**	Recovery Speed:	**117**	Recovery Revolutions:	**0 7/8**
Cooper-Harper Rating:	**5**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 117 mph. Recorded time from stall to spin recovery was 15.2 sec. Calculated average vertical velocity during maneuver was 86 ft/sec. Aircraft continued to spin for 0.875 rev after initiation of recovery controls. Recovery time was 2.2 sec with a calculated average spin rate of 0.40 rev/sec Comparing the 16R, 19R, and 20R methods reveal all three with elevator up combined with various aileron input methods result in different spin recovery characteristics. In the cases of elevator up controls neutral aileron input produced a significantly higher recovery altitude than pro/ant-spin aileron 3750ft versus 3700ft and 3700ft. Pro/Anti-spin inputs result in similar recovery altitudes, although with slightly different flight path characteristics. When comparing 06R, 09R, 10R, 16R, 19R, and 20R we see that all of the methods with full rudder input, 16R, 19R, and 20R, produce better results than methods with neutral input. This indicates that rudder input will be a significant factor in determining a spin recovery model.
Pilot noted a dirty stall break. Control inputs provided little control which cause the stability of the aircraft to suffer as control surfaces provided little control power in the desired recovery controls. Workload was high due to searching for correct position. Pilot made multiple attempts to get stick position correct.

FLIGHT TEST CARD 0101

01 L	**Test Point: 0101** Neut Rud, Free Stick – L Throttle: **0** Rudder: **0** Elevator: **F** Aileron: **F**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Free – release after fully developed

Recovery Altitude:	**3250**	Recovery Speed:	**140**	Recovery Revolutions:	**1 5/8**
Cooper-Harper Rating:	**10**	Bedford Rating:	**2**		

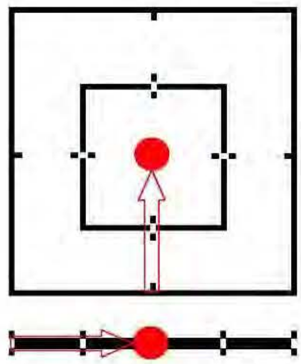
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3250' MSL. Total altitude loss during maneuver was calculated to be 1750'. The Maximum indicated speed during spin recovery was 140 mph. Recorded time from stall to spin recovery was 18.1 sec. Calculated average vertical velocity during maneuver was 97 ft/sec. Aircraft continued to spin for 1.625 rev after initiation of recovery controls. Recovery time was 4.2 sec with a calculated average spin rate of 0.39 rev/sec. Comparing the 00FF methods (01R vs 01L), for left and right spins reveals that the aircraft has significantly higher spin rates for right spiraling spins. Regardless of this favoritism, recovery altitudes end in the same result. This illustrates an important reality that the min recovery altitude is determined by both recovery velocity and the shape of the flight path during spin recovery. In this study, the spin rate is the primary indicator of the flight path shape.
Pilot noted the aircraft provided no feedback during recovery. This sensation loss could be the result of not having a hand on the control stick. The mechanical connections to the control surfaces provide a conscious sense of a control feedback loop. Video playback confirms pilot notions of rotation rate increasing before a gradual decrease with a questionable recovery indication. Recovery was slow with a delayed dirty break. Pilot noted that the addition of rudder input to neutral from a true free condition where all controls are released was favorable. A true free condition was not included in this study as the test maneuver could not be completed within provided airspace and test safety guidelines.

FLIGHT TEST CARD 0102

02 L	**Test Point: 0102** Neut Rud, Neut Stick – L Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Neutral, Neutral – push after fully developed

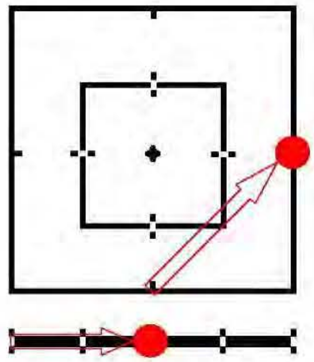
Recovery Altitude:	**3550**	Recovery Speed:	**130**	Recovery Revolutions:	**1**
Cooper-Harper Rating:	**3**		Bedford Rating:	**1**	

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3550' MSL. Total altitude loss during maneuver was calculated to be 1450'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 90 ft/sec. Aircraft continued to spin for 1.000 rev after initiation of recovery controls. Recovery time was 2.3 sec with a calculated average spin rate of 0.43 rev/sec. Comparing the 0000 methods (02R vs 02L) for left and right spins reveals that the aircraft has similar spin rates for right spiraling spins, 0.42 vs 0.43 rev/sec. This indicates that the shape of the recovery spin was similar. Maximum recovery velocity and average vertical velocity for 02L was slightly higher which predictably summed into a lower minimum recovery altitude, 3550' vs 3700'. Surprisingly the recovery time for 02L was 0.7sec quicker than 02R indicating that higher indicated velocities aid recovery time.
Pilot noted positive control with ample feedback throughout the spin recovery. Stall break was marginally clean and distinguishable. Rotation rate did not increase during initial recovery as with method 01L. Pilot was able to accurately recall all three prime test parameters; recovery altitude, recovery speed, and revolutions. Workload was found to almost non-existent. Neutral position for both rudder pedal and stick was easily located. Video playback of controls showed neutral position was correct. Pilot noted that the addition of stick inputs added stability to the recovery and there was less pitching and yaw rate changes. Video playback confirmed this observation.

FLIGHT TEST CARD 0103

03 L	**Test Point: 0103** Neut Rud, Neut Elv, Anti Spin Roll – L Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

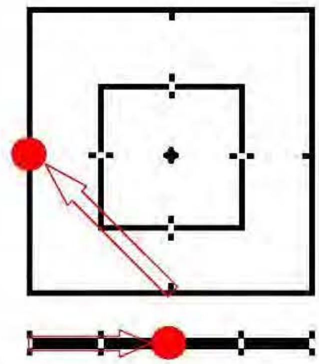
Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Neutral, Right – push after fully developed

Recovery Altitude:	**3500**	Recovery Speed:	**130**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**4**	Bedford Rating:	**2**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3500' MSL. Total altitude loss during maneuver was calculated to be 1500'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 93 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 3.2 sec with a calculated average spin rate of 0.35 rev/sec. Comparing the 02L, 03L, and 04L methods reveal that method 02L and 03L with neutral elevator, regardless of aileron input, result in similar spin recovery characteristics. Method 04L with is vastly different result highlights that the physics of left and right spins differ and that control inputs for a left spin may not match those of a right spin. In the case of 04L we should expect that it resemble 02L and 03L as previous results for 02R, 03R, and 04R were very similar. Here it is important to remember that propeller forces acting on the aircraft become relevant in stalled flight. Predictably, the anti-spin aileron did produce a slower spin rate while pro-spin aileron produced higher spin rates. In this particular case, pro-spin aileron delayed spin recovery.
Pilot noted less control with 03L than with 02L indicating that the additional input of anti-spin aileron added some instability to the system aggravating the return to controlled flight. A negative g sensation was felt at breaking point. Pilot additionally noted a flatter spin attitude then seen in 02L. This phenomenon is noticeable in video playback indicating the addition of anti-spin aileron produces a faster flatter spiral.

FLIGHT TEST CARD 0104

04 L	**Test Point: 0104** Neut Rud, Neut Elv, Pro Spin Roll – L Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **-1**



Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Neutral, Left – push after fully developed

Recovery Altitude:	**3400**	Recovery Speed:	**140**	Recovery Revolutions:	**1 5/8**
Cooper-Harper Rating:	**4**	Bedford Rating:	**2**		

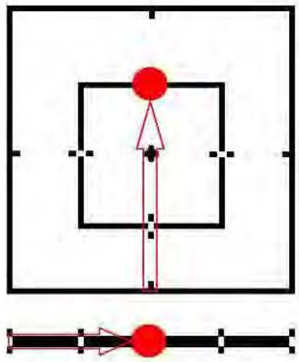
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3400' MSL. Total altitude loss during maneuver was calculated to be 1600'. The Maximum indicated speed during spin recovery was 140 mph. Recorded time from stall to spin recovery was 17.2 sec. Calculated average vertical velocity during maneuver was 93 ft/sec. Aircraft continued to spin for 1.625 rev after initiation of recovery controls. Recovery time was 3.3sec with a calculated average spin rate of 0.49 rev/sec. Comparing the 02L, 03L, and 04L methods reveal that method 02L and 03L with neutral elevator, regardless of aileron input, result in similar spin recovery characteristics. Method 04L with is vastly different result highlights that the physics of left and right spins differ and that control inputs for a left spin may not match those of a right spin. In the case of 04L we should expect that it resemble 02L and 03L as previous results for 02R, 03R, and 04R were very similar. Here it is important to remember that propeller forces acting on the aircraft become relevant in stalled flight. Predictably, the anti-spin aileron did produce a slower spin rate while pro-spin aileron produced higher spin rates. In this particular case, pro-spin aileron delayed spin recovery.
Pilot noted more roll rate and less control with 04L than with 02L indicating that the additional input of pro-spin aileron added some instability to the system aggravating the return to controlled flight. Pilot additionally noted an more agitated nose down spin attitude then seen in 02L. This phenomenon is noticeable in video playback indicating the addition of pro-spin aileron produces a faster deeper spiral.

FLIGHT TEST CARD 0105

05 L	**Test Point: 0105** Neut Rud, Pitch Down, Neut Aileron – L Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **0**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Fwd, Neutral – push after fully developed

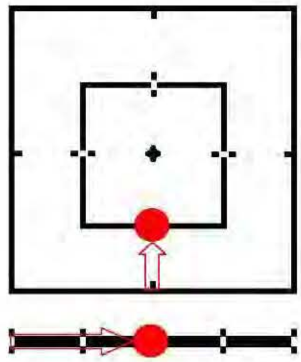
Recovery Altitude:	**3575**	Recovery Speed:	**135**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**3**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3575' MSL. Total altitude loss during maneuver was calculated to be 1425'. The Maximum indicated speed during spin recovery was 135 mph. Recorded time from stall to spin recovery was 17.3 sec. Calculated average vertical velocity during maneuver was 82 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 2.4 sec with a calculated average spin rate of 0.47 rev/sec. Comparing the 02L, 05L, and 06L methods reveal all three with neutral aileron, with variation of elevator input, result in different spin recovery characteristics. These results indicate that elevator input will be a significant factor in the development of a spin recovery model. The data indicates the there is a relationship between elevator input and spin recovery time & altitude. There exists a sweet spot in elevator deflection that will produce the highest recovery altitudes along with fastest recovery times. This is predictable as we understood that full elevator down deflection (Stick AFT) produces a spin and full elevator up deflection (Stick FWD) will crossover to an inverted spin.
Pilot noted a severe pitch down during recovery resulting in a negative g experience. The sharp pitch down created an acceleration of rotation rate. This can be seen in video playback and a results in higher average spin rate during recovery. Upon recovery, the pilot again noted that the recovery speed was undesirable similar to note in 05R. The buildup of speed was more rapid during the recovery dive. This may have led to the perception of higher exit velocities.

FLIGHT TEST CARD 0106

06 L	**Test Point: 0106** Neut Rud, Pitch Up, Neut Aileron – L Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Aft, Neutral – push after fully developed

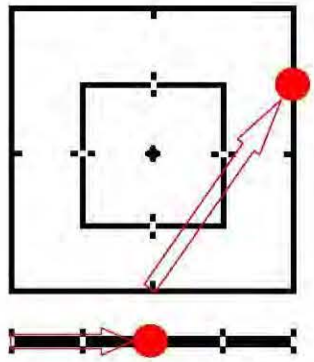
Recovery Altitude:	XXXX	Recovery Speed:	XXX	Recovery Revolutions:	X
Cooper-Harper Rating:	10	Bedford Rating:	2		

Notes:
Stall was initiated at 5000' MSL. Spin was unrecoverable prior to minimum recovery altitude. Pilot noted the aircraft acted like it wanted to recover with deceleration of rotation then accelerated out of the second revolution. The wing never became unstalled.

FLIGHT TEST CARD 0107

07 L	**Test Point: 0107** Neut Rud, Pitch Down, Anti Spin Roll – L Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Fwd, Right – push after fully developed

Recovery Altitude:	**3550**	Recovery Speed:	**130**	Recovery Revolutions:	**1 3/8**
Cooper-Harper Rating:	**6**	Bedford Rating:	**6**		

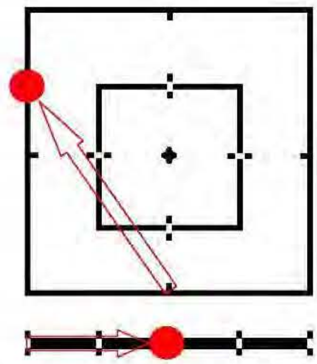
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3550' MSL. Total altitude loss during maneuver was calculated to be 1450'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 17.1 sec. Calculated average vertical velocity during maneuver was 85 ft/sec. Aircraft continued to spin for 1.375 rev after initiation of recovery controls. Recovery time was 3.1 sec with a calculated average spin rate of 0.44 rev/sec. Comparing the 05L, 07L, and 08L methods reveal all three with elevator down combined with various aileron input methods result in different spin recovery characteristics. This result differs from the relative indifference in aileron position found when comparing methods 02R, 03R, and 04R. In the cases of elevator down controls anti spin roll input produced a significantly higher recovery altitude than pro spin aileron 3550ft versus 3350ft. While the spin rates were the similar between 07R and 08R anti spin roll input again produces a better result with 1.375 versus 1.625 revolutions. Neutral aileron 05L predictably produced the best result of the three. These results indicate that elevator input will be a significant factor in the development of a spin recovery model.
Pilot noted this method was a higher than normal workload caused by searching for the correct stick position. The spin produced a flatter shape with slight acceleration in yaw. Stability suffered but added elevator down control provided better stability than 03L. Pilot noted all recovery methods with stick forward 05L, 07L, and 08L of neutral produced clean stall breaks.

FLIGHT TEST CARD 0108

08 L	**Test Point: 0108** Neut Rud, Pitch Down, Pro Spin Roll – L Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **-1**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Fwd, Left – push after fully developed

Recovery Altitude: **3350**	Recovery Speed: **150**	Recovery Revolutions: **1 5/8**
Cooper-Harper Rating: **6**	Bedford Rating: **6**	

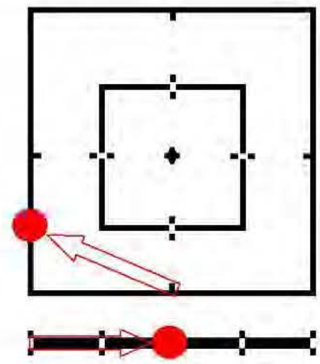
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3350' MSL. Total altitude loss during maneuver was calculated to be 1650'. The Maximum indicated speed during spin recovery was 150 mph. Recorded time from stall to spin recovery was 17.2 sec. Calculated average vertical velocity during maneuver was 96 ft/sec. Aircraft continued to spin for 1.625 rev after initiation of recovery controls. Recovery time was 4.0 sec with a calculated average spin rate of 0.41 rev/sec. Comparing the 05L, 07L, and 08L methods reveal all three with elevator down combined with various aileron input methods result in different spin recovery characteristics. This result differs from the relative indifference in aileron position found when comparing methods 02R, 03R, and 04R. In the cases of elevator down controls anti spin roll input produced a significantly higher recovery altitude than pro spin aileron 3550ft versus 3350ft. While the spin rates were the similar between 07R and 08R anti spin roll input again produces a better result with 1.375 versus 1.625 revolutions. Neutral aileron 05L predictably produced the best result of the three. These results indicate that elevator input will be a significant factor in the development of a spin recovery model.
Pilot noted this method was a higher than normal workload caused by searching for the correct stick position. Spin rotation and roll rate accelerated and nose dug in with a steeper spin attitude with input of controls. Stability was reduced producing worst gyrations of all three methods, similar to 08R. Pilot noted 08L produced the least clean stall break of 05L, 07L, and 08L.

FLIGHT TEST CARD 0109

09 L	**Test Point: 0109** Neut Rud, Pitch Down, Pro Spin Roll – L Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Aft, Left – push after fully developed

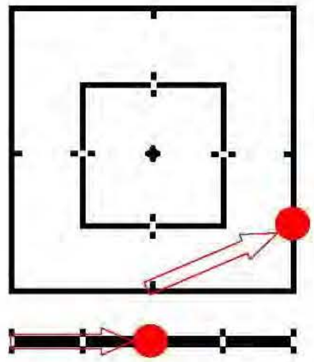
Recovery Altitude:	XXXX	Recovery Speed:	XXX	Recovery Revolutions:	X
Cooper-Harper Rating:	10		Bedford Rating:	4	

Notes:
Stall was initiated at 5000' MSL. Spin was unrecoverable prior to minimum recovery altitude.
Pilot noted the control inputs caused a deep aggravated spin with acceleration in roll and yaw. No feeling of recovery was indicated. Pilot correctly indicated upon initiation of recovery controls that no recovery was possible.

FLIGHT TEST CARD 0110

10 L	**Test Point: 0110** Neut Rud, Pitch up, Anti Spin Roll – L Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Neutral – stomp after fully developed
    Stick- Mid Aft, Right – push after fully developed

Recovery Altitude:	XXXX	Recovery Speed:	XXX	Recovery Revolutions:	X
Cooper-Harper Rating:	10	Bedford Rating:	4		

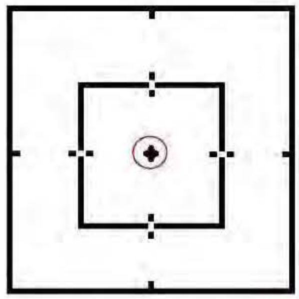
Notes:
Stall was initiated at 5000' MSL. Spin was unrecoverable prior to minimum recovery altitude.
Pilot noted the control inputs caused a deep aggravated spin with an initial deceleration then a rapid acceleration in roll and yaw. Pilot noted the aircraft acted like it wanted to recover, but the wing never became unstalled.

FLIGHT TEST CARD 0111

11 L	**Test Point: 0111** Neut Rud, Free Stick – L Throttle: **0** Rudder: **1** Elevator: **F** Aileron: **F**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Free – release after fully developed

Recovery Altitude:	**3500**	Recovery Speed:	**140**	Recovery Revolutions:	**1 3/8**
Cooper-Harper Rating:	**10**	Bedford Rating:	**1**		

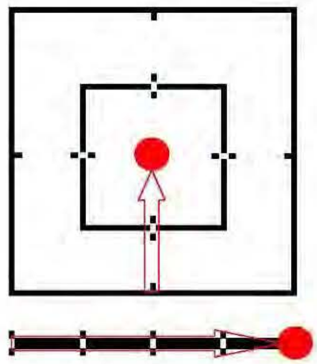
Notes:
Stall was initiated at 5025' MSL. Minimum altitude reached during recovery was 3500' MSL. Total altitude loss during maneuver was calculated to be 1525'. The Maximum indicated speed during spin recovery was 140 mph. Recorded time from stall to spin recovery was 15.9 sec. Calculated average vertical velocity during maneuver was 96 ft/sec. Aircraft continued to spin for 1.375 rev after initiation of recovery controls. Recovery time was 2.8 sec with a calculated average spin rate of 0.49 rev/sec. Comparing the 01FF methods (11R vs 11L) for left and right spins reveals that the aircraft has similar spin rates for right and left spiraling spins while 11L displays both a larger maximum velocity and vertical velocity, 140 versus 130 and 96 versus 84. Recovery altitude loss ends with different results, 1350ft versus 1525ft. This illustrates an important reality that the min recovery altitude is determined by both recovery velocity and the shape of the flight path during spin recovery. In this study, the spin rate is the primary indicator of the flight path shape.
Pilot noted a dramatic nose over when stall broke with zero or negative g sensation of the body. Aircraft accelerated nose down. The aircraft provided little feedback during recovery. This sensation loss could be the result of not having a hand on the control stick. The mechanical connections to the control surfaces provide a conscious sense of a control feedback loop. Feedback varied based on pedal pressure against the pedal stop. The stall break upon recovery was noted as dirty and added a concern that positive breaking response to control inputs took longer than expected. Pilot noted that the addition of rudder input to full input from a neutral position was favorable.

FLIGHT TEST CARD 0112

12 L	**Test Point: 0112** Neut Rud, Neut Stick – L Throttle: **0** Rudder: **1** Elevator: **0** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Neutral, Neutral – push after fully developed

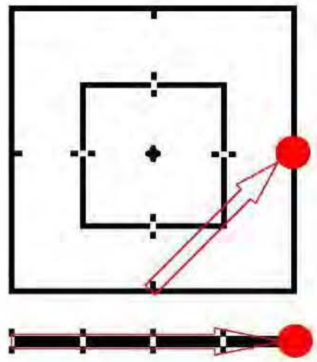
Recovery Altitude:	**3700**	Recovery Speed:	**125**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**2**	Bedford Rating:	**1**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 125 mph. Recorded time from stall to spin recovery was 16.9 sec. Calculated average vertical velocity during maneuver was 77 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.36 rev/sec. Comparing methods 02L and 12L we can directly show the impacts of neutral rudder and full control of anti-spin rudder. A comparison of the recovery altitudes shows noticeable difference between the methods as full rudder input produces a 150ft higher recovery altitude. Looking at the number of revolutions occurring during the spin we see that 12L reduces the yaw rate with ¾ of a revolution while 02L results in 1 revolution. This result highlights that rudder may in fact be a significant factor in spin recovery, rudder is likely not dominate to elevator. This also illustrate why many sources dissect the spin recovery into two components: breaking the stall and breaking the yaw.
Pilot noted a slight nose over upon initiation of recovery controls. 1/2g sensation continued through the very clean stall break. Positive control was felt throughout the recovery with a feeling of ample control, with adequate control power for requested response. Slight roll and yaw acceleration felt at initial input of recovery controls.

FLIGHT TEST CARD 0113

13 L	**Test Point: 0113** Neut Rud, Neut Elv, Anti Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **0** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Neutral, Right – push after fully developed

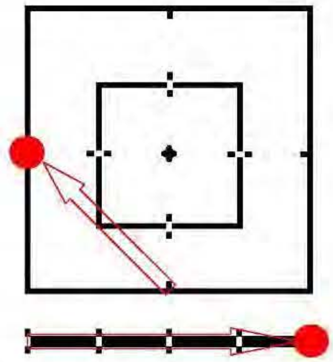
Recovery Altitude:	**3850**	Recovery Speed:	**120**	Recovery Revolutions:	**0 1/2**
Cooper-Harper Rating:	**3**	Bedford Rating:	**2**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3850' MSL. Total altitude loss during maneuver was calculated to be 1150'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 14.5 sec. Calculated average vertical velocity during maneuver was 79 ft/sec. Aircraft continued to spin for 0.500 rev after initiation of recovery controls. Recovery time was 1.8 sec with a calculated average spin rate of 0.28 rev/sec. Comparing the four results for 02L, 03L, 04L, 12L, 13L, and 14L we can dive deeper into the effects that rudder has on spin recovery by adding aileron inputs. We can see in comparing the results of full rudder 12L, 13L, and 14L versus neutral rudder 02L, 03L, and 04L, Full rudder out performs neutral rudder in every performance measure. Common between left and right spins all of the methods with full rudder input, 12R/L, 13R/L, and 14R/L, produce better results than methods with neutral input. Neutral aileron with full rudder inputs produces the best on all the neutral elevator combinations. This result highlights that rudder is a significant factor in spin recovery model development.
Pilot noted a deceleration in both roll and yaw upon initiation of recovery controls. With the roll and yaw motion a sensation of asymmetric loading of the aircraft was felt. The stall break was marginally clean but lack the sharpness of 12L. This may be do the initial deceleration in roll and yaw. Workload was higher than 12L. This is likely due to the pulling away from the neutral aileron position with the right hand as is customary of center stick with throttle on left control layout.

FLIGHT TEST CARD 0114

14 L	**Test Point: 0114** Neut Rud, Neut Elv, Pro Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **0** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Neutral, Left – push after fully developed

Recovery Altitude:	3600	Recovery Speed:	130	Recovery Revolutions:	1 1/4
Cooper-Harper Rating:	3		Bedford Rating:	2	

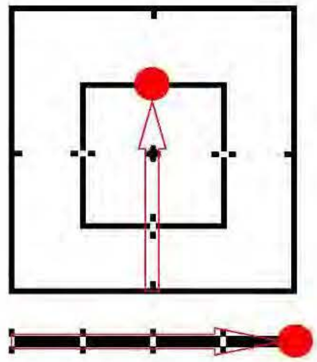
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3600' MSL. Total altitude loss during maneuver was calculated to be 1400'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 18.0 sec. Calculated average vertical velocity during maneuver was 78 ft/sec. Aircraft continued to spin for 1.250 rev after initiation of recovery controls. Recovery time was 3.0 sec with a calculated average spin rate of 0.42 rev/sec. Comparing the four results for 02L, 03L, 04L, 12L, 13L, and 14L we can dive deeper into the effects that rudder has on spin recovery by adding aileron inputs. We can see in comparing the results of full rudder 12L, 13L, and 14L versus neutral rudder 02L, 03L, and 04L, Full rudder out performs neutral rudder in every performance measure. Common between left and right spins all of the methods with full rudder input, 12R/L, 13R/L, and 14R/L, produce better results than methods with neutral input. Neutral aileron with full rudder inputs produces the best on all the neutral elevator combinations. This result highlights that rudder is a significant factor in spin recovery model development.
Pilot noted a slight nose over during initiation of control inputs with a low 1/4g sensation. Aircraft showed acceleration in roll and felt unstable about the roll axis. Stall break was moderate break as it display adequate response and feedback but was notable less crisp that noted in 12L. Workload was not a high as 13L however more difficult than 12L.

FLIGHT TEST CARD 0115

15 L	**Test Point: 0115** Neut Rud, Pitch Down, Neut Aileron – L Throttle: **0** Rudder: **1** Elevator: **1** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Mid Fwd, Neutral – push after fully developed

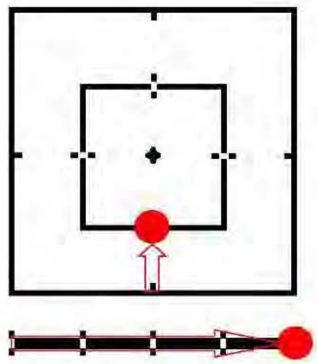
Recovery Altitude:	**3650**	Recovery Speed:	**130**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**2**	Bedford Rating:	**3**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3650' MSL. Total altitude loss during maneuver was calculated to be 1350'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 16.9 sec. Calculated average vertical velocity during maneuver was 80 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.0 sec with a calculated average spin rate of 0.38 rev/sec. Comparing the four results for 02L, 05L, 06L, 12L, 15L, and 16L we can dive deeper into the effects that rudder has on spin recovery by adding elevator inputs. We know that both elevator and rudder input will be a significant factor in the development of a spin recovery model. We can quickly point out that 16L produces the best result with a recovery altitude of 3775ft. Common between left and right spins all of the methods with full rudder input, 12R/L, 15R/L, and 16R/L, produce better results than methods with neutral input. Additionally, when reviewing 12R, 15R, and 16R there exists a sweet spot in elevator deflection that will produce the highest recovery altitudes along with fastest recovery times.
Pilot noted a dramatic nose over when stall broke with zero or negative g sensation of the body. Aircraft accelerated nose down. 0g sensation continued through the very clean stall break with very positive and responsive control. The response of control hit at break neck speeds which led to a preference to response found in 12L. Workload was slightly higher that 12L and less than 13L,14L. this is likely due to input request is closer to the limit of arms reach away from the pilot.

FLIGHT TEST CARD 0116

16 L	**Test Point: 0116** Neut Rud, Pitch Up, Neut Aileron – L Throttle: **0** Rudder: **1** Elevator: **-1** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Mid Aft, Neutral – push after fully developed

Recovery Altitude:	**3775**	Recovery Speed:	**115**	Recovery Revolutions:	**0 7/8**
Cooper-Harper Rating:	**1**	Bedford Rating:	**1**		

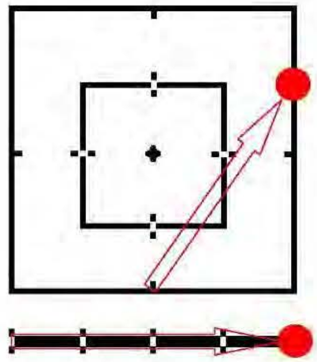
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3775' MSL. Total altitude loss during maneuver was calculated to be 1225'. The Maximum indicated speed during spin recovery was 115 mph. Recorded time from stall to spin recovery was 16.0 sec. Calculated average vertical velocity during maneuver was 77 ft/sec. Aircraft continued to spin for 0.875 rev after initiation of recovery controls. Recovery time was 2.2 sec with a calculated average spin rate of 0.40 rev/sec. Comparing the four results for 02L, 05L, 06L, 12L, 15L, and 16L we can dive deeper into the effects that rudder has on spin recovery by adding elevator inputs. We know that both elevator and rudder input will be a significant factor in the development of a spin recovery model. We can quickly point out that 16L produces the best result with a recovery altitude of 3775ft. We can also cite that all of the methods with full rudder input, 12R, 15R, and 16R, produce better results than methods with neutral input. Additionally, when reviewing 12R, 15R, and 16R there exists a sweet spot in elevator deflection that will produce the highest recovery altitudes along with fastest recovery times.
Pilot noted a moderately poor stall break. The aircraft did not accelerate or decelerate in any direction roll or yaw. Pitch over was slow and undramatic. Input response was barely adequate and provided on the minimum of positive response. This led to a delay in time from initiation of recovery controls to recovery. Pilot workload was negligible. Locating position was only slightly more difficult that locating neutral position in 12L.

FLIGHT TEST CARD 0117

17 L	**Test Point: 0117** Neut Rud, Pitch Down, Anti Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **1** Aileron: **1**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Mid Fwd, Right – push after fully developed

Recovery Altitude:	**3650**	Recovery Speed:	**130**	Recovery Revolutions:	**0 5/8**
Cooper-Harper Rating:	**6**	Bedford Rating:	**5**		

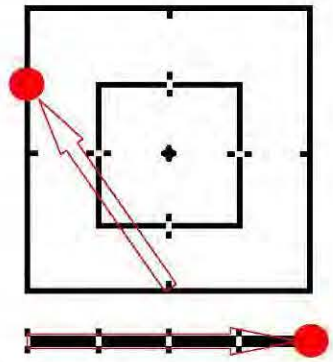
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3650' MSL. Total altitude loss during maneuver was calculated to be 1350'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 83 ft/sec. Aircraft continued to spin for 0.625 rev after initiation of recovery controls. Recovery time was 1.5 sec with a calculated average spin rate of 0.42 rev/sec. Comparing the 15R, 17R, and 18R methods reveal all three with elevator down combined with various aileron input methods result in different spin recovery characteristics. In the cases of elevator down controls anti spin roll input produced a marginally higher recovery altitude than pro spin aileron 3675ft versus 3650ft. While the spin rates were the similar between 07R and 08R anti spin roll input again produces a better overall revolution count with 0.625 versus 1.250 revolutions. When comparing 05R, 07R, 08R, 15R, 17R, and 18R we again see that all of the methods with full rudder input, 15R, 17R, and 18R, produce better results than methods with neutral input.
Pilot noted a nose over when stall broke with zero or negative g sensation of the body. Aircraft accelerated nose down. The aircraft accelerated in yaw upon recovery controls and appeared unstable in roll and yaw. Workload was higher than 13L. This is likely due to the pulling away from the neutral aileron position with the right hand combined with the push away from the pilot. The input request is at the limit of arms reach away from the pilot.

FLIGHT TEST CARD 0118

18 L	**Test Point: 0118** Neut Rud, Pitch Down, Pro Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Mid Fwd, Left – push after fully developed

Recovery Altitude:	**3675**	Recovery Speed:	**135**	Recovery Revolutions:	**1**
Cooper-Harper Rating:	**6**	Bedford Rating:	**5**		

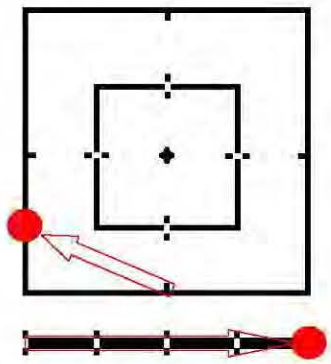
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3675' MSL. Total altitude loss during maneuver was calculated to be 1325'. The Maximum indicated speed during spin recovery was 135 mph. Recorded time from stall to spin recovery was 16.0 sec. Calculated average vertical velocity during maneuver was 83 ft/sec. Aircraft continued to spin for 1.000 rev after initiation of recovery controls. Recovery time was 2.5 sec with a calculated average spin rate of 0.40 rev/sec. Comparing the 15R, 17R, and 18R methods reveal all three with elevator down combined with various aileron input methods result in different spin recovery characteristics. In the cases of elevator down controls anti spin roll input produced a marginally higher recovery altitude than pro spin aileron 3675ft versus 3650ft. While the spin rates were the similar between 07R and 08R anti spin roll input again produces a better overall revolution count with 0.625 versus 1.250 revolutions. When comparing 05R, 07R, 08R, 15R, 17R, and 18R we again see that all of the methods with full rudder input, 15R, 17R, and 18R, produce better results than methods with neutral input.
Pilot noted a nose over when stall broke with zero or negative g sensation of the body. Aircraft accelerated nose down. The aircraft accelerated in roll upon recovery controls and appeared unstable in roll and yaw. Workload was higher than 14L. This is likely due to the pulling away from the neutral aileron position with the right hand combined with the push away from the pilot. The input request is at the limit of arms reach away from the pilot.

FLIGHT TEST CARD 0119

19 L	**Test Point: 0119** Neut Rud, Pitch Down, Pro Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **-1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Mid Aft, Left – push after fully developed

Recovery Altitude:	3600	Recovery Speed:	130	Recovery Revolutions:	1 1/8
Cooper-Harper Rating:	5	Bedford Rating:	4		

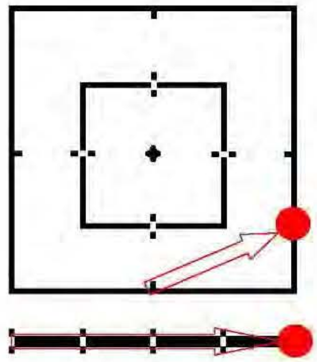
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3600' MSL. Total altitude loss during maneuver was calculated to be 1400'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 17.2 sec. Calculated average vertical velocity during maneuver was 81 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.54 rev/sec. Comparing the 16L, 19L, and 20L methods reveal all three with elevator up combined with various aileron input methods result in different spin recovery characteristics. In the cases of elevator up controls neutral aileron input produced a significantly higher recovery altitude than pro/ant-spin aileron 3775ft versus 3600ft and 3700ft. When comparing 06L, 09L, 10L, 16L, 19L, and 20L we again see that all of the methods with full rudder input, 16L, 19L, and 20L, produce better results than methods with neutral input. This comparison highlights that full rudder input versus neutral rudder input was the difference between a recoverable and non-recoverable spin. This indicates that rudder input will be a significant factor in determining a spin recovery model.
Pilot noted a dramatic yaw during control input and stall break. Control inputs provided little control which cause the stability of the aircraft to suffer as control surfaces provided little control power in the desired recovery controls. Marginal Stall recovery with multiple noted unstall/stall actions. Pilot made multiple attempts to get initial stick position correct and maintain though out recovery.

FLIGHT TEST CARD 0120

20 L	**Test Point: 0120** Neut Rud, Pitch up, Anti Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **-1** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
    Stick- Mid Aft, Right – push after fully developed

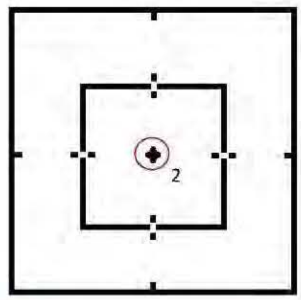
Recovery Altitude:	**3700**	Recovery Speed:	**120**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**5**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 81 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.0 sec with a calculated average spin rate of 0.38 rev/sec. Comparing the 16L, 19L, and 20L methods reveal all three with elevator up combined with various aileron input methods result in different spin recovery characteristics. In the cases of elevator up controls neutral aileron input produced a significantly higher recovery altitude than pro/ant-spin aileron 3775ft versus 3600ft and 3700ft. When comparing 06L, 09L, 10L, 16L, 19L, and 20L we again see that all of the methods with full rudder input, 16L, 19L, and 20L, produce better results than methods with neutral input. This comparison highlights that full rudder input versus neutral rudder input was the difference between a recoverable and non-recoverable spin. This indicates that rudder input will be a significant factor in determining a spin recovery model.
Pilot noted a deceleration in roll and yaw upon initiation of recovery controls. Stall break was marginal. Input response was barely adequate and provided on the minimum of positive response. This led to a delay in time from initiation of recovery controls to recovery. Workload was higher than 13L. Locating position was only slightly more difficult that locating neutral aileron position in 16L.

FLIGHT TEST CARD 1011

11R*	**Test Point: 1011** Opp Rud, Free Stick – R Throttle: **0** Rudder: **F** Elevator: **F** Aileron: **F**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Free – release after fully developed

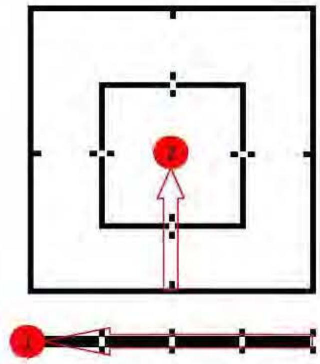
Recovery Altitude:	**3600**	Recovery Speed:	**135**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**10**	Bedford Rating:	**2**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3600' MSL. Total altitude loss during maneuver was calculated to be 1400'. The Maximum indicated speed during spin recovery was 135 mph. Recorded time from stall to spin recovery was 17.1 sec. Calculated average vertical velocity during maneuver was 82 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 3.1 sec with a calculated average spin rate of 0.36 rev/sec. Comparing 11R* with 11R we attempt to answer the question of the effectiveness of splitting the rudder input actions from aileron and elevator actions. A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a marginal 50ft higher recovery altitude, 3650ft versus 3600ft. We see that all other factors are similar as well. The only noticeable difference is the spin rate and the recovery time. The two spins recovery methods obtain the same number of revolutions, 1.125 revolutions. However, the spin rate for 11R* produced a slower spin rate with a longer recovery time: 0.36 versus 0.49 rev/sec and 3.1 versus 2.3 sec.
Pilot noted the airplane response in 11R* (pause) was similar to the response noted in 11R (no pause). Airplane presented a slight zero g sensation of the body during stall break. Inclusion of a pause raised the workload slightly; however, the already low workload did not affect the overall workload rating.

FLIGHT TEST CARD 1012

12R*	**Test Point: 1012** Opp Rud, Neut Stick – R Throttle: **0** Rudder: **1** Elevator: **0** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Neutral, Neutral – push after fully developed

Recovery Altitude:	**3600**	Recovery Speed:	**130**	Recovery Revolutions:	**1 1/2**
Cooper-Harper Rating:	**4**	Bedford Rating:	**3**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3600' MSL. Total altitude loss during maneuver was calculated to be 1400'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 87 ft/sec. Aircraft continued to spin for 1.500 rev after initiation of recovery controls. Recovery time was 3.2 sec with a calculated average spin rate of 0.47 rev/sec. Comparing 12R* and 12R, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a significant 100ft higher recovery altitude, 3700ft versus 3600ft. 12R* produces a higher average spin recovery rate then 12R, 0.47 versus 0.36 rev/sec. Additionally, recovery time of 12R* took an additional 1.1 seconds. Both of these characteristics add an additional 0.75 revolutions to 12R*. Note this method is nearly identical to PARE method with the exception that elevator push is to neutral stick position and not through neutral.
Pilot noted airplane felt unrecoverable prior to stick input. This condition where only recovery rudder and full aft stick input is a known condition of spin entry as the decathlon has more than enough elevator authority to enter a spin with no other pro spin control. Addition of the pause did not create a lower average spin rate; however, it is notable that the pilot did comment this was the condition prior to looking at the data to compare 12R and 12R*.

FLIGHT TEST CARD 1013

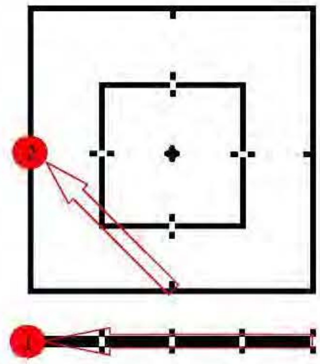
13$_R^*$	**Test Point: 1013** Opp Rud, Neut Elv, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **1**

Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right



Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Neutral, Left – push after fully developed

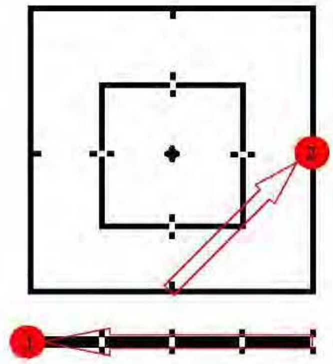
Recovery Altitude:	**3675**	Recovery Speed:	**125**	Recovery Revolutions:	**0 5/8**
Cooper-Harper Rating:	**4**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3675' MSL. Total altitude loss during maneuver was calculated to be 1325'. The Maximum indicated speed during spin recovery was 125 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 82 ft/sec. Aircraft continued to spin for 0.875 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.42 rev/sec. Comparing 13R* and 13R, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a significant 125ft higher recovery altitude, 3800ft versus 3675ft. 13R* produces a higher average spin recovery rate then 13R, 0.42 versus 0.36 rev/sec. Recovery time was the same for both methods. The higher average vertical velocity of method 13R* contributed to the lower recovery altitude, 82 versus 78 ft/sec.
Pilot differences in 13R* and 13L* where the right hand spin recovery, 13R*, was significantly more positive in stability and control than the left hand spin recovery, 13L*. While 13L* felt poor in nearly all attributes 13R* exhibited pro spin recover attributes with a clean stall break, crisp and responsive controls through recovery, and no acceleration of spin motions. This results defies the majority of results as left hand spiraling spins are the preferred recoveries. The inclusion of anti-spin aileron methods,13 and 17, seam to consistently prefer right hand spiraling spins. Inclusion of a pause raised the workload.

FLIGHT TEST CARD 1014

14* R	**Test Point: 1014** Opp Rud, Neut Elv, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **0** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Neutral, Right – push after fully developed

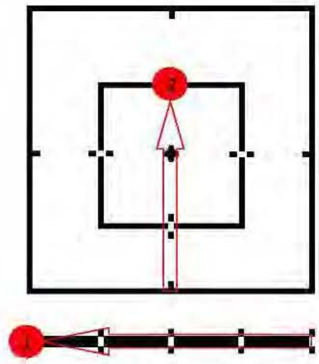
Recovery Altitude:	**3675**	Recovery Speed:	**130**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**4**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3675' MSL. Total altitude loss during maneuver was calculated to be 1325'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 82 ft/sec. Aircraft continued to spin for 1.125 rev after initiation of recovery controls. Recovery time was 3.0 sec with a calculated average spin rate of 0.38 rev/sec. Comparing 14R* and 14R, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a marginal 50ft higher recovery altitude, 3725ft versus 3675ft. We see that all other factors are similar as well. The only noticeable difference is the spin rate and the recovery time. The two spins recovery methods obtain the same number of revolutions, 1.125 revolutions. However, the spin rate for 14R* produced a slower spin rate with a longer recovery time: 0.38 versus 0.54 rev/sec and 3.0 versus 2.1 sec. The Higher average spin rate on 14R may be attributable to the fact that pro-spin aileron controls is introduce sooner than with 14R*.
Pilot noted that the workload for inclusion of the pause raises the workload. Additionally for more complex inputs with roll and pitch stick combined inputs that additional workload is more significant. The delay is almost required to think about next response. Feeling of slight increase in elevator authority with inputting elevator control is diminished by complexity of movements.

FLIGHT TEST CARD 1015

15$_R^*$	**Test Point: 1015** Opp Rud, Pitch Down, Neut Aileron – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Mid Fwd, Neutral – push after fully developed

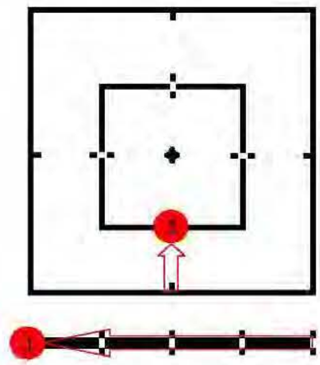
Recovery Altitude:	3650	Recovery Speed:	133	Recovery Revolutions:	0 7/8
Cooper-Harper Rating:	3	Bedford Rating:	4		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3650' MSL. Total altitude loss during maneuver was calculated to be 1350'. The Maximum indicated speed during spin recovery was 133 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 84 ft/sec. Aircraft continued to spin for 0.875 rev after initiation of recovery controls. Recovery time was 2.1 sec with a calculated average spin rate of 0.42 rev/sec. Comparing 15R* and 15R, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a marginal 50ft higher recovery altitude, 3700ft versus 3650ft. 15R* produces a higher average recovery spin rate then 15R, 0.42 versus 0.38 rev/sec. Recovery time was the similar for both methods. Note this method is identical to PARE method as the elevator push is through neutral stick position.
Pilot noted that the advertised and expected increase in rudder authority from the inclusion of the delay, was not felt or observed. Stall break and recovery where clean with no observed stability issues. After review of the data, test measurements supported the pilots observations. While the recovery for 15R* had positive attributes similar to 15R, there was no addition gains in performance factors of the recovery. The inclusion of the delay in control inputs only delayed recovery from the spin.

FLIGHT TEST CARD 1016

16* R	**Test Point: 1016** Opp Rud, Pitch Up, Neut Aileron – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Mid Aft, Neutral – push after fully developed

Recovery Altitude:	**3725**	Recovery Speed:	**120**	Recovery Revolutions:	**1 1/4**
Cooper-Harper Rating:	**3**	Bedford Rating:	**3**		

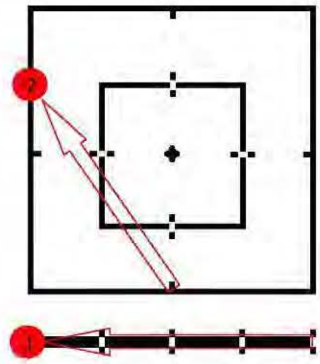
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3725' MSL. Total altitude loss during maneuver was calculated to be 1275'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 18.2 sec. Calculated average vertical velocity during maneuver was 70 ft/sec. Aircraft continued to spin for 1.250 rev after initiation of recovery controls. Recovery time was 3.1 sec with a calculated average spin rate of 0.40 rev/sec. Comparing 16R* and 16R, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a marginal 25ft higher recovery altitude, 3750ft versus 3725ft. 16R* produces a higher average spin recovery rate then 16R, 0.40 versus 0.38 rev/sec. Recovery time was the similar for both methods. Note this method is nearly identical to PARE method with the exception that elevator push is a 1/2 elevator up input short of neutral.
Pilot noted that the advertised and expected increase in rudder authority from the inclusion of the delay, was not felt or observed. Stall break and recovery where clean with no observed stability issues. After review of the data, test measurements supported the pilots observations. While the recovery for 16R* had positive attributes similar to 16R, there was no addition gains in performance factors of the recovery. The inclusion of the delay in control inputs only delayed recovery from the spin.

FLIGHT TEST CARD 1017

17* R	**Test Point: 1017** Opp Rud, Pitch Down, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Mid Fwd, Left – push after fully developed

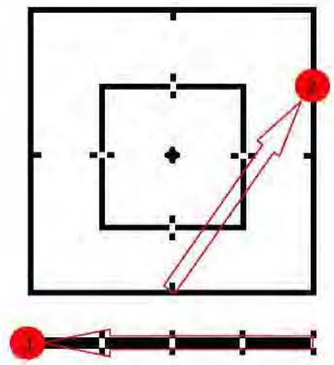
Recovery Altitude:	**3800**	Recovery Speed:	**125**	Recovery Revolutions:	**0 1/2**
Cooper-Harper Rating:	**6**	Bedford Rating:	**6**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3800' MSL. Total altitude loss during maneuver was calculated to be 1200'. The Maximum indicated speed during spin recovery was 125 mph. Recorded time from stall to spin recovery was 15.2 sec. Calculated average vertical velocity during maneuver was 79 ft/sec. Aircraft continued to spin for 0.500 rev after initiation of recovery controls. Recovery time was 1.3 sec with a calculated average spin rate of 0.38 rev/sec. Comparing 17R* and 17R, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a remarkably worse higher recovery altitude, 3675ft versus 3800ft. We see that all other factors are dramatically different as well. 17R* is the only method which a pause between rudder and stick actions provides a favorable recovery altitude.
Pilot noted differences in 17R* and 17L* where the right hand spin recovery, 17R*, was significantly more positive in stability and control than the left hand spin recovery, 17L*. 17L* felt poor in nearly all attributes 17R* exhibited pro spin recover attributes with a clean stall break, crisp and responsive controls through recovery, and no acceleration of spin motions. This results defies the majority of results as left hand spiraling spins are the preferred recoveries. The inclusion of anti-spin aileron methods,13 and 17, seam to consistently prefer right hand spiraling spins. Inclusion of a pause raised the workload.

FLIGHT TEST CARD 1018

18* R	**Test Point: 1018** Opp Rud, Pitch Down, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

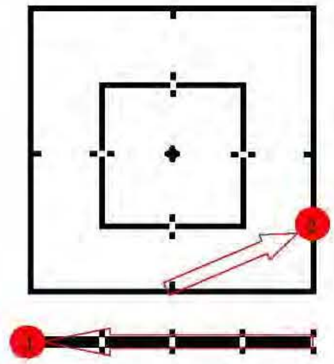
Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Mid Fwd, Right – push after fully developed

Recovery Altitude:	3500	Recovery Speed:	145	Recovery Revolutions:	1 3/8
Cooper-Harper Rating:	6	Bedford Rating:	6		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3500' MSL. Total altitude loss during maneuver was calculated to be 1500'. The Maximum indicated speed during spin recovery was 145 mph. Recorded time from stall to spin recovery was 17.1 sec. Calculated average vertical velocity during maneuver was 88 ft/sec. Aircraft continued to spin for 1.375 rev after initiation of recovery controls. Recovery time was 3.2 sec with a calculated average spin rate of 0.43 rev/sec. Comparing 18R* and 18R, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a significant 150ft higher recovery altitude, 3650ft versus 3500ft. We see that all other factors are different as well.
Pilot noted that the workload for inclusion of the pause raises the workload. Additionally for more complex inputs with roll and pitch stick combined inputs that additional workload is more significant. The delay is almost required to think about next response. Feeling of slight increase in elevator authority with inputting elevator control is diminished by complexity of movements. Additionally for more complex inputs with roll and pitch stick combined inputs that additional workload is more significant. The delay is almost required to think about next response. Feeling of slight increase in elevator authority with inputting elevator control is diminished by complexity of movements.

FLIGHT TEST CARD 1019

19* R	**Test Point: 1019** Opp Rud, Pitch Down, Pro Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **-1**



Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Mid Aft, Right – push after fully developed

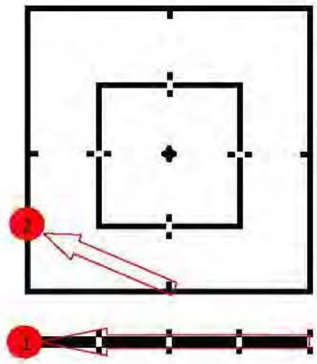
Recovery Altitude:	**3400**	Recovery Speed:	**130**	Recovery Revolutions:	**2 5/8**
Cooper-Harper Rating:	**5**	Bedford Rating:	**5**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3400' MSL. Total altitude loss during maneuver was calculated to be 1600'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 19.2 sec. Calculated average vertical velocity during maneuver was 83 ft/sec. Aircraft continued to spin for 2.625 rev after initiation of recovery controls. Recovery time was 4.1 sec with a calculated average spin rate of 0.64 rev/sec. Comparing 19R* and 19R, a direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a significant 150ft higher recovery altitude, 3700ft versus 3400ft. A noticeable difference is the spin rate and the recovery time. The spin rate for 19R* produced a slower spin rate with a longer recovery time: 0.64 versus 0.65 rev/sec and 4.1 versus 2.3 sec. The Higher average spin rate on 19R may be attributable to the fact that pro-spin aileron controls is introduce sooner than with 19R*.
Pilot noted aircraft was on the verge of being unrecoverable. While video recovery shows that recovery was achieved at 3400ft MSL, the pilot recognized a much lower recovery altitude of 3300ft demonstrating the increased complexity in recovery controls, poor stability, and lack of control response added to pilots workload causing assigned tasks to be shed.

FLIGHT TEST CARD 1020

20$^{*}_{R}$	**Test Point: 1020** Opp Rud, Pitch up, Anti Spin Roll – R Throttle: **0** Rudder: **0** Elevator: **-1** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Right

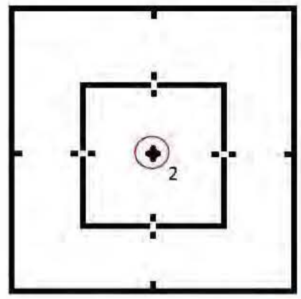
Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Left – stomp after fully developed
  - (pause)
  - Stick- Mid Aft, Left – push after fully developed

Recovery Altitude:	3700	Recovery Speed:	120	Recovery Revolutions:	1 1/4
Cooper-Harper Rating:	5	Bedford Rating:	5		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 80 ft/sec. Aircraft continued to spin for 1.250 rev after initiation of recovery controls. Recovery time was 3.2 sec with a calculated average spin rate of 0.39 rev/sec. Comparing 14R* and 14R, we see while both methods arrive at the same recovery altitude, 3700ft. All other factors are different. The number of revolutions for 20R* and 20R are 1.250 and 0.875 revolutions respectively. The spin rate for 14R* produced a marginally slower spin rate with a significantly longer recovery time: 0.39 versus 0.40 rev/sec and 3.2 versus 2.2 sec.
Pilot noted differences in 19R* and 20R* where the right hand spin recovery, 20R*, was significantly more positive in stability and control than the right hand spin recovery, 19L*. 19L* was nearly unrecoverable while 20R* exhibited pro spin recover attributes with clean stall break, crisp and responsive controls through recovery, and no acceleration of spin motions. The inclusion of anti-spin aileron seams to completely change the dynamics of the response of the airplane during spin recovery.

FLIGHT TEST CARD 1111

11L*	**Test Point: 1111** Neut Rud, Free Stick – L Throttle: **0** Rudder: **1** Elevator: **F** Aileron: **F**



Test Point Setup:

- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:

- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:

- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Free – release after fully developed

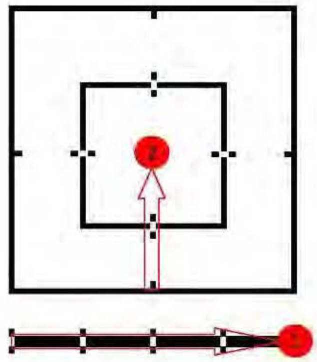
Recovery Altitude:	3350	Recovery Speed:	135	Recovery Revolutions:	1
Cooper-Harper Rating:	10	Bedford Rating:	2		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3350' MSL. Total altitude loss during maneuver was calculated to be 1650'. The Maximum indicated speed during spin recovery was 135 mph. Recorded time from stall to spin recovery was 20.1 sec. Calculated average vertical velocity during maneuver was 82 ft/sec. Aircraft continued to spin for 1.000 rev after initiation of recovery controls. Recovery time was 2.3 sec with a calculated average spin rate of 0.43 rev/sec. Comparing 11L* with 11L we attempt to answer the question of the effectiveness of splitting the rudder input actions from aileron and elevator actions. A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a significant 125ft higher recovery altitude, 3500ft versus 3350ft (note 11L initiated at 5025ft).
Pilot noted the airplane response in 11L* (pause) was similar to the response noted in 11L (no pause). Airplane presented a sharp nose over upon initiation of recovery controls with a zero g sensation. Loss of feedback control was same as the mechanical connections to the control surfaces provide a conscious sense of a control feedback loop. The stall break upon recovery was noted as dirty and added a concern that positive breaking response to control inputs took longer than expected. Inclusion of a pause raised the workload slightly; however, the already low workload did not affect the overall workload rating.

FLIGHT TEST CARD 1112

12^{*}_{L}	**Test Point: 1112** Neut Rud, Neut Stick – L Throttle: **0** Rudder: **1** Elevator: **0** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Neutral, Neutral – push after fully developed

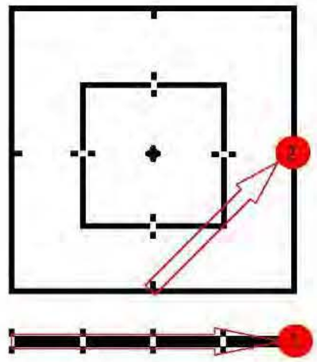
Recovery Altitude:	**3500**	Recovery Speed:	**135**	Recovery Revolutions:	**0 1/2**
Cooper-Harper Rating:	**2**	Bedford Rating:	**3**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3500' MSL. Total altitude loss during maneuver was calculated to be 1500'. The Maximum indicated speed during spin recovery was 135 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 93 ft/sec. Aircraft continued to spin for 0.500 rev after initiation of recovery controls. Recovery time was 1.2 sec with a calculated average spin rate of 0.42 rev/sec. Comparing 12L* and 12L, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a significant 200ft higher recovery altitude, 3700ft versus 3500ft. 12L* produces a higher average recovery spin rate then 12L, 0.42 versus 0.36 rev/sec. Additionally, recovery time of 12R* was shorter by 0.9 seconds. However, as the average vertical velocity was 16 kts faster for 12R* the shorter recovery time made no difference. Comparing 12R* with 12L* we see similar results between the two methods allowing variation for left versus right spin directions.
Pilot noted no difference in stability or control from 12L to 12L*. Aircraft responded with a very clean stall break and slight nose over upon initiation of recovery controls. Low g sensation was similar as well. Positive control was felt throughout the recovery with a feeling of ample control. Slight roll and yaw sensation was less pronounced than with 12L.

FLIGHT TEST CARD 1113

13*L	Test Point: 1113 Neut Rud, Neut Elv, Anti Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **0** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Neutral, Right – push after fully developed

Recovery Altitude:	**3500**	Recovery Speed:	**137**	Recovery Revolutions:	**1 1/2**
Cooper-Harper Rating:	**4**	Bedford Rating:	**4**		

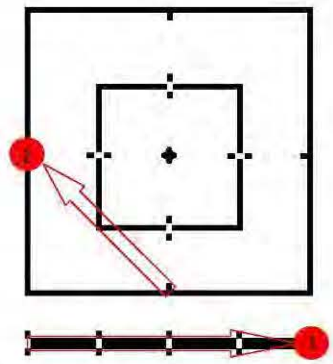
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3500' MSL. Total altitude loss during maneuver was calculated to be 1500'. The Maximum indicated speed during spin recovery was 137 mph. Recorded time from stall to spin recovery was 16.1 sec. Calculated average vertical velocity during maneuver was 93 ft/sec. Aircraft continued to spin for 1.500 rev after initiation of recovery controls. Recovery time was 3.2 sec with a calculated average spin rate of 0.47 rev/sec. Comparing 13L* and 13L, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a significant 350ft higher recovery altitude, 3850ft versus 3500ft. 13L* produces a higher spin recovery rate than 13L, 0.47 versus 0.28 rev/sec. The higher average vertical velocity of method 13L* contributed to the lower recovery altitude, 93 versus 79 ft/sec. Pilot noted discomfort with recovery with unusual loading of the aircraft. Recognized asymmetric loading was present on 13L. This unusual loading is likely similar in fashion; however, presenting differently due to the pause on the stick inputs. Stall break was very dirty with unstable responses in both pitch and yaw. . Inclusion of a pause raised the workload slightly.

FLIGHT TEST CARD 1114

14$_{L}^{*}$	**Test Point: 1114** Neut Rud, Neut Elv, Pro Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **0** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Neutral, Left – push after fully developed

Recovery Altitude:	**3500**	Recovery Speed:	**140**	Recovery Revolutions:	**0 7/8**
Cooper-Harper Rating:	**4**	Bedford Rating:	**4**		

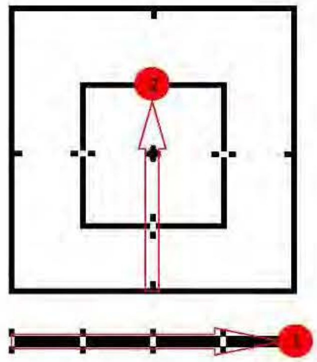
Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3500' MSL. Total altitude loss during maneuver was calculated to be 1500'. The Maximum indicated speed during spin recovery was 140 mph. Recorded time from stall to spin recovery was 15.1 sec. Calculated average vertical velocity during maneuver was 99 ft/sec. Aircraft continued to spin for 0.875 rev after initiation of recovery controls. Recovery time was 2.2 sec with a calculated average spin rate of 0.40 rev/sec. Comparing 14L* and 14L, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a 100ft higher recovery altitude, 3600ft versus 3500ft. Included pause for 14L* contributed to the higher average vertical velocity, 99 versus 78 ft/sec. The spin rate was lower for 14L* however the difference of 0.40 vs 0.42 rev/sec is insignificant.
Pilot noted discomfort with recovery with unusual loading of the aircraft. This unusual loading was similar in fashion to 13*L. The included pause created an immediate response in the elevator with a notable increase in effectiveness which may have contributed to the unusual loading conditions. Stall break was very dirty with unstable responses in both pitch and yaw. . Inclusion of a pause raised the workload slightly.

FLIGHT TEST CARD 1115

15^{*}_{L}	**Test Point: 1115** Neut Rud, Pitch Down, Neut Aileron – L Throttle: **0** Rudder: **1** Elevator: **1** Aileron: **0**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left



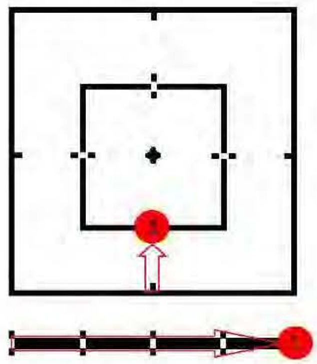
Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Mid Fwd, Neutral – push after fully developed

Recovery Altitude:	**3500**	Recovery Speed:	**140**	Recovery Revolutions:	**0 5/8**
Cooper-Harper Rating:	**3**	Bedford Rating:	**4**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3500' MSL. Total altitude loss during maneuver was calculated to be 1500'. The Maximum indicated speed during spin recovery was 140 mph. Recorded time from stall to spin recovery was 17.1 sec. Calculated average vertical velocity during maneuver was 88 ft/sec. Aircraft continued to spin for 0.625 rev after initiation of recovery controls. Recovery time was 1.3 sec with a calculated average spin rate of 0.48 rev/sec. Comparing 15L* and 15L, A direct comparison of the recovery altitudes shows that simultaneous inputs of stick and rudder produced a 150ft higher recovery altitude, 3650ft versus 3500ft. 15L* produces a higher average recovery spin rate then 13L, 0.48 versus 0.38 rev/sec. Recovery time was the quicker with the pause; however, the added pause again produced worse results. Note this method is identical to PARE method as the elevator push is through neutral stick position.
Pilot noted the included pause created an immediate response in the elevator with a notable increase in effectiveness. This is likely to have contributed to the negative g loading on the aircraft felt post elevator input and throughout the remainder of the recovery. This was dramatically more abrupt in onset rate then recoveries without pause.

FLIGHT TEST CARD 1116

16* L	**Test Point: 1116** Neut Rud, Pitch Up, Neut Aileron – L Throttle: **0** Rudder: **1** Elevator: **-1** Aileron: **0**



Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

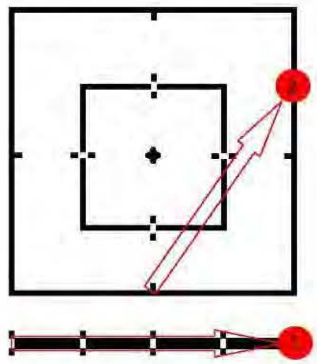
Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Mid Aft, Neutral – push after fully developed

Recovery Altitude:	**3800**	Recovery Speed:	**115**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**3**	Bedford Rating:	**3**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3800' MSL. Total altitude loss during maneuver was calculated to be 1200'. The Maximum indicated speed during spin recovery was 115 mph. Recorded time from stall to spin recovery was 15.2 sec. Calculated average vertical velocity during maneuver was 79 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 1.3 sec with a calculated average spin rate of 0.48 rev/sec. Comparing 16L* and 16L, a direct comparison of nearly all performance indicators reveals that both methods produce similar results with insignificant differences. This is likely due to the requested recovery controls are minimal and any performance gains from pausing or not pausing between inputs is washed out in the effectiveness of the minimal request of the control surface.
Pilot noted no differences in the response or feedback from these inputs. Elevator did not provide the typical abrupt pitch loading found with previous recovery controls that included a pause between rudder and elevator. Stall break was poor but adequate to identify break only after input from elevator.

FLIGHT TEST CARD 1117

17^{*}_{L}	**Test Point: 1117** Neut Rud, Pitch Down, Anti Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **1** Aileron: **1**



Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm

Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Mid Fwd, Right – push after fully developed

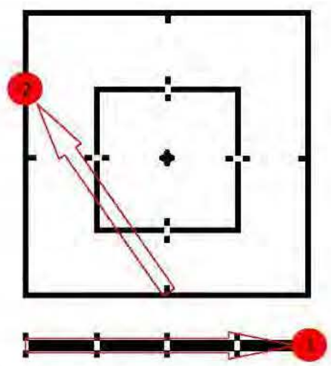
Recovery Altitude:	**3600**	Recovery Speed:	**130**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**6**	Bedford Rating:	**6**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3600' MSL. Total altitude loss during maneuver was calculated to be 1400'. The Maximum indicated speed during spin recovery was 130 mph. Recorded time from stall to spin recovery was 17.1 sec. Calculated average vertical velocity during maneuver was 82 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.0 sec with a calculated average spin rate of 0.38 rev/sec. Comparing 17*L and 18*L with the no pause counterparts 17L and 18L we see that there are similarities between left and right spin directions. 17*L and 18*L have similar performance results as do 17L and 18L. However, the inclusion of the pause in 17*L and 18*R produced worse results with lower recovery altitudes.
Pilot noted differences in 17R* and 17L* where the right hand spin recovery, 17R*, was significantly more positive in stability and control than the left hand spin recovery, 17L*. 17L* felt poor in nearly all attributes 17R* exhibited pro spin recover attributes with a clean stall break, crisp and responsive controls through recovery, and no acceleration of spin motions. This results defies the majority of results as left hand spiraling spins are the preferred recoveries. The inclusion of anti-spin aileron methods,13 and 17, seam to consistently prefer right hand spiraling spins. Inclusion of a pause raised the workload.

FLIGHT TEST CARD 1118

18* L	**Test Point: 1118** Neut Rud, Pitch Down, Pro Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Mid Fwd, Left – push after fully developed

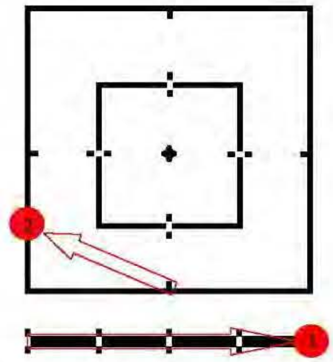
Recovery Altitude:	**3600**	Recovery Speed:	**135**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**6**	Bedford Rating:	**6**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3600' MSL. Total altitude loss during maneuver was calculated to be 1400'. The Maximum indicated speed during spin recovery was 135 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 86 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.0 sec with a calculated average spin rate of 0.38 rev/sec. Comparing 17*L and 18*L with the no pause counterparts 17L and 18L we see that there are similarities between left and right spin directions. 17*L and 18*L have similar performance results as do 17L and 18L. However, the inclusion of the pause in 17*L and 18*R produced worse results with lower recovery altitudes.
Pilot noted that the workload for inclusion of the pause raises the workload. Additionally for more complex inputs with roll and pitch stick combined inputs that additional workload is more significant. The delay is almost required to think about next response. Feeling of slight increase in elevator authority with inputting elevator control is diminished by complexity of movements. Additionally for more complex inputs with roll and pitch stick combined inputs that additional workload is more significant. The delay is almost required to think about next response. Feeling of slight increase in elevator authority with inputting elevator control is diminished by complexity of movements.

FLIGHT TEST CARD 1119

19* L	**Test Point: 1119** Neut Rud, Pitch Down, Pro Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **-1** Aileron: **-1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Mid Aft, Left – push after fully developed

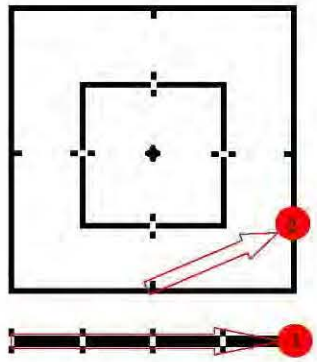
Recovery Altitude:	**3700**	Recovery Speed:	**120**	Recovery Revolutions:	**1 1/8**
Cooper-Harper Rating:	**5**	Bedford Rating:	**5**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3700' MSL. Total altitude loss during maneuver was calculated to be 1300'. The Maximum indicated speed during spin recovery was 120 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 80 ft/sec. Aircraft continued to spin for 1.125rev after initiation of recovery controls. Recovery time was 2.8 sec with a calculated average spin rate of 0.40 rev/sec. Comparing 19*L and 20*L with the no pause counterparts 19L and 20L we see that there are similarities between all four results. This is likely due to the results found in 16*L versus 16L where the requested recovery controls are minimal and any performance gains from pausing or not pausing between inputs is washed out in the effectiveness of the minimal request of the control surface. Additionally we see little difference in L versus R spin directions as with methods17 versus methods 18.
Pilot noted aircraft was on the verge of being unrecoverable similar to 19*R. Break was significantly more pronounced with 19*L then with 19*R as demonstrated in the higher recovery altitude. Pilot noted more variability with all mid aft pitch stick positions whether neutral of left and right ailerons. There seems to be a step in the recovery model where stick position is effector is extremely sensitive in this region and will impact recoverability.

FLIGHT TEST CARD 1120

20* L	**Test Point: 1120** Neut Rud, Pitch up, Anti Spin Roll – L Throttle: **0** Rudder: **1** Elevator: **-1** Aileron: **1**

Test Point Setup:
- Altitude: Trim 5000 MSL
- CG: < 60 min Fuel Burn
- Video: Rec
- Test Point: Confirm



Normal Spin:
- Throttle- Idle
- Altitude- Hold
  Wing Level Break
- Rudder- Full Left

Spin Recovery:
- Developed Spin: 3 Revolutions
- Initiate Recovery Controls:
  - Throttle- Idle – check idle
  - Rudder- Right – stomp after fully developed
  - (pause)
  - Stick- Mid Aft, Right – push after fully developed

Recovery Altitude:	**3725**	Recovery Speed:	**115**	Recovery Revolutions:	**0 3/4**
Cooper-Harper Rating:	**5**	Bedford Rating:	**5**		

Notes:
Stall was initiated at 5000' MSL. Minimum altitude reached during recovery was 3725' MSL. Total altitude loss during maneuver was calculated to be 1275'. The Maximum indicated speed during spin recovery was 115 mph. Recorded time from stall to spin recovery was 16.2 sec. Calculated average vertical velocity during maneuver was 79 ft/sec. Aircraft continued to spin for 0.750 rev after initiation of recovery controls. Recovery time was 2.0 sec with a calculated average spin rate of 0.38 rev/sec. Comparing 19*L and 20*L with the no pause counterparts 19L and 20L we see that there are similarities between all four results. This is likely due to the results found in 16*L versus 16L where the requested recovery controls are minimal and any performance gains from pausing or not pausing between inputs is washed out in the effectiveness of the minimal request of the control surface. Additionally we see little difference in L versus R spin directions as with methods17 versus methods 18.
Pilot noted similarities in 19L* and 20L* where both the left hand spin recovery, 20*L and the left hand spin recovery, 19L* were responsive controls through recovery, and no acceleration of spin motions. The inclusion of anti-spin aileron in this case seams a minor improvement in recovery altitudes. When taking into account the significantly lower recovery revolutions we can place a number to the improvement of the stall break from 1 1/8 revolutions with prospin 19*L and 3/4 revolutions with antispin 20*L.

Appendix C: Flight Test Data

Test Point	Throttle	Rudder	Elevator	Aileron	Beginning Altitude (ft)	Ending Altitude (ft)	Lost Altitude (ft)	Maximum Velocity (mph)	Time (sec)	Avg Vert Velocity (ft/sec)	Relvolutions	Time (sec)	Spin Rate (RPS)
1R	0	F	F	F	5000	3250	1750	135	19.2	91	3.125	5.2	0.60
2R	0	0	0	0	5000	3700	1300	120	16.2	80	1.250	3.0	0.42
3R	0	0	0	1	5000	3650	1350	120	16.2	83	1.125	3.2	0.35
4R	0	0	0	-1	5000	3675	1325	120	16.0	83	1.500	3.1	0.48
5R	0	0	1	0	5000	3650	1350	130	15.2	89	1.125	2.1	0.54
6R	0	0	-1	0	5000	3575	1425	125	16.3	87	1.750	4.1	0.43
7R	0	0	1	1	5000	3600	1400	130	16.1	87	0.875	2.1	0.42
8R	0	0	1	-1	5000	3525	1475	127	16.2	91	1.625	3.1	0.52
9R	0	0	-1	-1	5000	X	X	X	X	X	X	X	X
10R	0	0	-1	1	5000	3600	1400	125	18.2	77	1.500	4.2	0.36
11R	0	1	F	F	5000	3650	1350	130	16.1	84	1.125	2.3	0.49
12R	0	1	0	0	5000	3700	1300	123	15.4	84	0.750	2.1	0.36
13R	0	1	0	1	5000	3800	1200	120	15.3	78	0.750	2.1	0.36
14R	0	1	0	-1	5000	3725	1275	120	15.2	84	1.125	2.1	0.54
15R	0	1	1	0	5000	3700	1300	120	15.1	86	0.750	2.0	0.38
16R	0	1	-1	0	5000	3750	1250	115	16.1	78	1.125	3.0	0.38
17R	0	1	1	1	5000	3675	1325	130	15.0	88	0.625	1.2	0.52
18R	0	1	1	-1	5000	3650	1350	133	16.1	84	1.250	2.5	0.50
19R	0	1	-1	-1	5000	3700	1300	127	16.0	81	1.500	2.3	0.65
20R	0	1	-1	1	5000	3700	1300	117	15.2	86	0.875	2.2	0.40

Test Point	Throttle	Rudder	Elevator	Aileron	Beginning Altitude (ft)	Ending Altitude (ft)	Lost Altitude (ft)	Maximum Velocity (mph)	Time (sec)	Avg Vert Velocity (ft/sec)	Relvolutions	Time (sec)	Spin Rate (RPS)
1L	0	F	F	F	5000	3250	1750	140	18.1	97	1.625	4.2	0.39
2L	0	0	0	0	5000	3550	1450	130	16.1	90	1.000	2.3	0.43
3L	0	0	0	1	5000	3500	1500	130	16.2	93	1.125	3.2	0.35
4L	0	0	0	-1	5000	3400	1600	140	17.2	93	1.625	3.3	0.49
5L	0	0	1	0	5000	3575	1425	135	17.3	82	1.125	2.4	0.47
6L	0	0	-1	0	5000	X	X	X	X	X	X	X	X
7L	0	0	1	1	5000	3550	1450	130	17.1	85	1.375	3.1	0.44
8L	0	0	1	-1	5000	3350	1650	150	17.2	96	1.625	4.0	0.41
9L	0	0	-1	-1	5000	X	X	X	X	X	X	X	X
10L	0	0	-1	1	5000	X	X	X	X	X	X	X	X
11L	0	1	F	F	5025	3500	1525	140	15.9	96	1.375	2.8	0.49
12L	0	1	0	0	5000	3700	1300	125	16.9	77	0.750	2.1	0.36
13L	0	1	0	1	5000	3850	1150	120	14.5	79	0.500	1.8	0.28
14L	0	1	0	-1	5000	3600	1400	130	18.0	78	1.250	3.0	0.42
15L	0	1	1	0	5000	3650	1350	130	16.9	80	0.750	2.0	0.38
16L	0	1	-1	0	5000	3775	1225	115	16.0	77	0.875	2.2	0.40
17L	0	1	1	1	5000	3650	1350	130	16.2	83	0.625	1.5	0.42
18L	0	1	1	-1	5000	3675	1325	135	16.0	83	1.000	2.5	0.40
19L	0	1	-1	-1	5000	3600	1400	130	17.2	81	1.125	2.1	0.54
20L	0	1	-1	1	5000	3700	1300	120	16.1	81	0.750	2.0	0.38

Test Point	Throttle	Rudder	Elevator	Aileron	Beginning Altitude (ft)	Ending Altitude (ft)	Lost Altitude (ft)	Maximum Velocity (mph)	Time (sec)	Avg Vert Velocity (ft/sec)	Relvolutions	Time (sec)	Spin Rate (RPS)
11R*	0	1	F	F	5000	3600	1400	135	17.1	82	1.125	3.1	0.36
12R*	0	1	0	0	5000	3600	1400	130	16.1	87	1.500	3.2	0.47
13R*	0	1	0	1	5000	3675	1325	125	16.2	82	0.875	2.1	0.42
14R*	0	1	0	-1	5000	3675	1325	130	16.2	82	1.125	3.0	0.38
15R*	0	1	1	0	5000	3650	1350	133	16.1	84	0.875	2.1	0.42
16R*	0	1	-1	0	5000	3725	1275	120	18.2	70	1.250	3.1	0.40
17R*	0	1	1	1	5000	3800	1200	125	15.2	79	0.500	1.3	0.38
18R*	0	1	1	-1	5000	3500	1500	145	17.1	88	1.375	3.2	0.43
19R*	0	1	-1	-1	5000	3400	1600	130	19.2	83	2.625	4.1	0.64
20R*	0	1	-1	1	5000	3700	1300	120	16.2	80	1.250	3.2	0.39
11L*	0	1	F	F	5000	3350	1650	135	20.1	82	1.000	2.3	0.43
12L*	0	1	0	0	5000	3500	1500	135	16.2	93	0.500	1.2	0.42
13L*	0	1	0	1	5000	3500	1500	137	16.1	93	1.500	3.2	0.47
14L*	0	1	0	-1	5000	3500	1500	140	15.1	99	0.875	2.2	0.40
15L*	0	1	1	0	5000	3500	1500	140	17.1	88	0.625	1.3	0.48
16L*	0	1	-1	0	5000	3800	1200	115	15.2	79	0.750	2.1	0.36
17L*	0	1	1	1	5000	3600	1400	130	17.1	82	0.750	2.0	0.38
18L*	0	1	1	-1	5000	3600	1400	135	16.2	86	0.750	2.0	0.38
19L*	0	1	-1	-1	5000	3700	1300	120	16.2	80	1.125	2.8	0.40
20L*	0	1	-1	1	5000	3725	1275	115	16.2	79	0.750	2.0	0.38

Appendix D: REA.sim Model

Table 21: REA.sim Model Design (Actual)

Std	Block	Run	Factor 1 A:Rudder % Deflection	Factor 2 B:Elevator % Deflection	Factor 3 C:Aileron % Deflection	Response 1 Altitude Loss ft
6	Right Spins	1	0	0	0	1300
7	Right Spins	2	0	0	100	1350
1	Right Spins	3	0	0	-100	1325
4	Right Spins	4	0	50	0	1350
3	Right Spins	5	0	-50	0	1425
8	Right Spins	6	0	50	100	1400
2	Right Spins	7	0	50	-100	1475
~~5~~	~~Right Spins~~	~~(8)~~	~~0~~	~~-50~~	~~-100~~	~~0~~
9	Right Spins	9	0	-50	100	1400
11	Right Spins	10	100	0	0	1300
12	Right Spins	11	100	0	100	1200
10	Right Spins	12	100	0	-100	1275
13	Right Spins	13	100	50	0	1300
14	Right Spins	14	100	-50	0	1250
16	Right Spins	15	100	50	100	1325
15	Right Spins	16	100	50	-100	1350
17	Right Spins	17	100	-50	-100	1300
18	Right Spins	18	100	-50	100	1300
19	Left Spins	19	0	0	0	1450
20	Left Spins	20	0	0	100	1500
22	Left Spins	21	0	0	-100	1600
23	Left Spins	22	0	50	0	1425
~~24~~	~~Left Spins~~	~~(23)~~	~~0~~	~~-50~~	~~0~~	~~0~~
21	Left Spins	24	0	50	100	1450
25	Left Spins	25	0	50	-100	1650
~~26~~	~~Left Spins~~	~~(26)~~	~~0~~	~~-50~~	~~-100~~	~~0~~
~~27~~	~~Left Spins~~	~~(27)~~	~~0~~	~~-50~~	~~100~~	~~0~~
28	Left Spins	28	100	0	0	1300
29	Left Spins	29	100	0	100	1150
30	Left Spins	30	100	0	-100	1400
31	Left Spins	31	100	50	0	1350
32	Left Spins	32	100	-50	0	1225
33	Left Spins	33	100	50	100	1350
34	Left Spins	34	100	50	-100	1325
35	Left Spins	35	100	-50	-100	1400
36	Left Spins	36	100	-50	100	1300

Table 22: REA.sim Model Data Statistics (Actual)

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.	
A	Rudder	% Deflection	Numeric	Continuous	0	100	-1.000=0	1.000=100	50	50.7093	
B	Elevator	% Deflection	Numeric	Continuous	-50	50	-1.000=-50	1.000=50	0	41.4039	
C	Aileron	% Deflection	Numeric	Continuous	-100	100	-1.000=-100	1.000=100	0	82.8079	
Response	**Name**	**Units**	**Obs**	**Analysis**	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**	**Ratio**	**Trans**	**Model**
R1	Altitude Loss	ft	32	Factorial	1150	1650	1359.38	105.063	1.43478	None	3FI

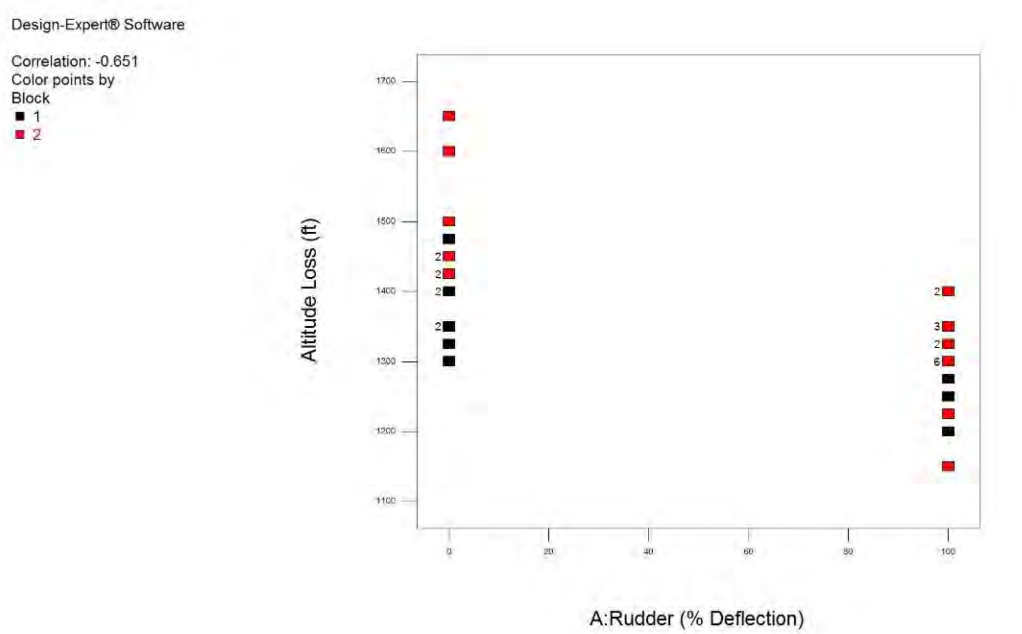


Figure 25: REA.sim Model: Rudder vs. Altitude Loss (Actual)

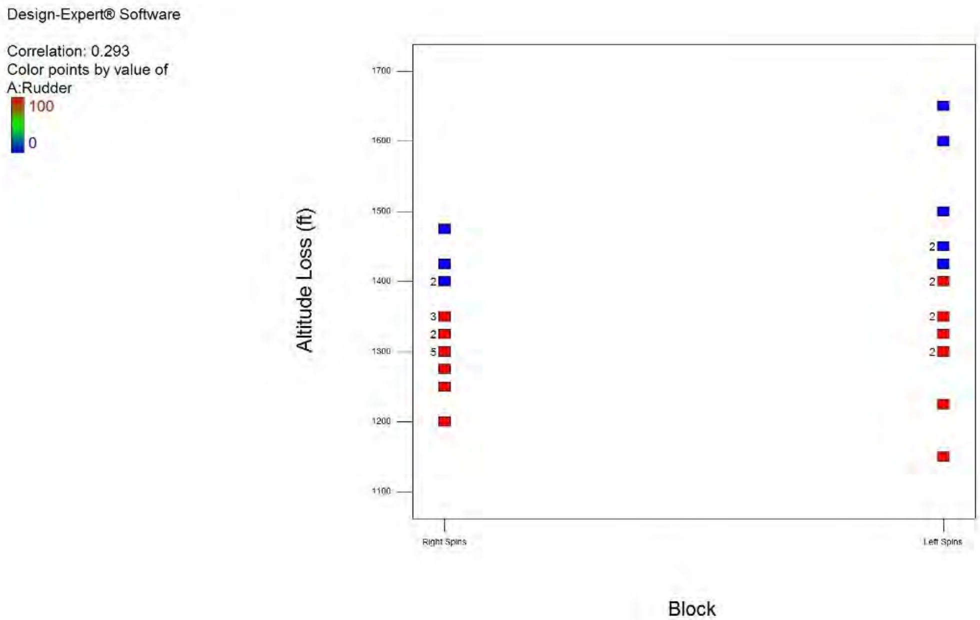


Figure 26: REA.sim Model: Block vs. Altitude Loss (Actual)

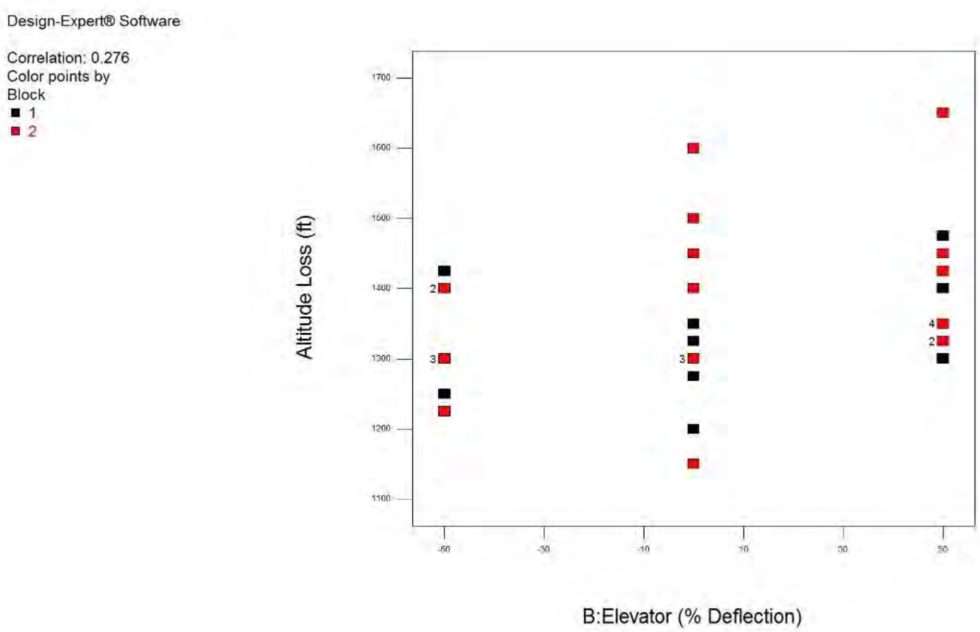


Figure 27: REA.sim Model: Elevator vs. Altitude Loss (Actual)

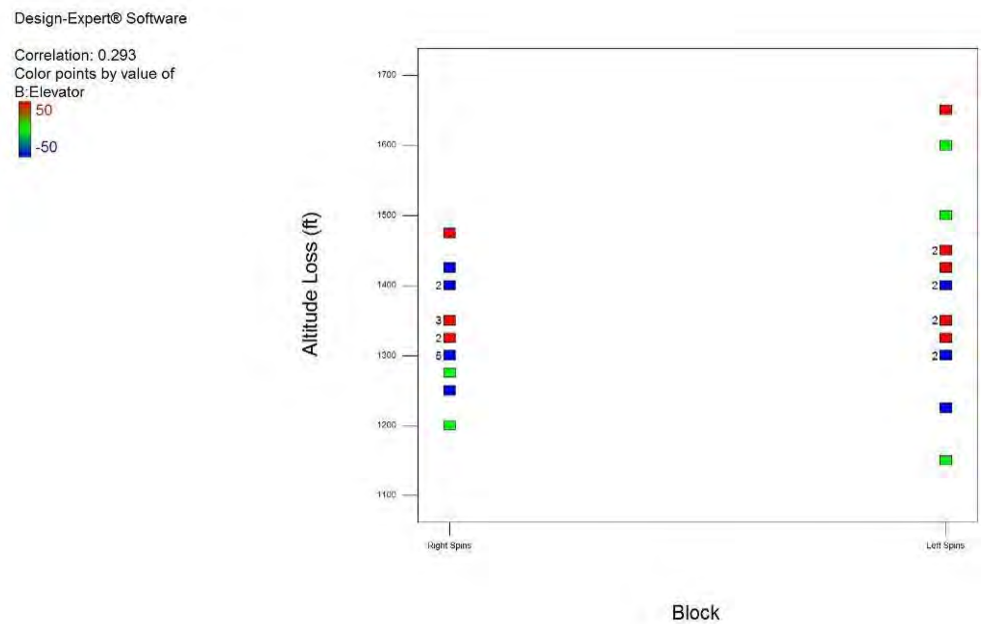


Figure 28: REA.sim Model: Block vs. Altitude Loss (Actual)

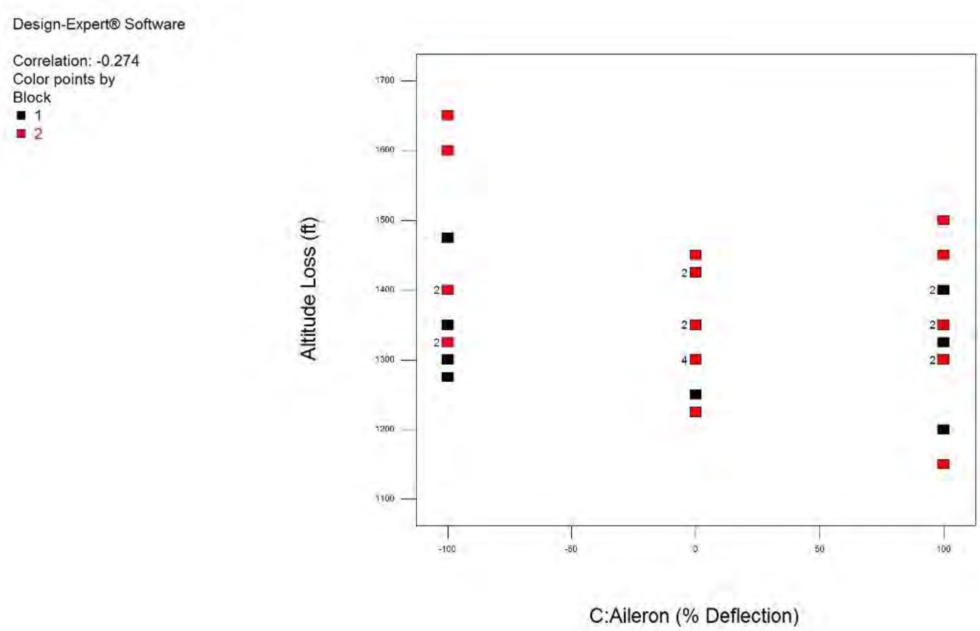


Figure 29: REA.sim Model: Aileron vs. Altitude Loss (Actual)

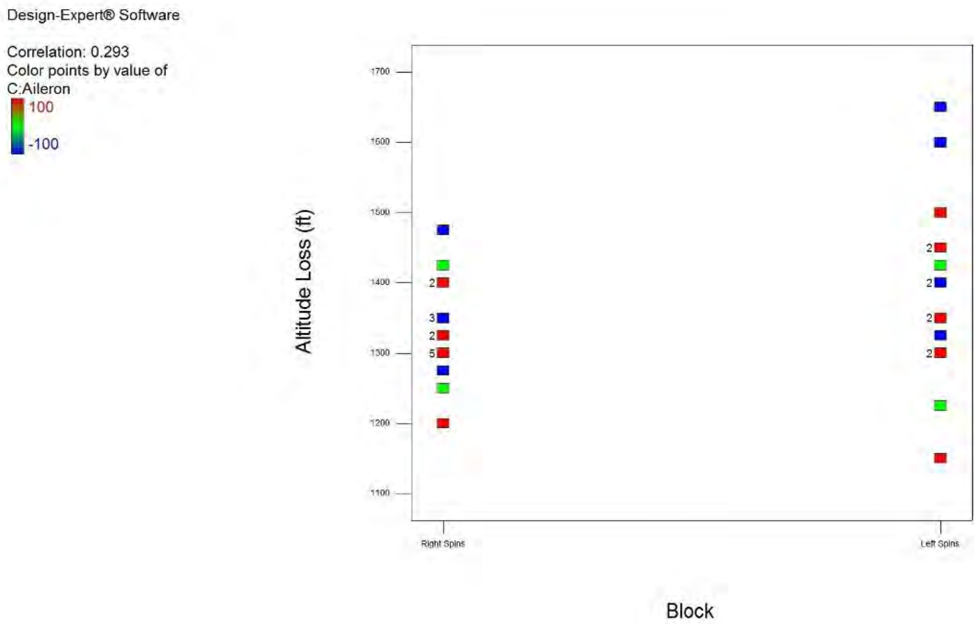


Figure 30: REA.sim Model Block vs. Altitude Loss (Actual)

Table 23: REA.sim Model Factor Selection

	Term	Stdized Effect	Sum of Squares	% Contribution
	Intercept			
M	A-Rudder	-133.70	1.184E+005	44.84
M	B-Elevator	28.35	5325.40	2.02
M	C-Aileron	-45.00	13412.16	5.08
M	AB	0.43	1.20	4.552E-004
M	AC	-11.04	807.05	0.31
M	BC	-20.09	2675.00	1.01
M	ABC	35.12	8172.05	3.09
e	Lack of Fit		1.153E+005	43.65
e	Pure Error		0.000	0.000

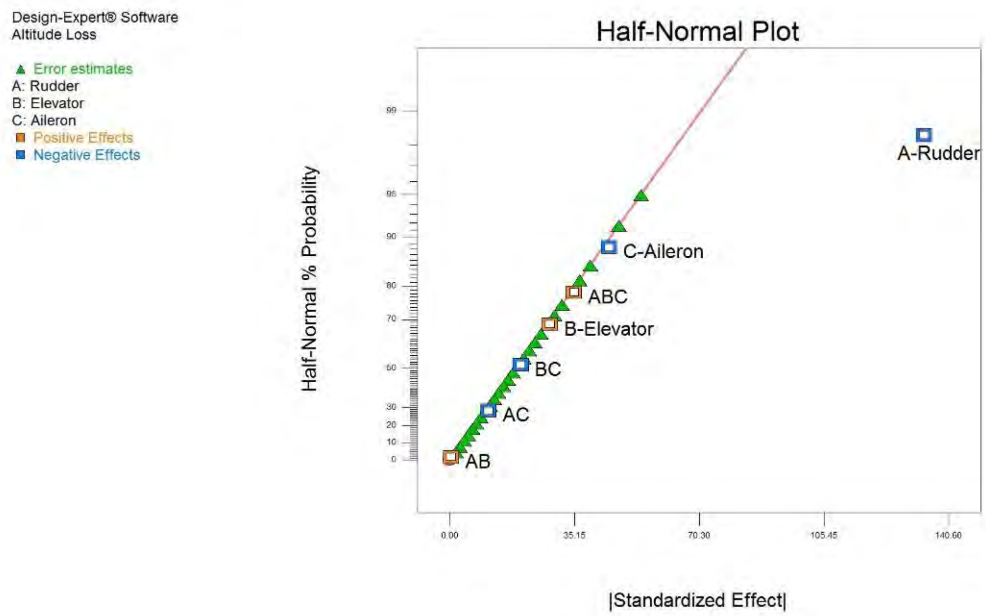


Figure 31: REA.sim Model Half-Normal Plot

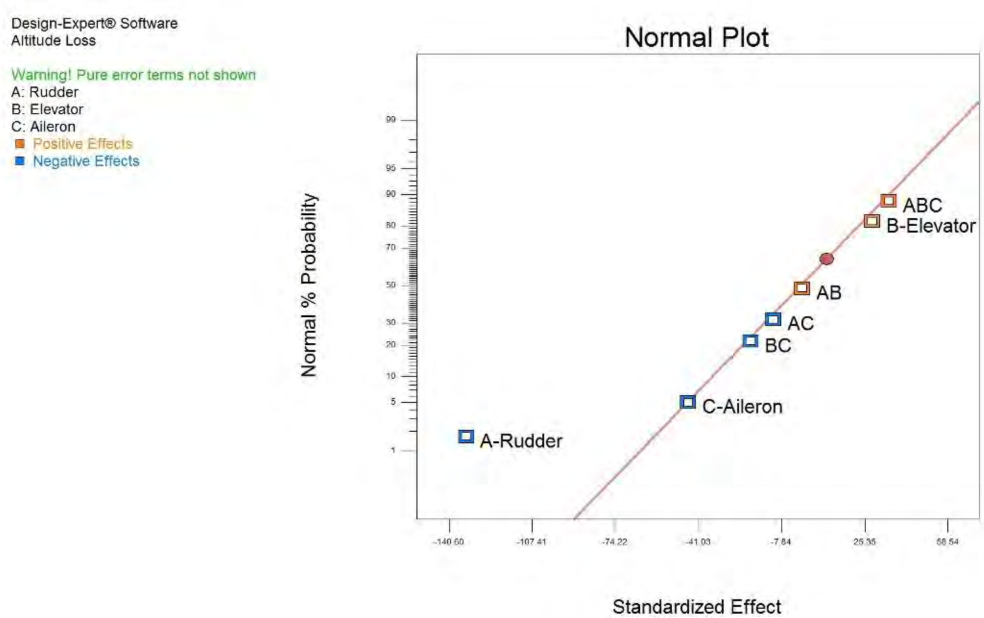


Figure 32: REA.sim Model Normal Plot

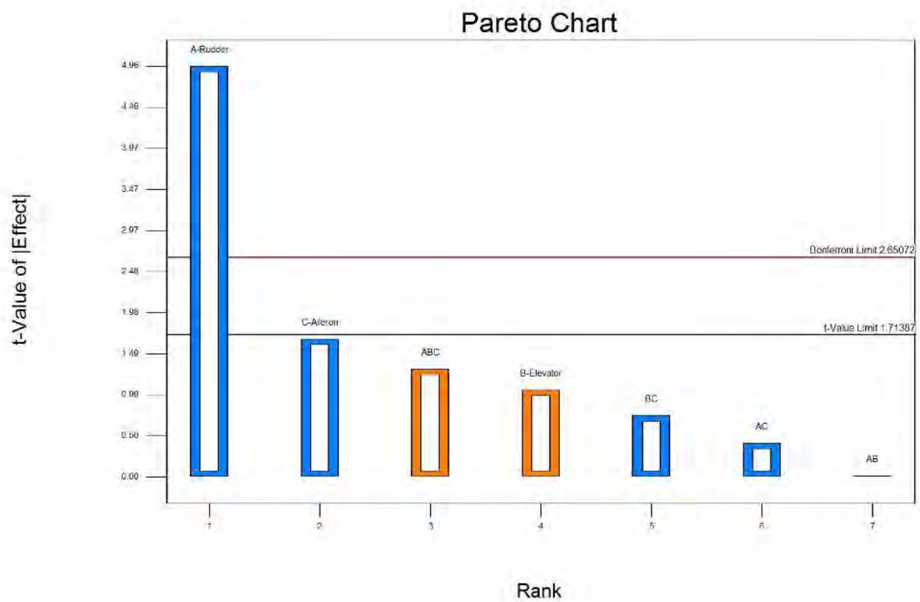


Figure 33: REA.sim Model Pareto Chart

Table 24: REA.sim Model ANOVA

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Block	29442.40	1	29442.40			
Model	1.974E+005	7	28206.79	5.63	0.0007	significant
A-Rudder	*1.184E+005*	*1*	*1.184E+005*	*23.62*	*< 0.0001*	
B-Elevator	*5325.40*	*1*	*5325.40*	*1.06*	*0.3134*	
C-Aileron	*13412.16*	*1*	*13412.16*	*2.68*	*0.1155*	
AB	*1.20*	*1*	*1.20*	*2.398E-004*	*0.9878*	
AC	*807.05*	*1*	*807.05*	*0.16*	*0.6919*	
BC	*2675.00*	*1*	*2675.00*	*0.53*	*0.4725*	
ABC	*8172.05*	*1*	*8172.05*	*1.63*	*0.2144*	
Residual	1.153E+005	23	5012.94			
Cor Total	3.422E+005	31				

Table 25: REA.sim Model Fit Statistics

Std. Dev.	70.80	R-Squared	0.6313
Mean	1359.38	Adj R-Squared	0.5191
C.V. %	5.21	Pred R-Square	0.2569
PRESS	2.324E+005	Adeq Precisior	9.456

Table 26: REA.sim Model Coefficient Statistics

Factor	Coefficient Estimate	df	Standard Error	90% CI Low	90% CI High	VIF
Intercept	1366.85	1	13.75	1343.28	1390.42	
Right Spins	-34.55	1				
Left Spins	34.55					
A-Rudder	-66.85	1	13.75	-90.42	-43.28	1.19
B-Elevator	18.47	1	17.92	-12.24	49.19	1.25
C-Aileron	-28.44	1	17.39	-58.24	1.36	1.26
AB	0.28	1	17.92	-30.44	30.99	1.25
AC	-6.98	1	17.39	-36.78	22.82	1.26
BC	-16.71	1	22.88	-55.93	22.50	1.35
ABC	29.21	1	22.88	-10.00	68.43	1.35

Table 27: REA.sim Model Equation (Coded Factors)

Final Equation in Terms of Coded Factors:

Altitude Loss	=
+1366.85	
-66.85	* A
+18.47	* B
-28.44	* C
+0.28	* AB
-6.98	* AC
-16.71	* BC
+29.21	* ABC

Table 28: REA.sim Model Equation (Actual Factors)

Final Equation in Terms of Actual Factors:

Altitude Loss	=
+1433.70340	
-1.33703	* Rudder
+0.36390	* Elevator
-0.21464	* Aileron
+1.11020E-004	* Rudder * Elevator
-1.39529E-003	* Rudder * Aileron
-9.18586E-003	* Elevator * Aileron
+1.16859E-004	* Rudder * Elevator * Aileron

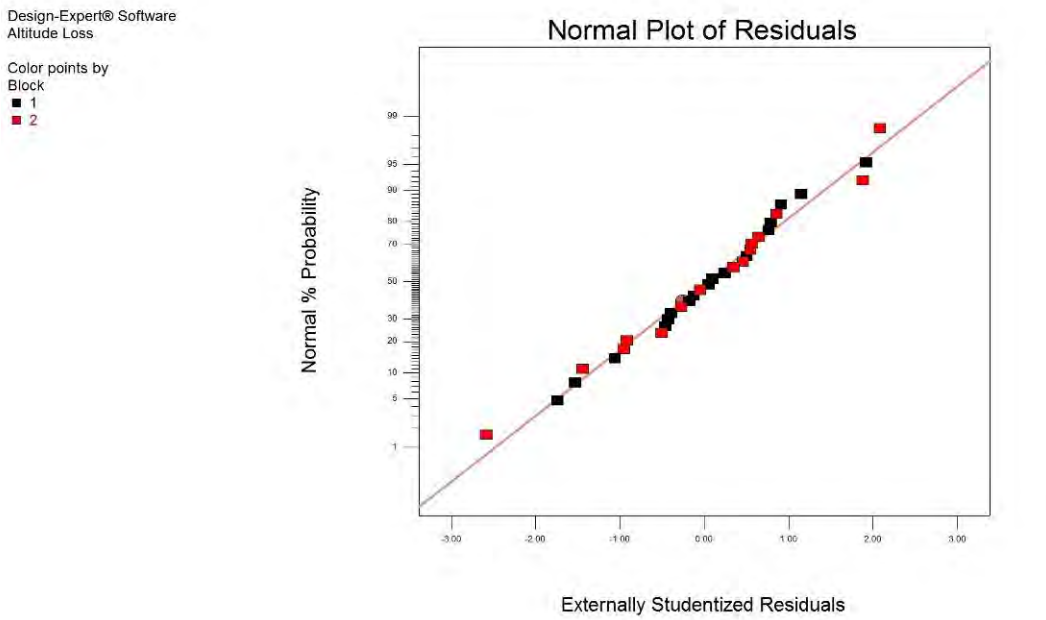


Figure 34: REA.sim Model Normal Plot of Residuals

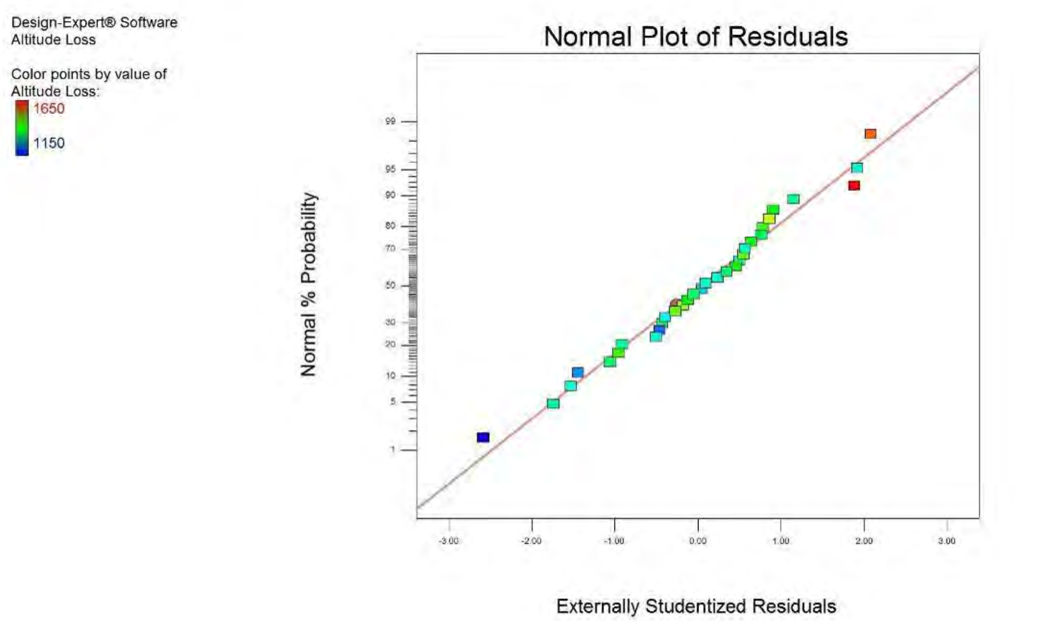


Figure 35: REA.sim Model Normal Plot of Residuals

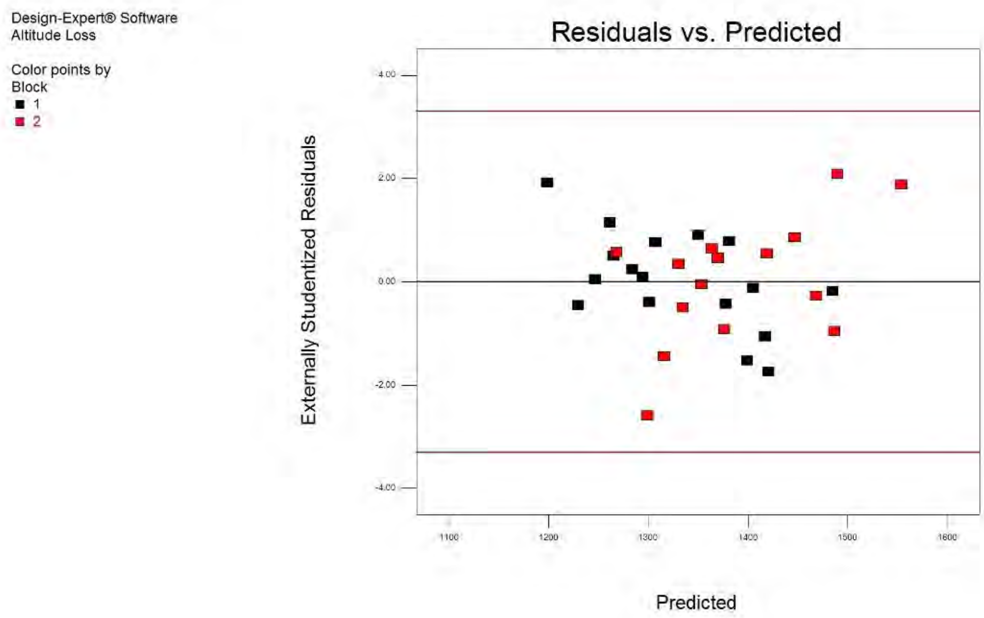


Figure 36: REA.sim Model: Residuals vs. Predicted

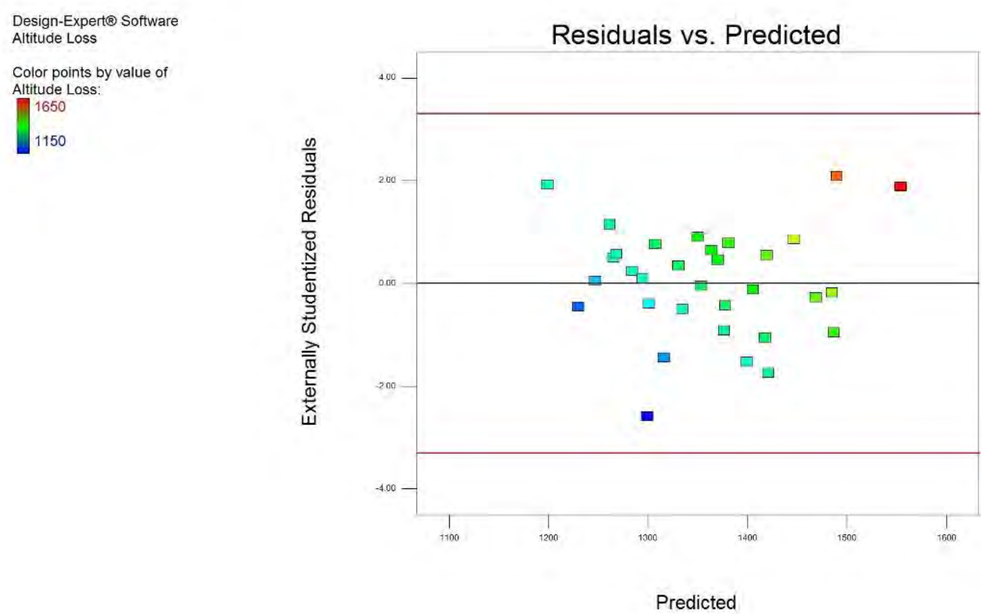


Figure 37: REA.sim Model: Residuals vs. Predicted

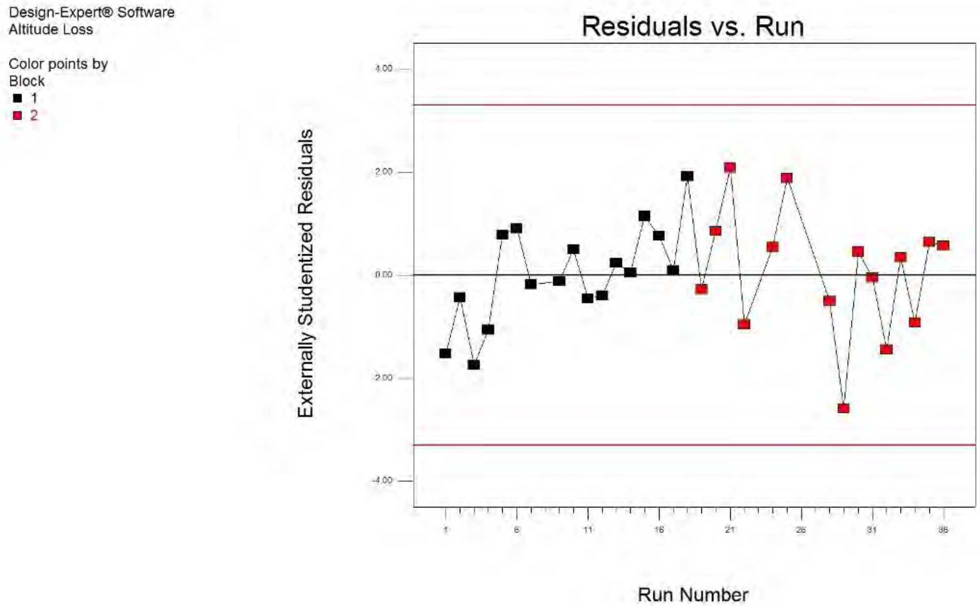


Figure 38: REA.sim Model: Residuals vs. Run

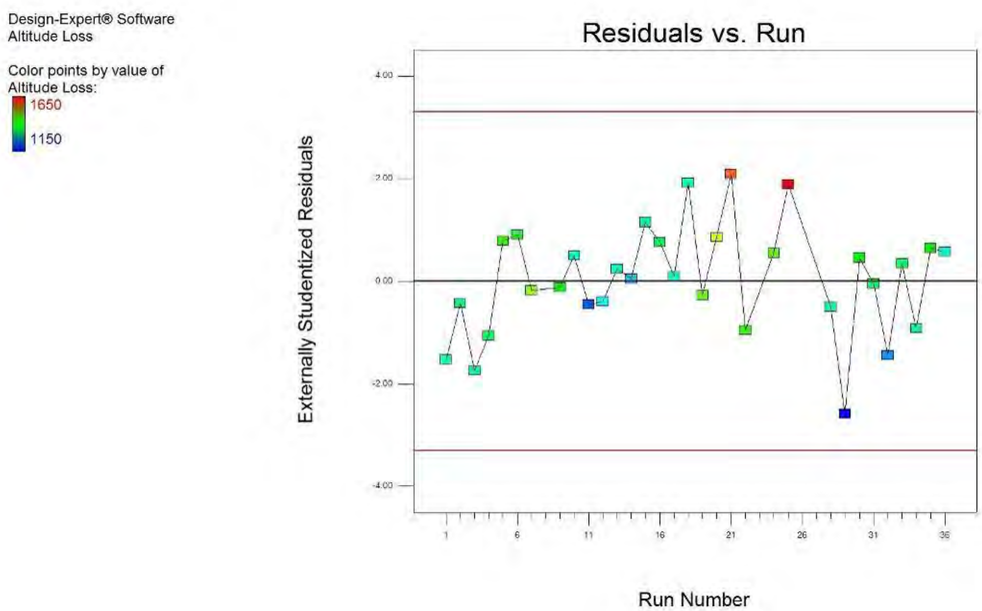


Figure 39: REA.sim Model: Residuals vs. Run

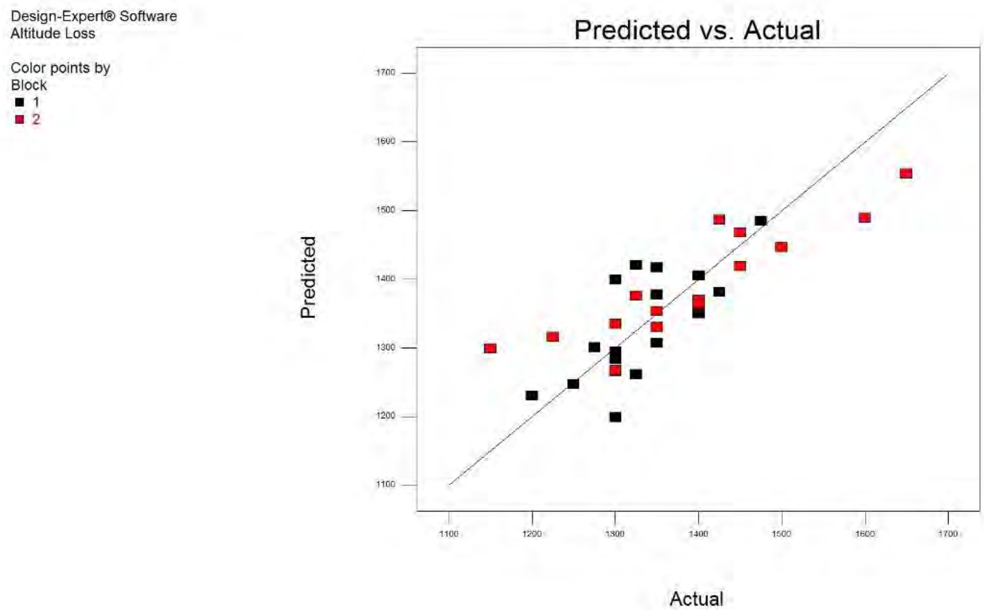


Figure 40: REA.sim Model: Predicted vs. Actual

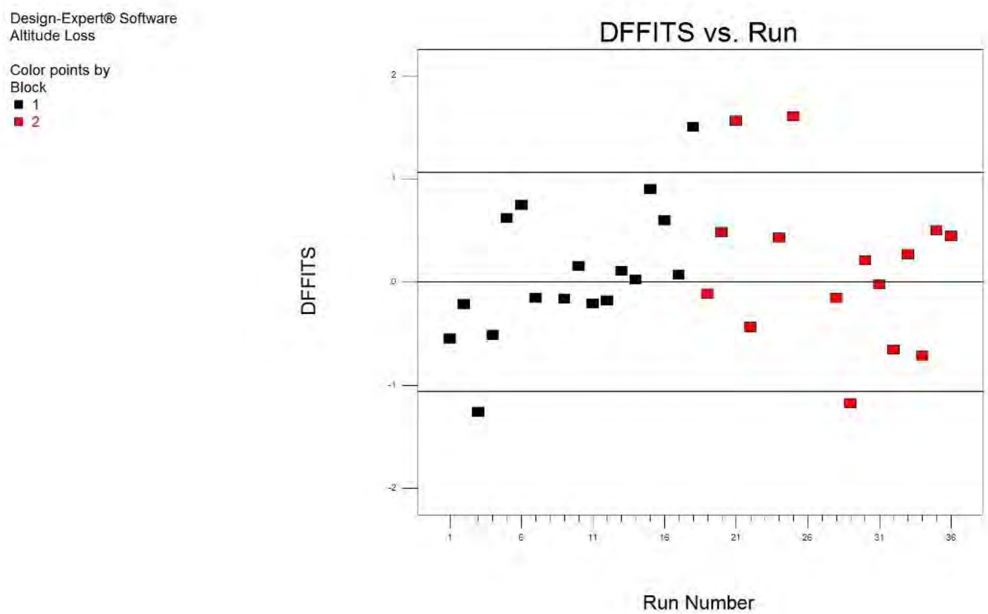


Figure 41: REA.sim Model: DFFITS vs. Run

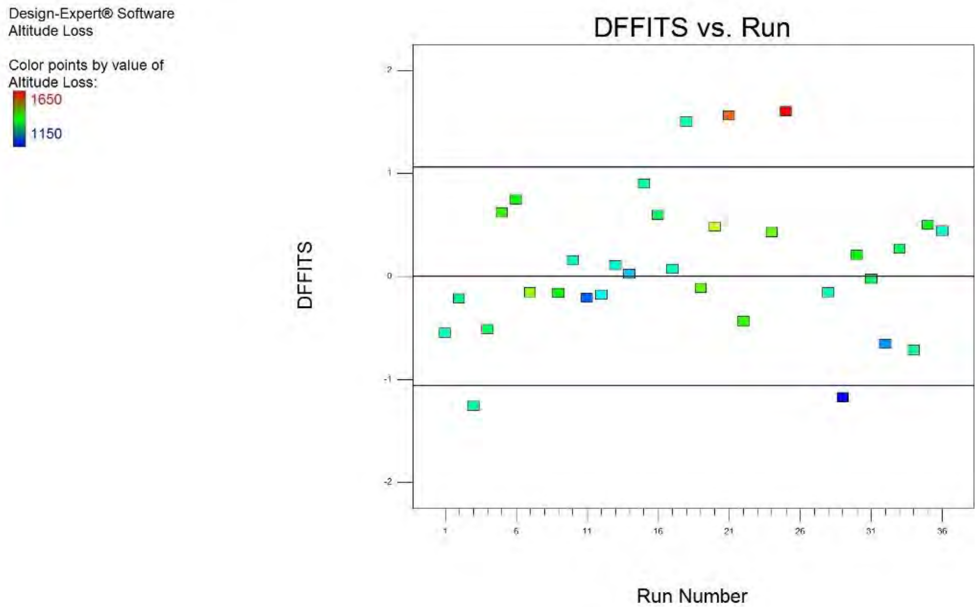


Figure 42: REA.sim Model: DFFITS vs. Run

Table 29: REA.sim Model Summary of Residuals

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residual	Externally Studentized Residual	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	1300.00	1399.16	-99.16	0.114	-1.488	-1.530	0.032	-0.548	6
2	1350.00	1377.69	-27.69	0.199	-0.437	-0.429	0.005	-0.214	7
3	1325.00	1420.62	-95.62	0.344	-1.667	-1.739	0.162	-1.260 *	1
4	1350.00	1417.35	-67.35	0.189	-1.056	-1.059	0.029	-0.510	4
5	1425.00	1380.96	44.04	0.385	0.793	0.786	0.044	0.622	3
6	1400.00	1349.96	50.04	0.402	0.914	0.911	0.063	0.747	8
7	1475.00	1484.75	-9.75	0.429	-0.182	-0.178	0.003	-0.154	2
9	1400.00	1405.43	-5.43	0.632 #	-0.126	-0.124	0.003	-0.162	9
10	1300.00	1265.45	34.55	0.088	0.511	0.503	0.003	0.156	11
11	1200.00	1230.04	-30.04	0.172	-0.466	-0.458	0.005	-0.208	12
12	1275.00	1300.87	-25.87	0.172	-0.401	-0.394	0.004	-0.179	10
13	1300.00	1284.20	15.80	0.172	0.245	0.240	0.001	0.109	13
14	1250.00	1246.70	3.30	0.172	0.051	0.050	0.000	0.023	14
15	1325.00	1261.29	63.71	0.380	1.143	1.151	0.089	0.901	16
16	1350.00	1307.12	42.88	0.380	0.769	0.762	0.040	0.596	15
17	1300.00	1294.62	5.38	0.380	0.096	0.094	0.001	0.074	17
18	1300.00	1198.79	101.21	0.380	1.815	1.918	0.224	1.501 *	18
19	1450.00	1468.25	-18.25	0.142	-0.278	-0.273	0.001	-0.111	19
20	1500.00	1446.79	53.21	0.241	0.863	0.858	0.026	0.483	20
21	1600.00	1489.71	110.29	0.359	1.946	2.083	0.236	1.560 *	22
22	1425.00	1486.44	-61.44	0.174	-0.955	-0.953	0.021	-0.438	23
24	1450.00	1419.05	30.95	0.382	0.556	0.547	0.021	0.430	21
25	1650.00	1553.84	96.16	0.421	1.785	1.881	0.257	1.604 *	25
28	1300.00	1334.55	-34.55	0.088	-0.511	-0.503	0.003	-0.156	28
29	1150.00	1299.13	-149.13	0.172	-2.314	-2.584	0.123	-1.176 *	29
30	1400.00	1369.96	30.04	0.172	0.466	0.458	0.005	0.208	30
31	1350.00	1353.30	-3.30	0.172	-0.051	-0.050	0.000	-0.023	31
32	1225.00	1315.80	-90.80	0.172	-1.409	-1.442	0.046	-0.656	32
33	1350.00	1330.38	19.62	0.380	0.352	0.345	0.008	0.270	33
34	1325.00	1376.21	-51.21	0.380	-0.919	-0.915	0.057	-0.716	34
35	1400.00	1363.71	36.29	0.380	0.651	0.642	0.029	0.503	35
36	1300.00	1267.88	32.12	0.380	0.576	0.568	0.023	0.444	36

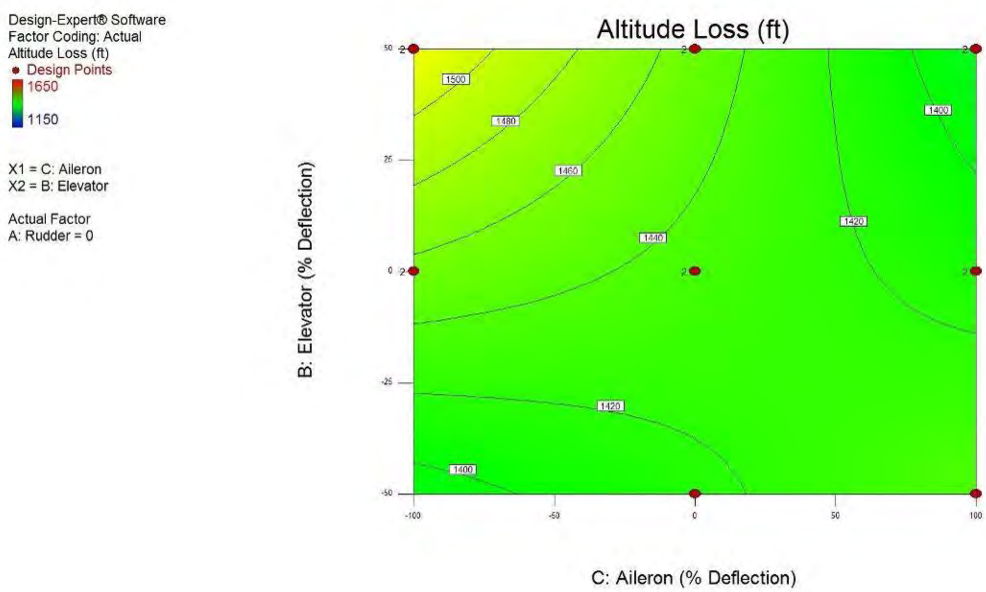


Figure 43: REA.sim Model Contour Plot; Altitude Loss, Rudder=0

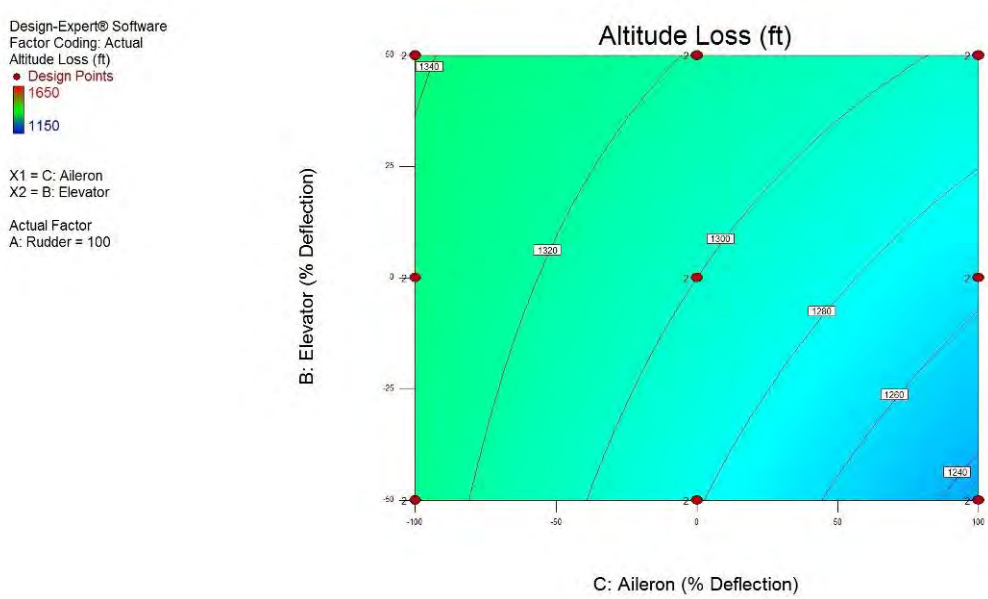


Figure 44: REA.sim Model Contour Plot; Altitude Loss Rudder=100

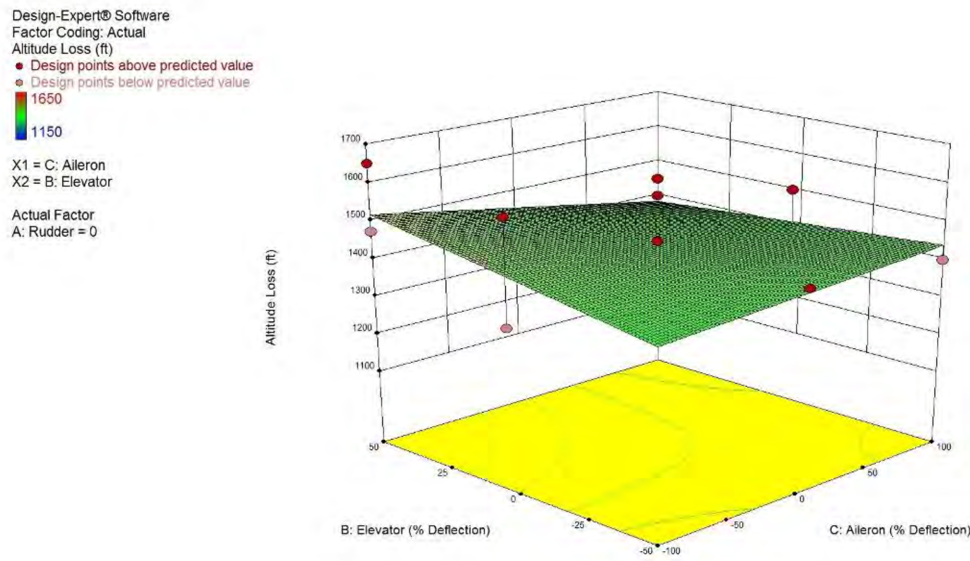


Figure 45: REA.sim Model 3D Plot; Aileron, Elevator, Altitude Loss, Rudder=0

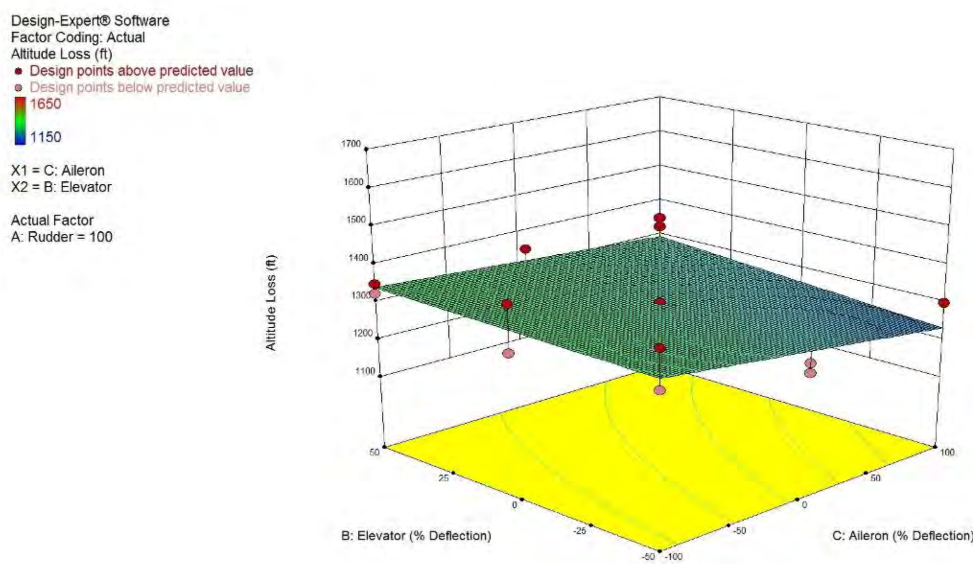


Figure 46: REA.sim Model 3D Plot; Aileron, Elevator, Altitude Loss, Rudder=100

Appendix E: EA.sim Model

Table 30: EA.sim Model Design (Actual)

Std	Block	Run	Factor 1 A:Elevator % Deflection	Factor 2 B:Aileron % Delfection	Response 1 Altitude Loss ft
3	Right Spins	1	0	0	1300
5	Right Spins	2	0	100	1200
1	Right Spins	3	0	-100	1275
7	Right Spins	4	50	0	1300
8	Right Spins	5	-50	0	1250
4	Right Spins	6	50	100	1325
2	Right Spins	7	50	-100	1350
6	Right Spins	8	-50	-100	1300
9	Right Spins	9	-50	100	1300
10	Left Spins	10	0	0	1300
11	Left Spins	11	0	100	1150
12	Left Spins	12	0	-100	1400
13	Left Spins	13	50	0	1350
14	Left Spins	14	-50	0	1225
15	Left Spins	15	50	100	1350
16	Left Spins	16	50	-100	1325
17	Left Spins	17	-50	-100	1400
18	Left Spins	18	-50	100	1300

Table 31: EA.sim Model Model Data Statistics (Actual)

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.	
A	Elevator	% Deflection	Numeric	Continuous	-50	50	-1.000=-50	1.000=50	0	42.0084	
B	Aileron	% Delfection	Numeric	Continuous	-100	100	-1.000=-100	1.000=100	0	84.0168	
Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Altitude Loss	ft	18	Factorial	1150	1400	1300	64.1689	1.21739	None	Main effects

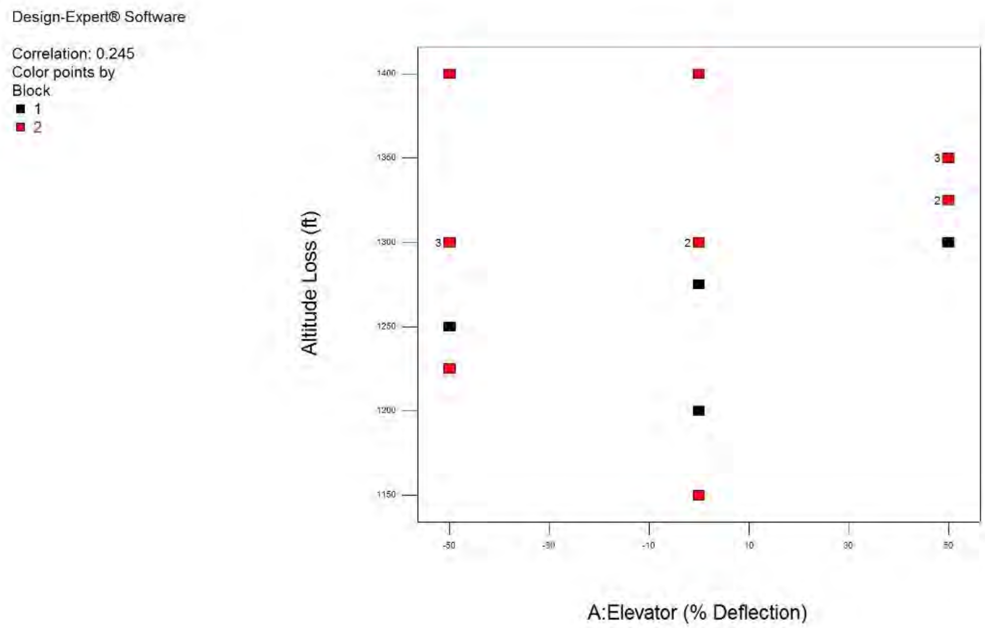


Figure 47: EA.sim Model: Elevator vs. Altitude Loss (Actual)

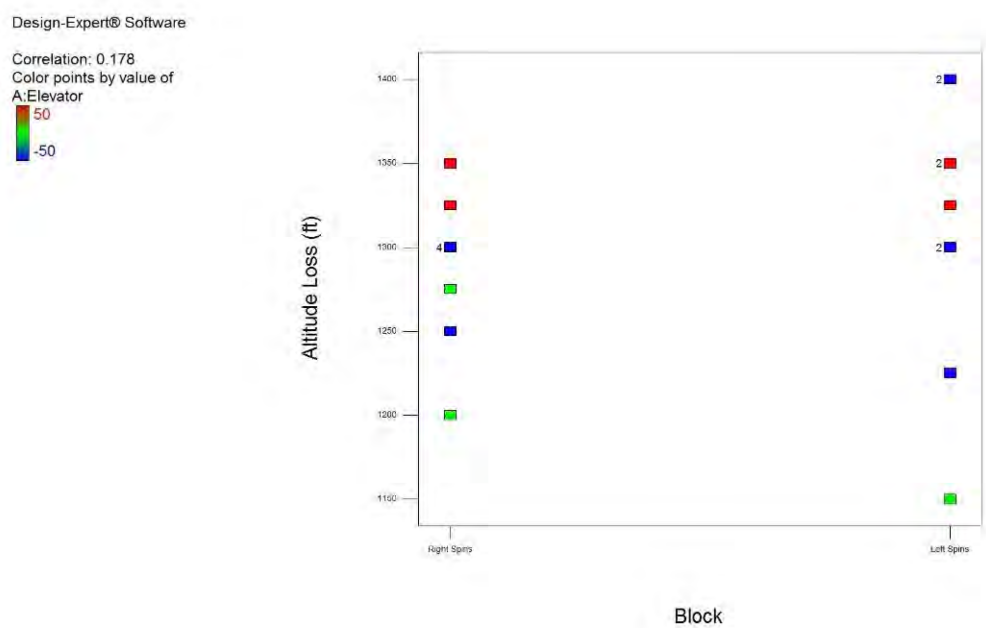


Figure 48: EA.sim Model: Block vs. Altitude Loss (Actual)

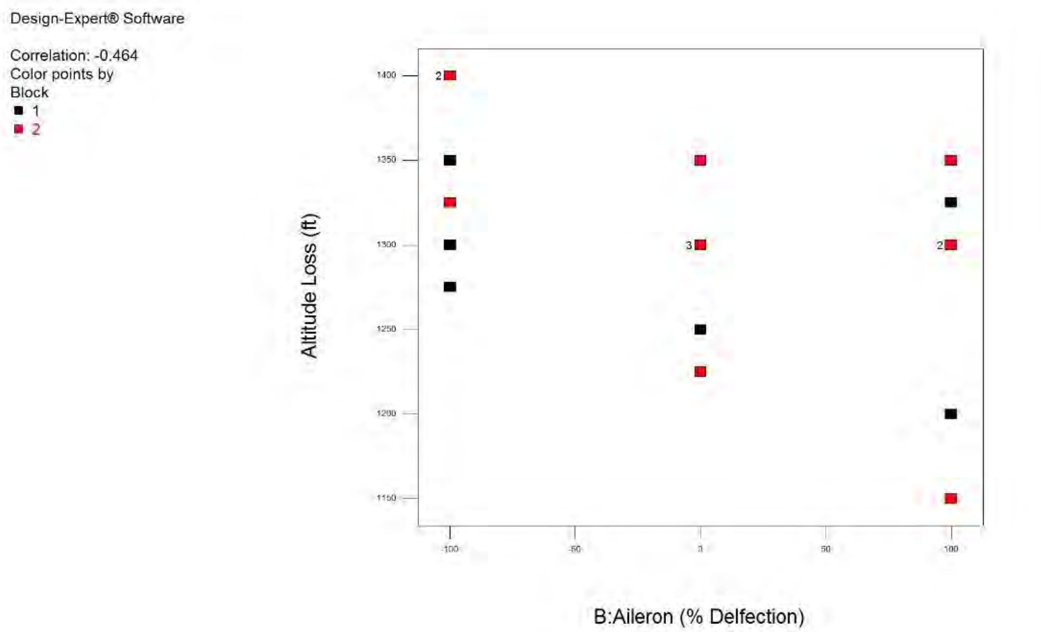


Figure 49: EA.sim Model: Aileron vs. Altitude Loss (Actual)

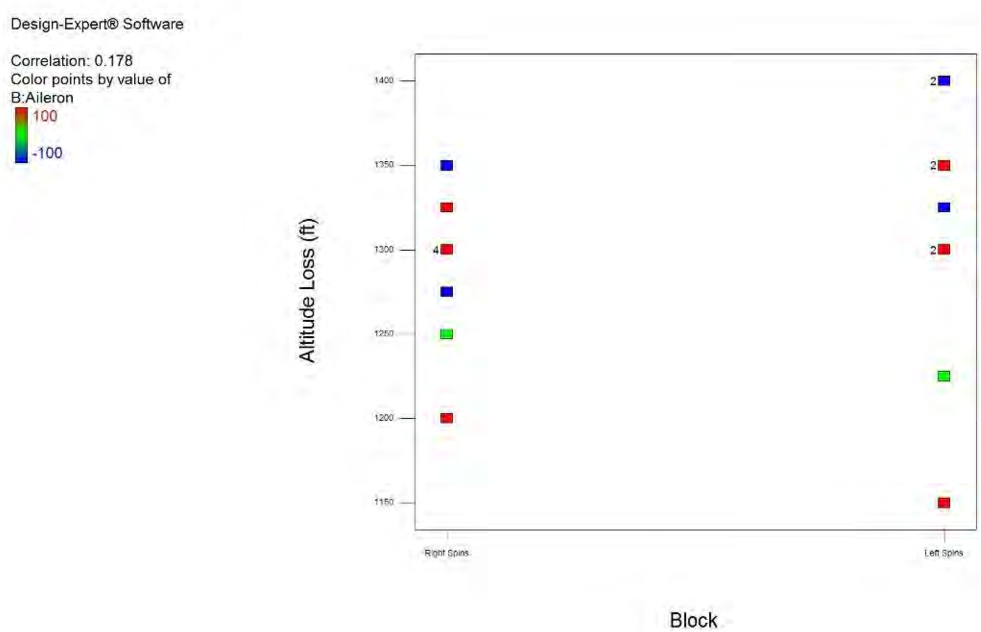


Figure 50: EA.sim Model: Block vs. Altitude Loss (Actual)

Table 32: EA.sim Model Factor Selection

Term	Stdized Effect	Sum of Squares	% Contribution
Intercept			
A-Elevator	37.50	4218.75	6.22
B-Aileron	-70.83	15052.08	22.21
AB	20.41	1250.00	1.84
Curvature	8.461E-015	7.276E-012	1.074E-014
Lack of Fit		47256.94	69.72
Pure Error		0.000	0.000

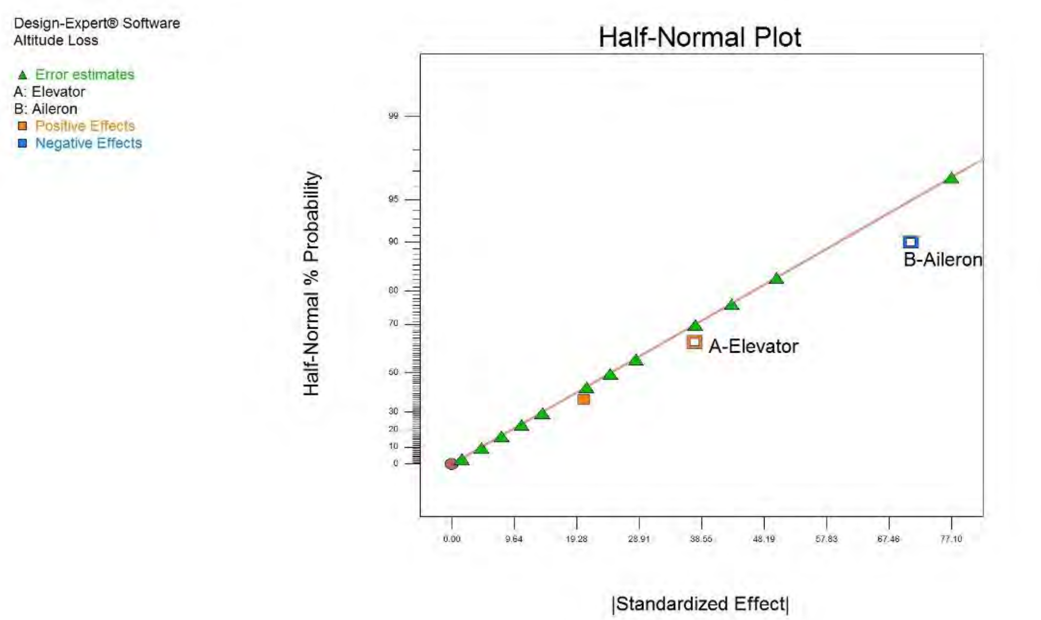


Figure 51: EA.sim Model Half-Normal Plot

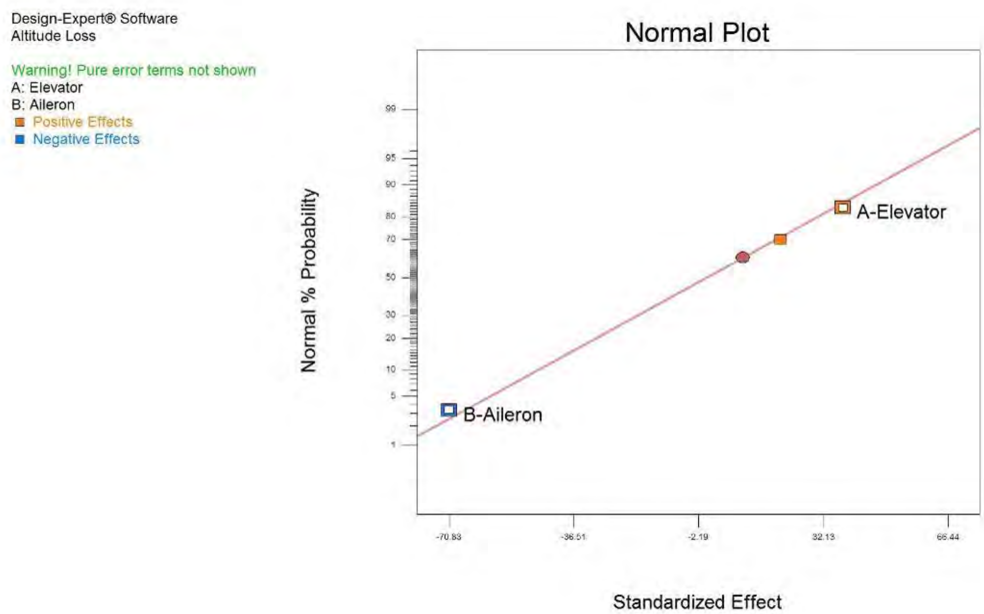


Figure 52: EA.sim Model Normal Plot

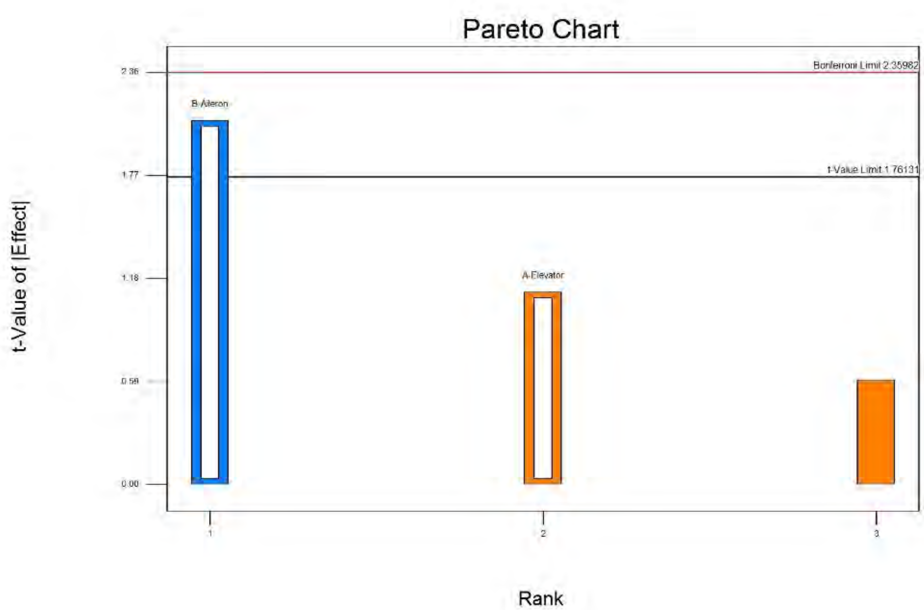


Figure 53: EA.sim Model Pareto Chart

Table 33: EA.sim Model ANOVA

Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Block	2222.22	1	2222.22			
Model	19270.83	2	9635.42	2.78	0.0962	significant
A-Elevator	*4218.75*	*1*	*4218.75*	*1.22*	*0.2884*	
B-Aileron	*15052.08*	*1*	*15052.08*	*4.34*	*0.0559*	
Residual	48506.94	14	3464.78			
Cor Total	70000.00	17				

Table 34: EA.sim Model Model Fit Statistics

Std. Dev.	58.86	R-Squared	0.2843
Mean	1300.00	Adj R-Squared	0.1821
C.V. %	4.53	Pred R-Square	-0.2068
PRESS	81792.92	Adeq Precisior	4.705

Table 35: EA.sim Model Model Coefficient Statistics

	Coefficient		Standard	90% CI	90% CI	
Factor	Estimate	df	Error	Low	High	VIF
Intercept	1300.00	1	13.87	1275.56	1324.44	
Right Spins	-11.11	1				
Left Spins	11.11					
A-Elevator	18.75	1	16.99	-11.18	48.68	1.00
B-Aileron	-35.42	1	16.99	-65.35	-5.49	1.00

Table 36: EA.sim Model Model Equation (Coded Factors)

Final Equation in Terms of Coded Factors:

Altitude Loss =
+1300.00
+18.75 * A
-35.42 * B

Table 37: EA.sim Model Model Equation (Actual Factors)

Final Equation in Terms of Actual Factors:

Altitude Loss	=
+1300.00000	
+0.37500	* Elevator
-0.35417	* Aileron

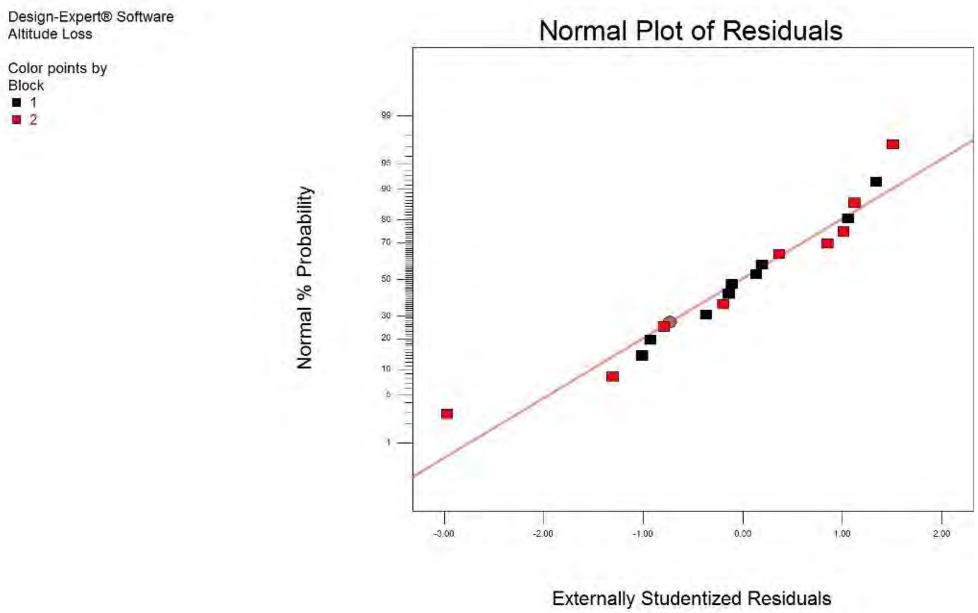


Figure 54: EA.sim Model Normal Plot of Residuals

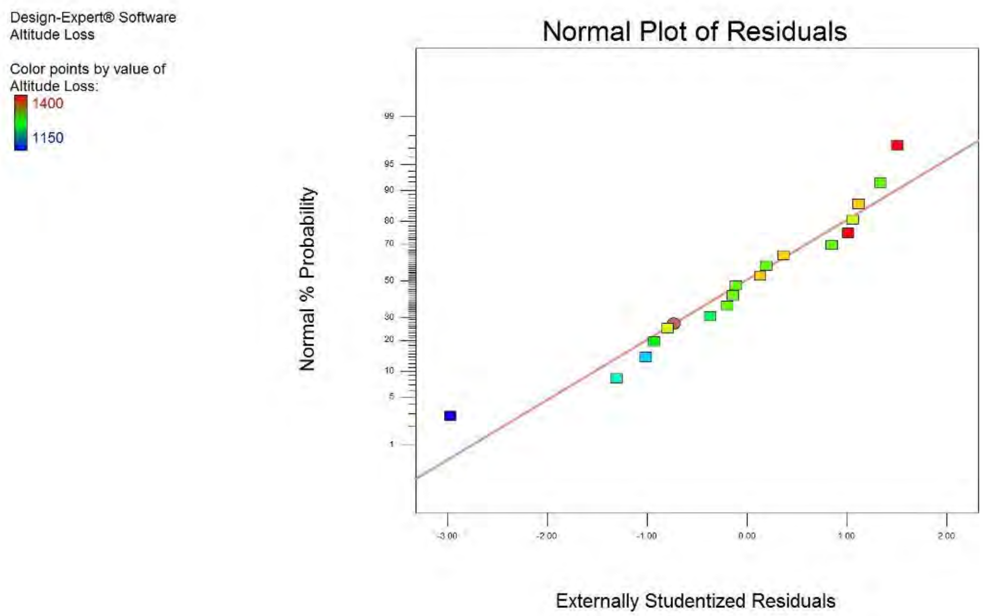


Figure 55: EA.sim Model Normal Plot of Residuals

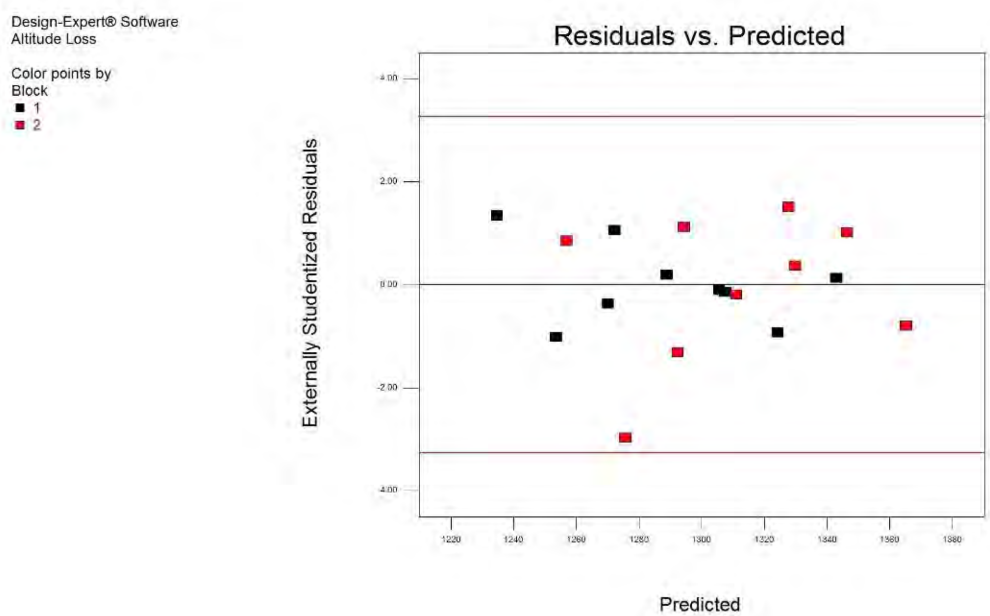


Figure 56: EA.sim Model: Residuals vs. Predicted

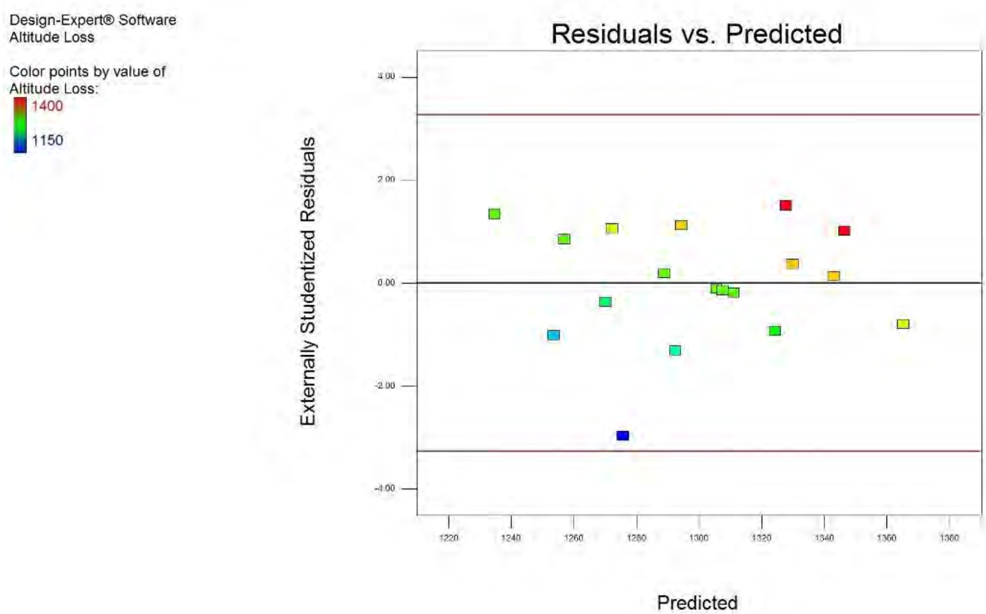


Figure 57: EA.sim Model: Residuals vs. Predicted

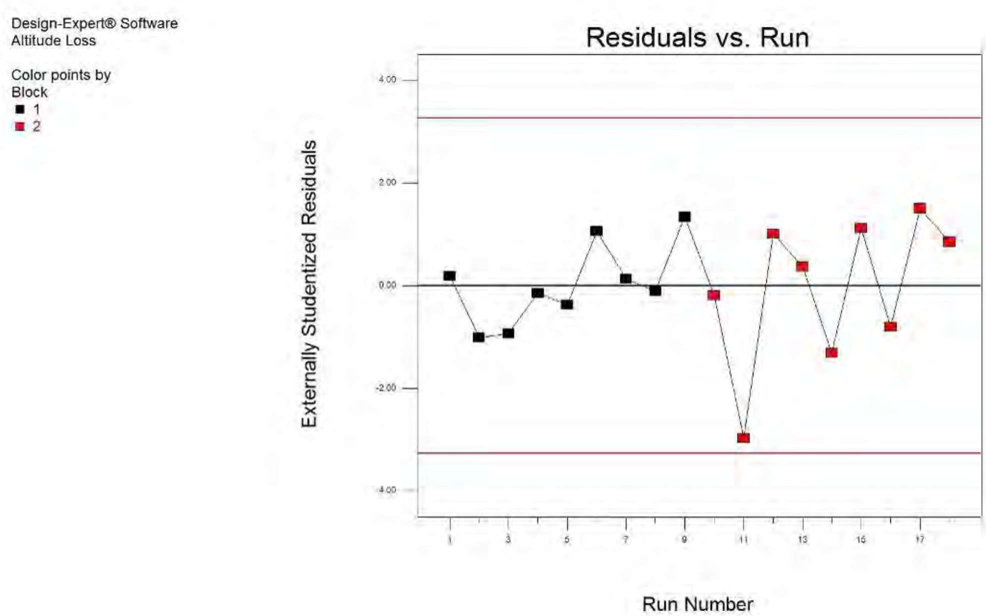


Figure 58: EA.sim Model: Residuals vs. Run

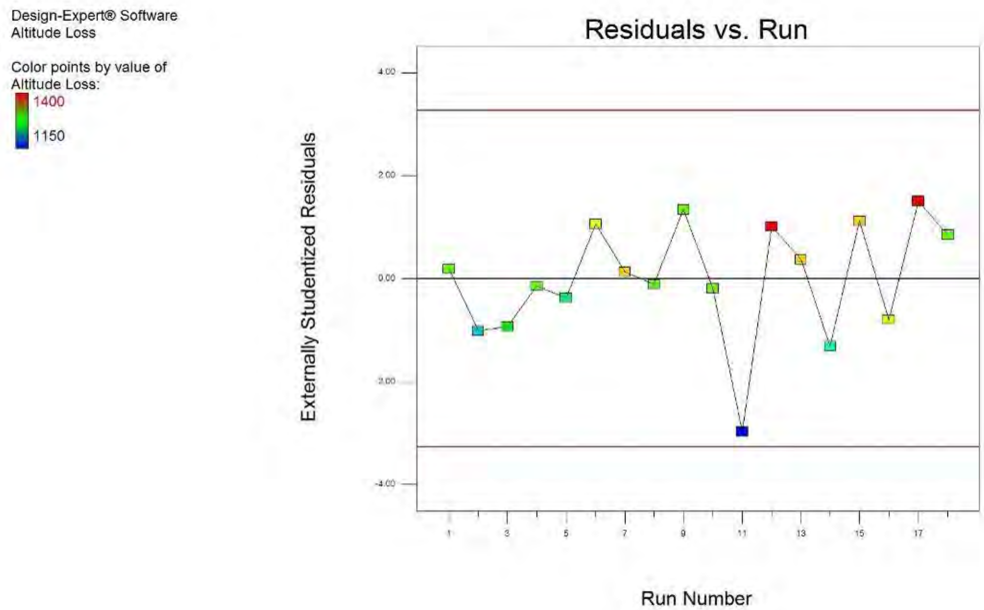


Figure 59: EA.sim Model: Residuals vs. Run

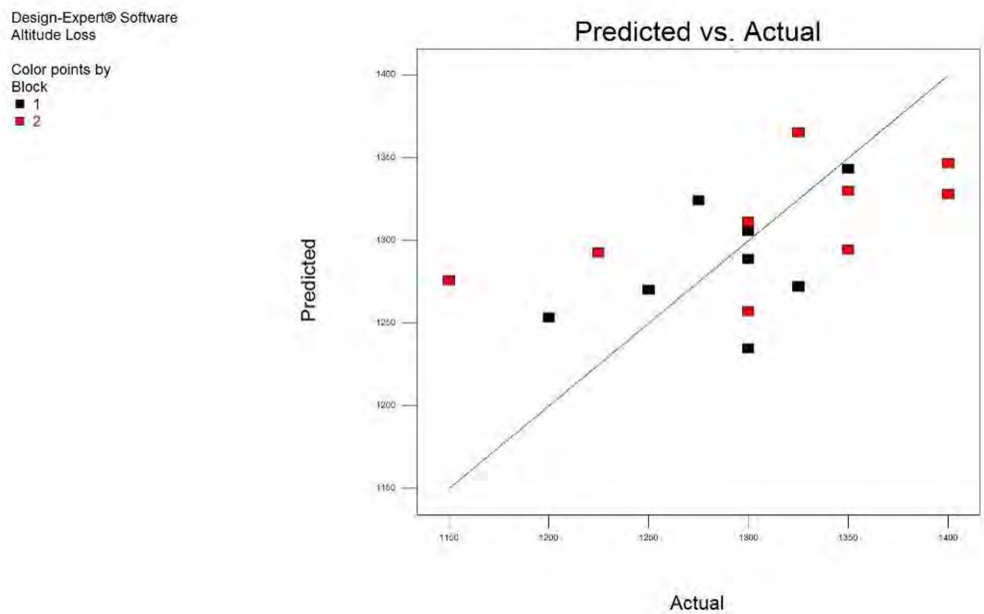


Figure 60: EA.sim Model: Predicted vs. Actual

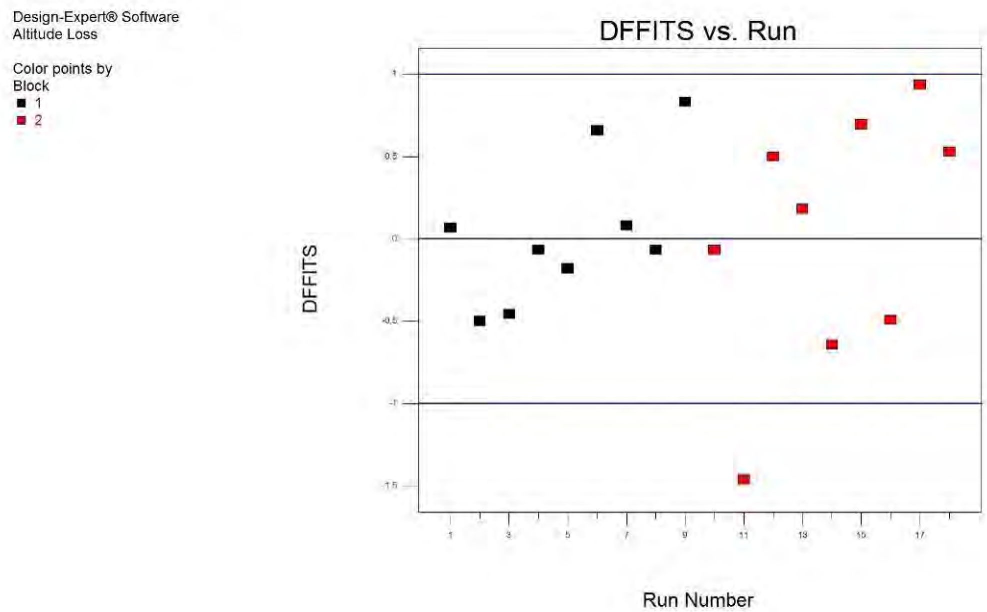


Figure 61: EA.sim Model: DFFITS vs. Run

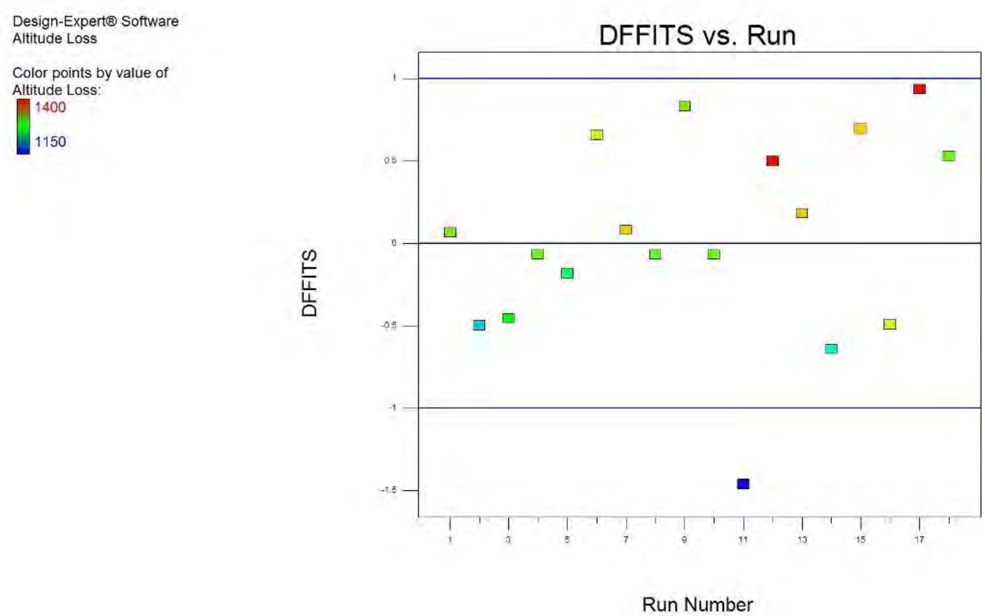


Figure 62: EA.sim Model: DFFITS vs. Run

Table 38: EA.sim Model Summary of Residuals

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residual	Externally Studentized Residual	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	1300.00	1288.89	11.11	0.111	0.200	0.193	0.001	0.068	3
2	1200.00	1253.47	-53.47	0.194	-1.012	-1.013	0.062	-0.498	5
3	1275.00	1324.31	-49.31	0.194	-0.933	-0.929	0.053	-0.456	1
4	1300.00	1307.64	-7.64	0.194	-0.145	-0.139	0.001	-0.069	7
5	1250.00	1270.14	-20.14	0.194	-0.381	-0.369	0.009	-0.181	8
6	1325.00	1272.22	52.78	0.278	1.055	1.060	0.107	0.657	4
7	1350.00	1343.06	6.94	0.278	0.139	0.134	0.002	0.083	2
8	1300.00	1305.56	-5.56	0.278	-0.111	-0.107	0.001	-0.066	6
9	1300.00	1234.72	65.28	0.278	1.305	1.342	0.164	0.832	9
10	1300.00	1311.11	-11.11	0.111	-0.200	-0.193	0.001	-0.068	10
11	1150.00	1275.69	-125.69	0.194	-2.379	-2.971	0.342	-1.459 *	11
12	1400.00	1346.53	53.47	0.194	1.012	1.013	0.062	0.498	12
13	1350.00	1329.86	20.14	0.194	0.381	0.369	0.009	0.181	13
14	1225.00	1292.36	-67.36	0.194	-1.275	-1.307	0.098	-0.642	14
15	1350.00	1294.44	55.56	0.278	1.111	1.121	0.119	0.695	15
16	1325.00	1365.28	-40.28	0.278	-0.805	-0.795	0.062	-0.493	16
17	1400.00	1327.78	72.22	0.278	1.444	1.508	0.200	0.935	17
18	1300.00	1256.94	43.06	0.278	0.861	0.852	0.071	0.529	18

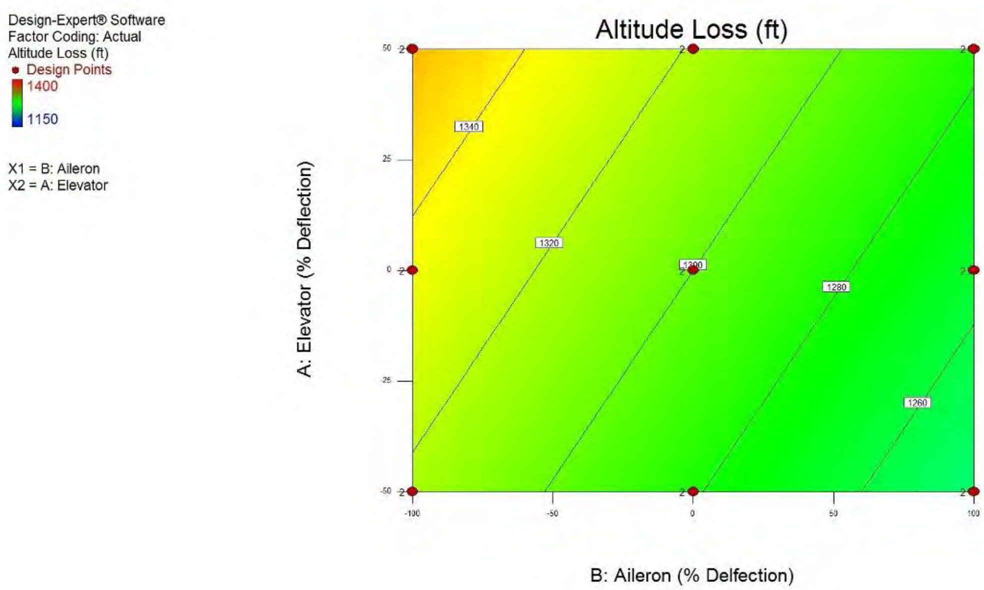


Figure 63: EA.sim Model Contour Plot; Aileron, Elevator, Altitude Loss

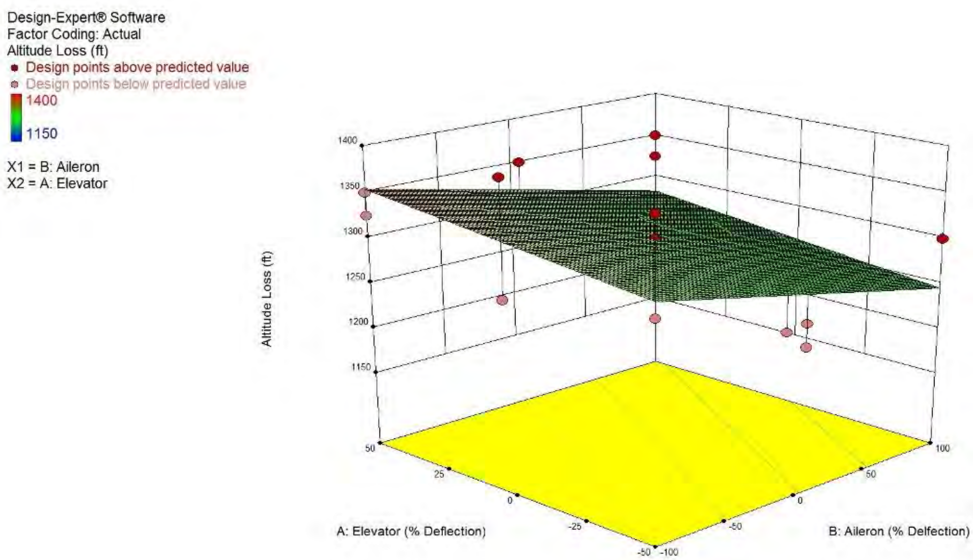


Figure 64: EA.sim Model 3D Plot; Aileron, Elevator, Altitude Loss

Appendix F: EA.seq Model

Table 39: EA.seq_all Model Design (Actual)

Std	Block	Run	Factor 1 A:Elevator % Deflection	Factor 2 B:Aileron % Delfection	Response 1 Altitude Loss ft
3	Right Spins	1	0	0	1400
5	Right Spins	2	0	100	1325
1	Right Spins	3	0	-100	1325
7	Right Spins	4	50	0	1350
8	Right Spins	5	-50	0	1275
4	Right Spins	6	50	100	1200
2	Right Spins	7	50	-100	1500
6	Right Spins	8	-50	-100	1600
9	Right Spins	9	-50	100	1300
10	Left Spins	10	0	0	1500
11	Left Spins	11	0	100	1500
12	Left Spins	12	0	-100	1500
13	Left Spins	13	50	0	1500
14	Left Spins	14	-50	0	1200
15	Left Spins	15	50	100	1400
16	Left Spins	16	50	-100	1400
17	Left Spins	17	-50	-100	1300
18	Left Spins	18	-50	100	1275

Table 40: EA.seq_all Model Data Statistics (Actual)

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Elevator	% Deflection	Numeric	Continuous	-50	50	-1.000=-50	1.000=50	0	42.0084
B	Aileron	% Delfection	Numeric	Continuous	-100	100	-1.000=-100	1.000=100	0	84.0168

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Altitude Loss	ft	18	Factorial	1200	1600	1380.56	115.859	1.33333	None	Main effects

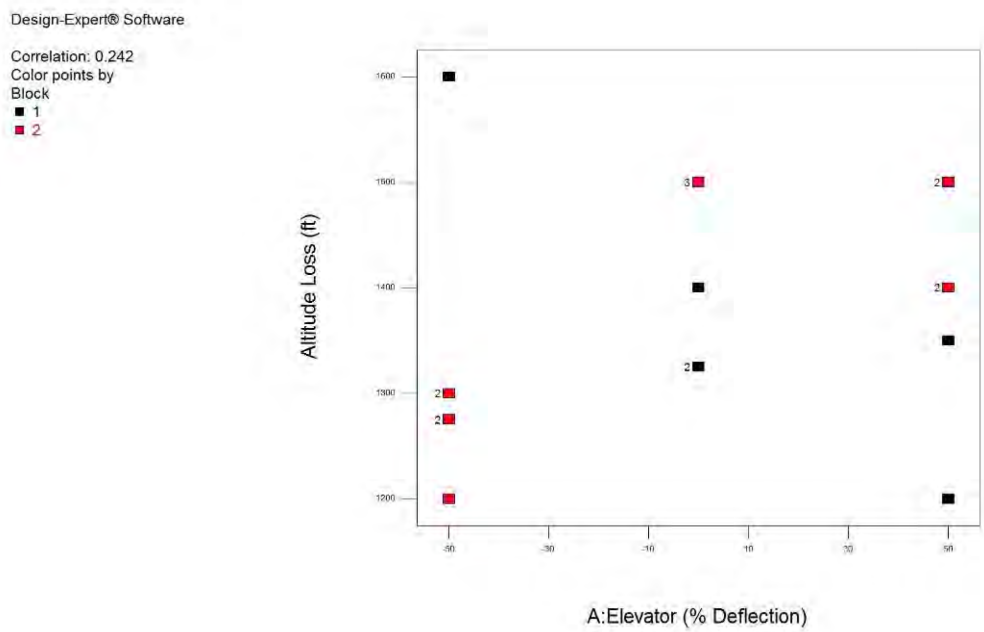


Figure 65: EA.seq_all Model: Aileron vs. Altitude Loss (Actual)

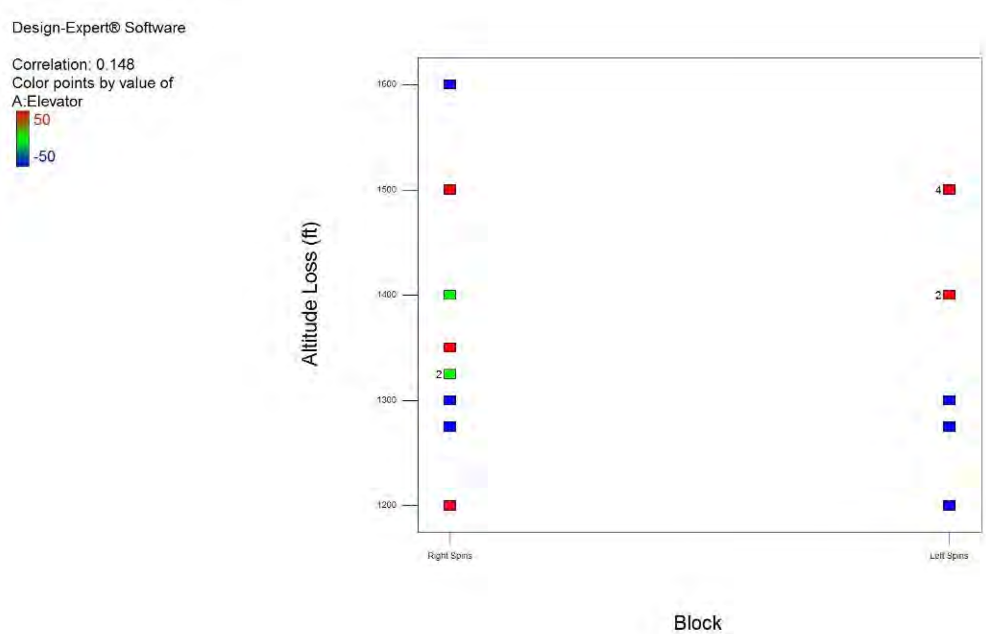


Figure 66: EA.seq_all Model: Block vs. Altitude Loss (Actual)

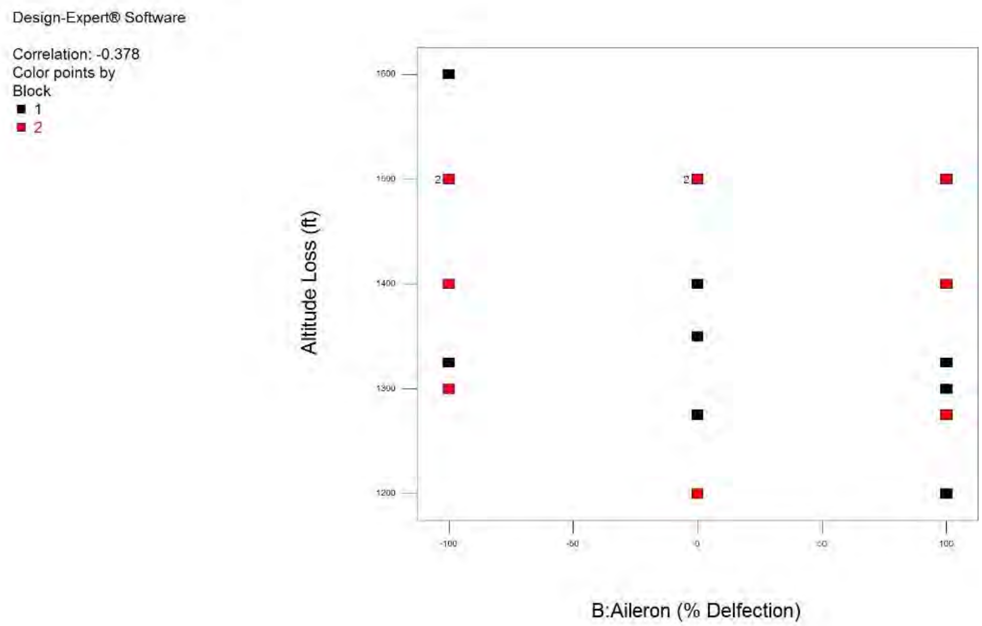


Figure 67: EA.seq_all Model: Aileron vs. Altitude Loss (Actual)

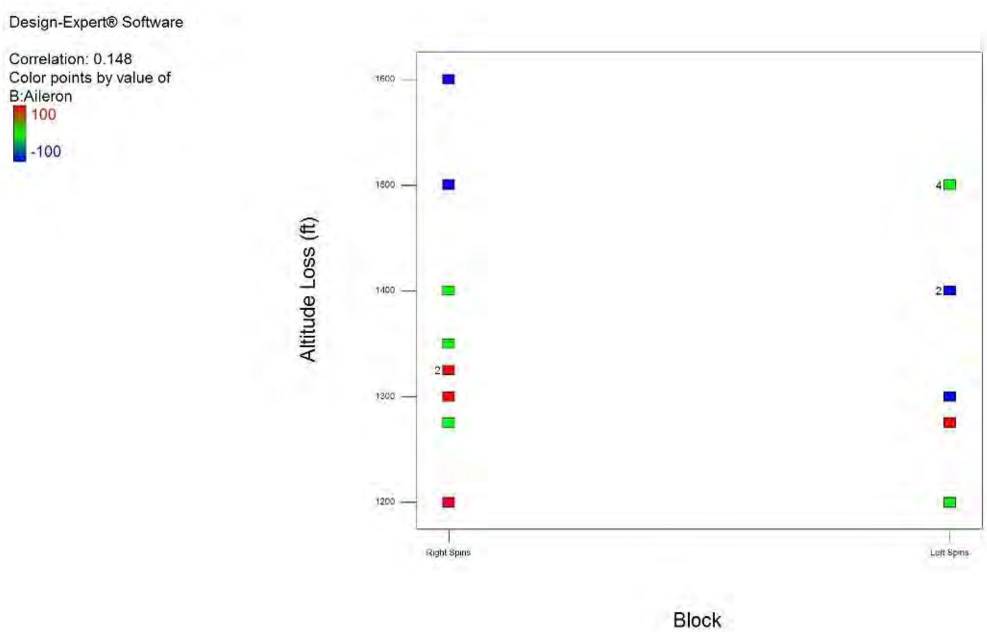


Figure 68: EA.seq_all Model: Block vs. Altitude Loss (Actual)

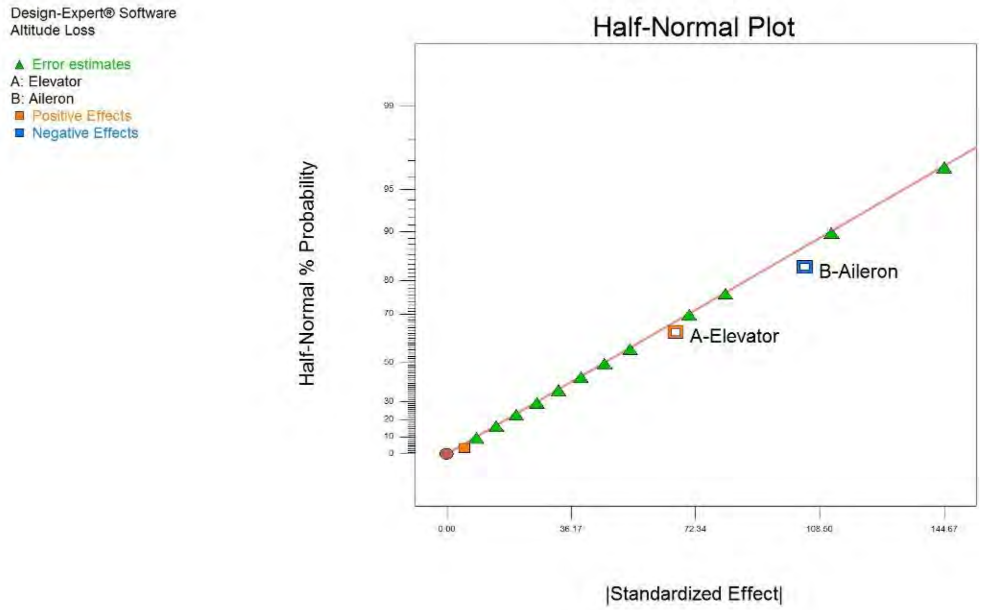


Figure 69: EA.seq_all Model Half-Normal Plot

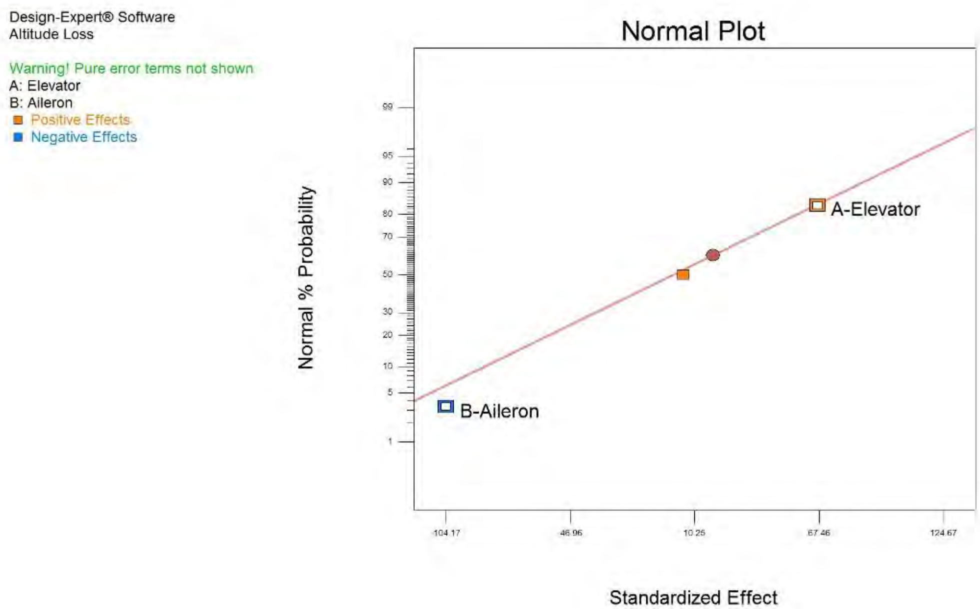


Figure 70: EA.seq_all Model Normal Plot

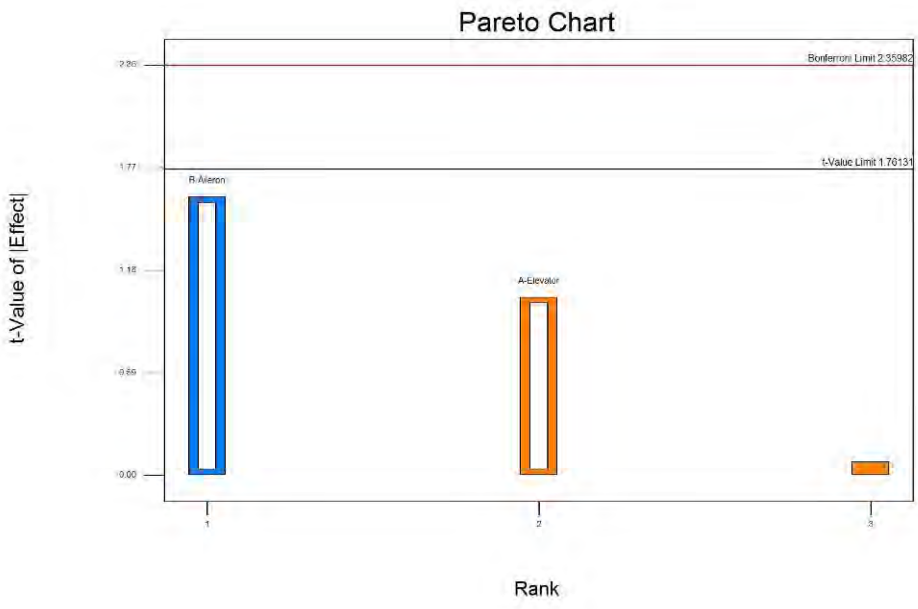


Figure 71: EA.seq_all Model Pareto Chart

Table 41: EA.seq_all Model ANOVA

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Block	5000.00	1	5000.00			
Model	45885.42	2	22942.71	1.81	0.1997	not significant
A-Elevator	*13333.33*	*1*	*13333.33*	*1.05*	*0.3223*	
B-Aileron	*32552.08*	*1*	*32552.08*	*2.57*	*0.1312*	
Residual	1.773E+005	14	12664.93			
Cor Total	2.282E+005	17				

Table 42: EA.seq_all Model Fit Statistics

Std. Dev.	112.54	R-Squared	0.2056
Mean	1380.56	Adj R-Squared	0.0921
C.V. %	8.15	Pred R-Square	-0.3670
PRESS	3.051E+005	Adeq Precisior	3.848

Table 43: EA.seq_all Model Coefficient Statistics

Factor	Coefficient Estimate	df	Standard Error	90% CI Low	90% CI High	VIF
Intercept	1380.56	1	26.53	1333.84	1427.28	
Right Spins	-16.67	1				
Left Spins	16.67					
A-Elevator	33.33	1	32.49	-23.89	90.55	1.00
B-Aileron	-52.08	1	32.49	-109.30	5.14	1.00

Table 44: EA.seq_all Model Equation (Coded Factors)

Final Equation in Terms of Coded Factors:

Altitude Loss =
+1380.56
+33.33 * A
-52.08 * B

Table 45: EA.seq_all Model Equation (Actual Factors)

Final Equation in Terms of Actual Factors:

Altitude Loss =
+1380.55556
+0.66667 * Elevator
-0.52083 * Aileron

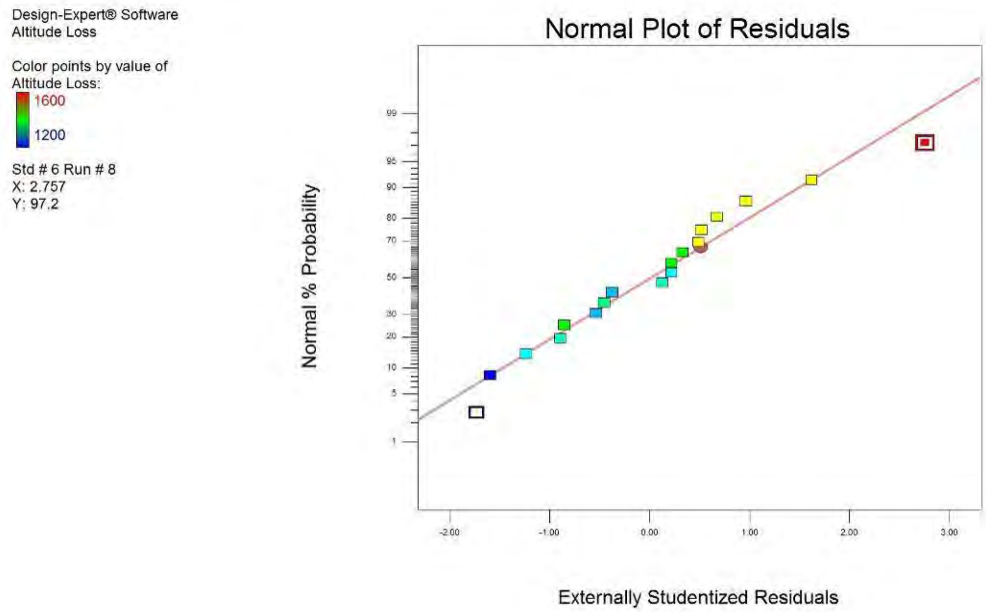


Figure 72: EA.seq_all Model Normal Plot of Residuals

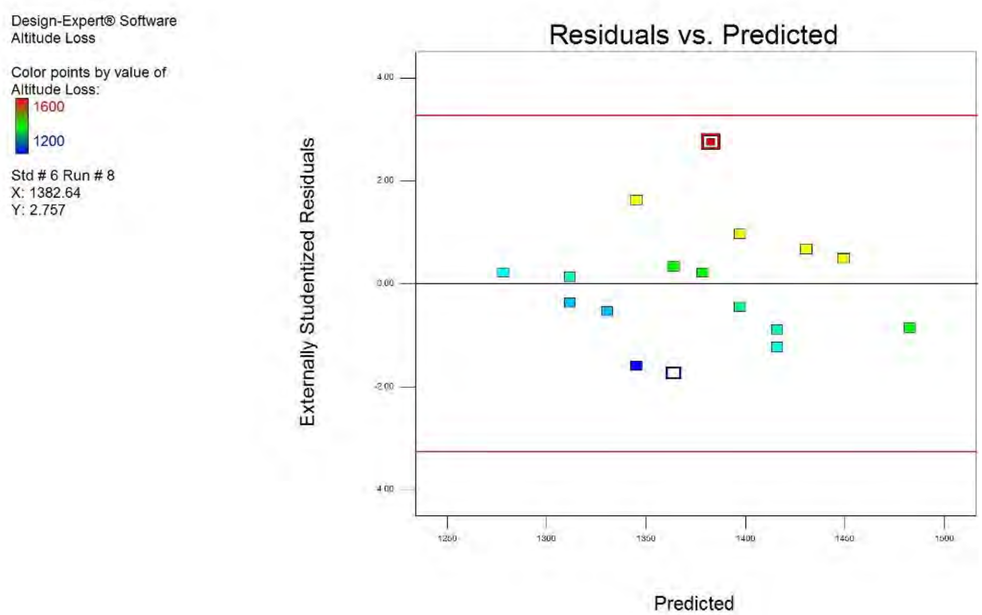


Figure 73: EA.seq_all Model: Residuals vs. Predicted

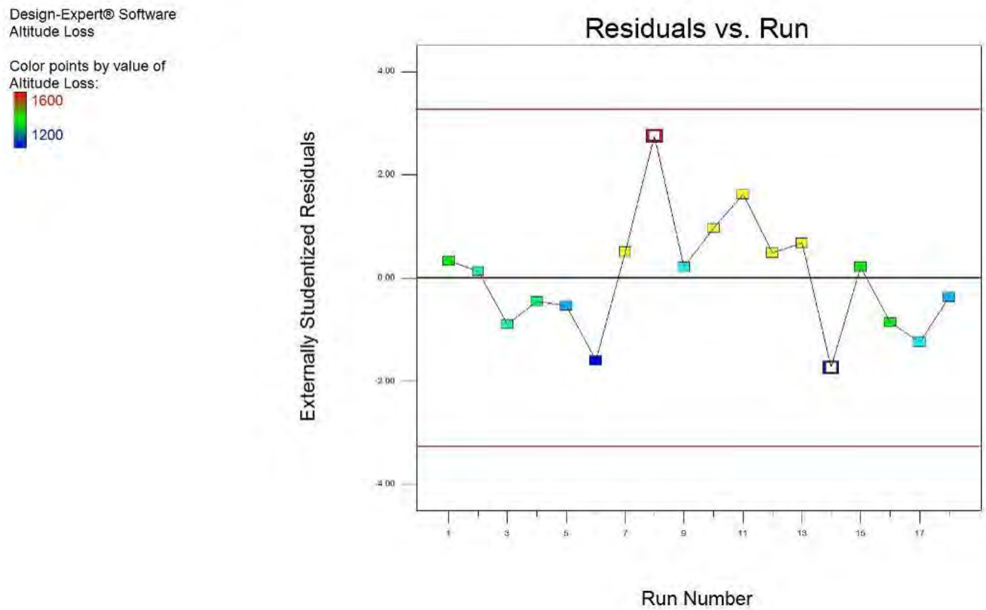


Figure 74: EA.seq_all Model: Residuals vs. Run

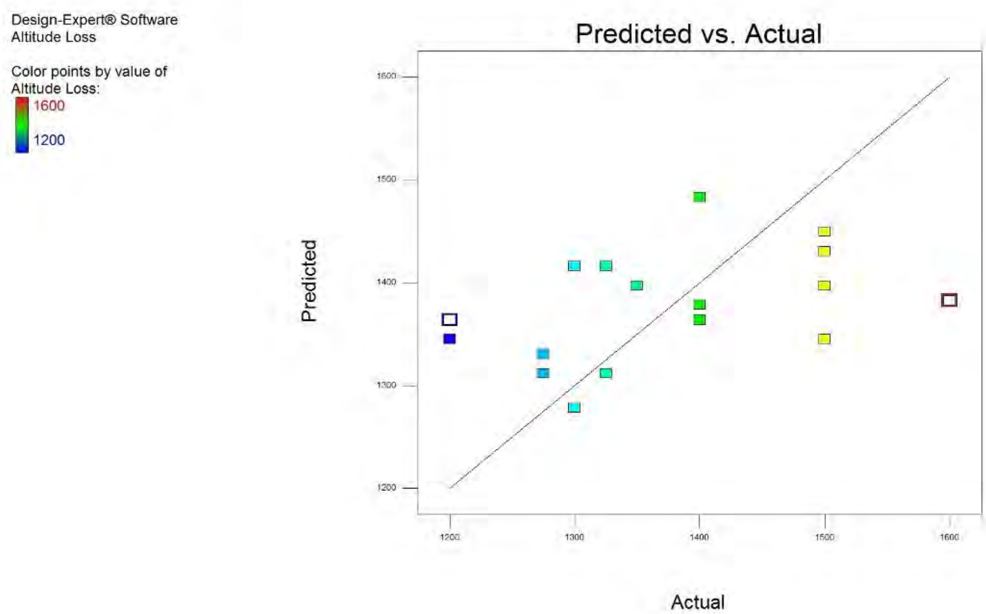


Figure 75: EA.seq_all Model: DFFITS vs. Run

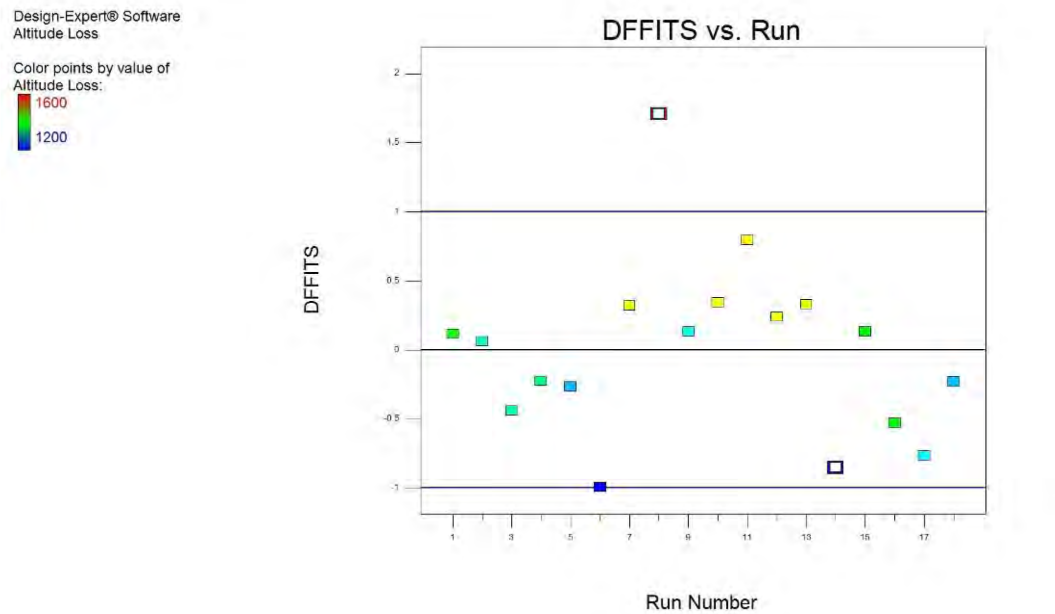


Figure 76: EA.seq_all Model: DFFITS vs. Run

Table 46: EA.seq Model Summary of Residuals

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residual	Externally Studentized Residual	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	1400.00	1363.89	36.11	0.111	0.340	0.329	0.004	0.116	3
2	1325.00	1311.81	13.19	0.194	0.131	0.126	0.001	0.062	5
3	1325.00	1415.97	-90.97	0.194	-0.901	-0.894	0.049	-0.439	1
4	1350.00	1397.22	-47.22	0.194	-0.468	-0.454	0.013	-0.223	7
5	1275.00	1330.56	-55.56	0.194	-0.550	-0.536	0.018	-0.263	8
6	1200.00	1345.14	-145.14	0.278	-1.518	-1.600	0.221	-0.992	4
7	1500.00	1449.31	50.69	0.278	0.530	0.516	0.027	0.320	2
8	*1600.00*	*1382.64*	*217.36*	*0.278*	*2.273*	*2.757*	*0.497*	*1.710 **	*6*
9	1300.00	1278.47	21.53	0.278	0.225	0.217	0.005	0.135	9
10	1500.00	1397.22	102.78	0.111	0.969	0.966	0.029	0.342	10
11	1500.00	1345.14	154.86	0.194	1.533	1.620	0.142	0.796	11
12	1500.00	1449.31	50.69	0.194	0.502	0.488	0.015	0.240	12
13	1500.00	1430.56	69.44	0.194	0.688	0.674	0.029	0.331	13
14	*1200.00*	*1363.89*	*-163.89*	*0.194*	*-1.623*	*-1.735*	*0.159*	*-0.852*	*14*
15	1400.00	1378.47	21.53	0.278	0.225	0.217	0.005	0.135	15
16	1400.00	1482.64	-82.64	0.278	-0.864	-0.856	0.072	-0.531	16
17	1300.00	1415.97	-115.97	0.278	-1.213	-1.235	0.141	-0.766	17
18	1275.00	1311.81	-36.81	0.278	-0.385	-0.373	0.014	-0.231	18

Table 47: EA.seq Model Design (Actual)

Std	Block	Run	Factor 1 A:Elevator % Deflection	Factor 2 B:Aileron % Delfection	Response 1 Altitude Loss ft
3	Right Spins	1	0	0	1400
5	Right Spins	2	0	100	1325
1	Right Spins	3	0	-100	1325
7	Right Spins	4	50	0	1350
8	Right Spins	5	-50	0	1275
4	Right Spins	6	50	100	1200
2	Right Spins	7	50	-100	1500
~~6~~	~~Right Spins~~	~~{8}~~	~~-50~~	~~-100~~	~~1600~~
9	Right Spins	9	-50	100	1300
10	Left Spins	10	0	0	1500
11	Left Spins	11	0	100	1500
12	Left Spins	12	0	-100	1500
13	Left Spins	13	50	0	1500
14	Left Spins	14	-50	0	1200
15	Left Spins	15	50	100	1400
16	Left Spins	16	50	-100	1400
17	Left Spins	17	-50	-100	1300
18	Left Spins	18	-50	100	1275

Table 48: EA.seq Model Data Statistics (Actual)

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Elevator	% Deflection	Numeric	Continuous	-50	50	-1.000=-50	1.000=50	0	42.0084
B	Aileron	% Delfection	Numeric	Continuous	-100	100	-1.000=-100	1.000=100	0	84.0168

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Altitude Loss	ft	17	Factorial	1200	1500	1367.65	105.24	1.25	None	Main effects

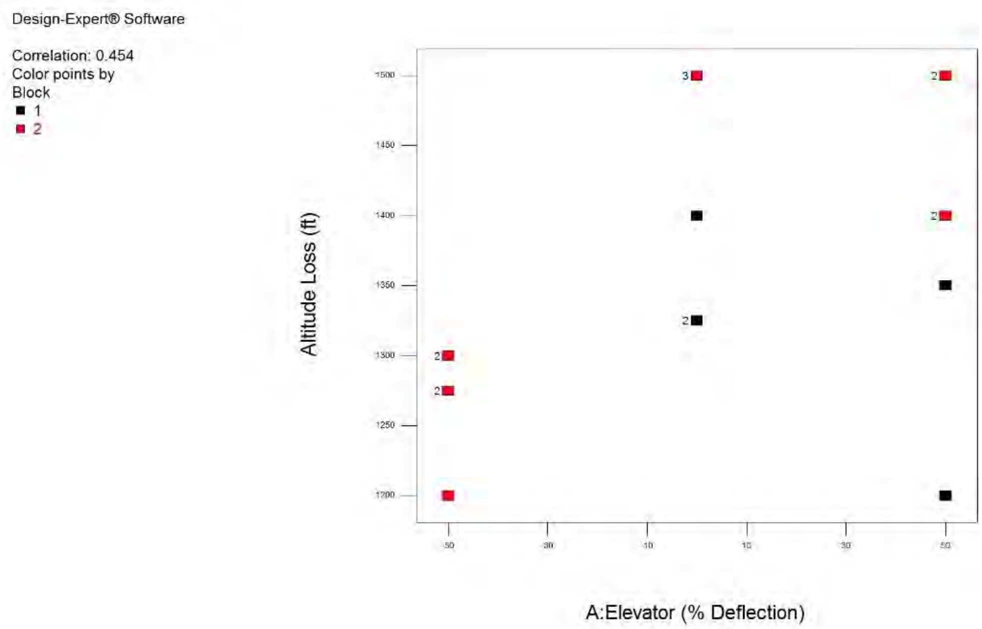


Figure 77: EA.seq Model: Elevator vs. Altitude Loss (Actual)

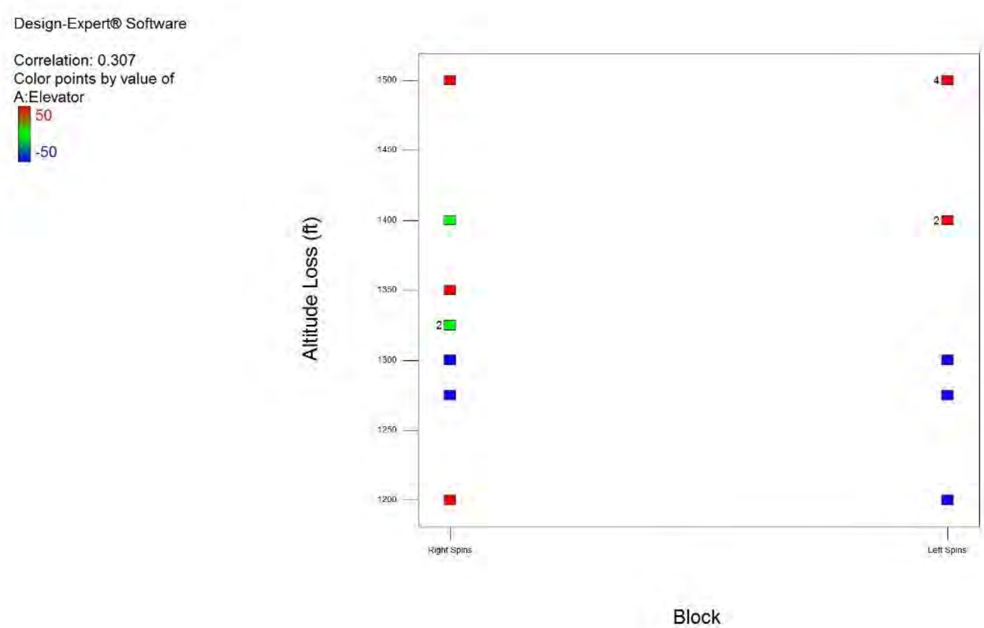


Figure 78: EA.seq Model: Block vs. Altitude Loss (Actual)

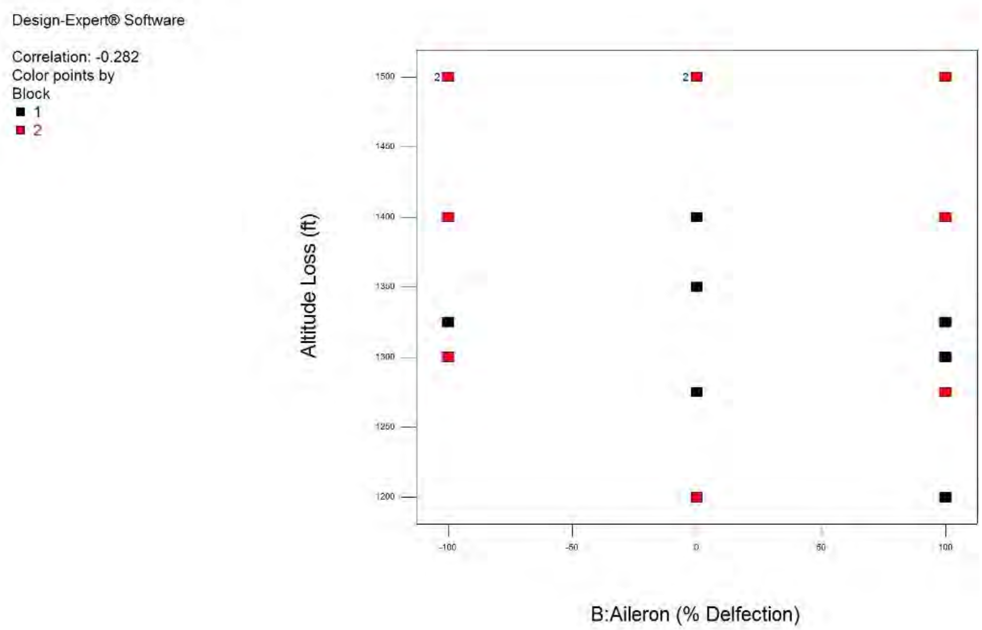


Figure 79: EA.seq Model: Aileron vs. Altitude Loss (Actual)

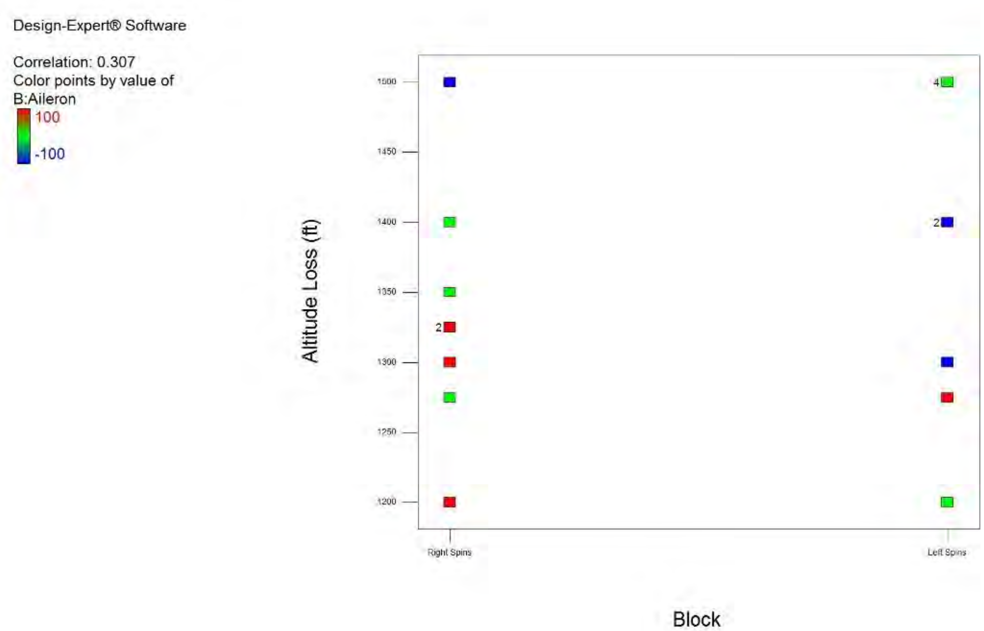


Figure 80: EA.seq Model: Block vs. Altitude Loss (Actual)

Table 49: EA.seq Model Factor Selection

Term	Stdized Effect	Sum of Squares	% Contribution
Intercept			
A-Elevator	119.34	38265.53	24.33
B-Aileron	-51.50	7125.58	4.53
AB	-69.10	12828.39	8.16
Curvature	79.23	16866.92	10.72
Lack of Fit		82196.38	52.26
Pure Error		0.000	0.000

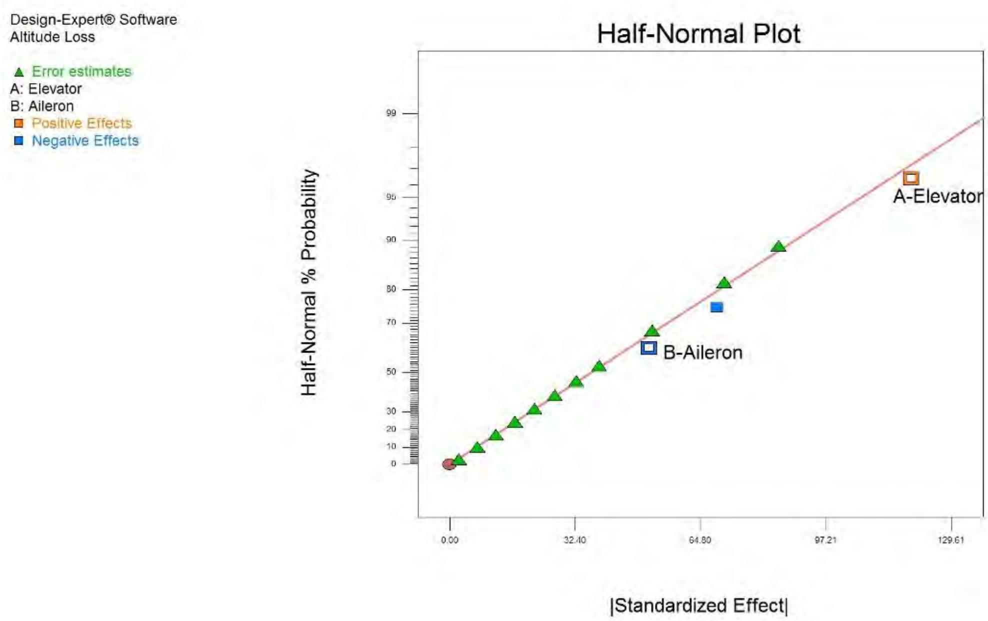


Figure 81: EA.seq Model Half-Normal Plot

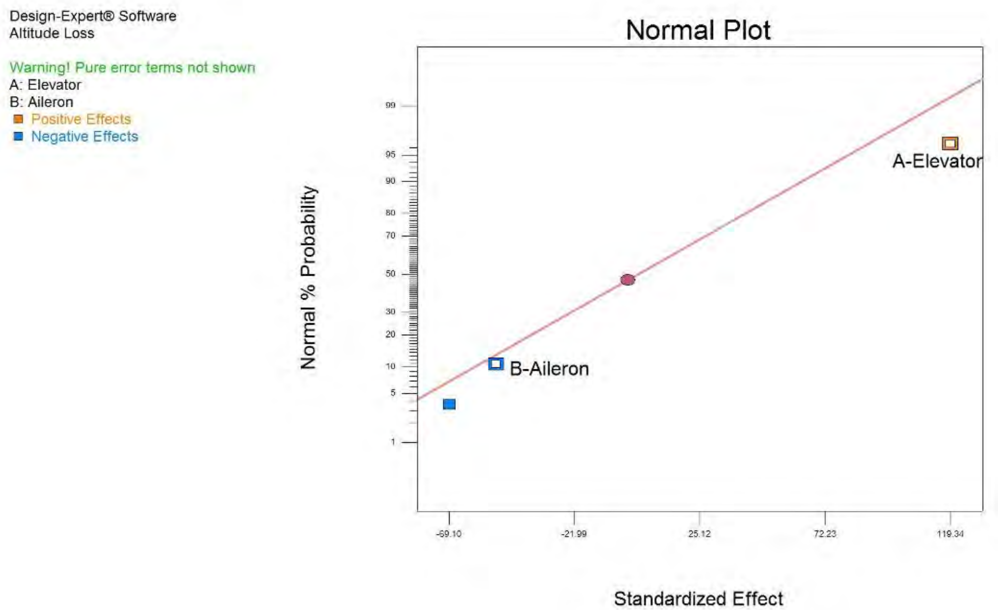


Figure 82: EA.seq Model Normal Plot

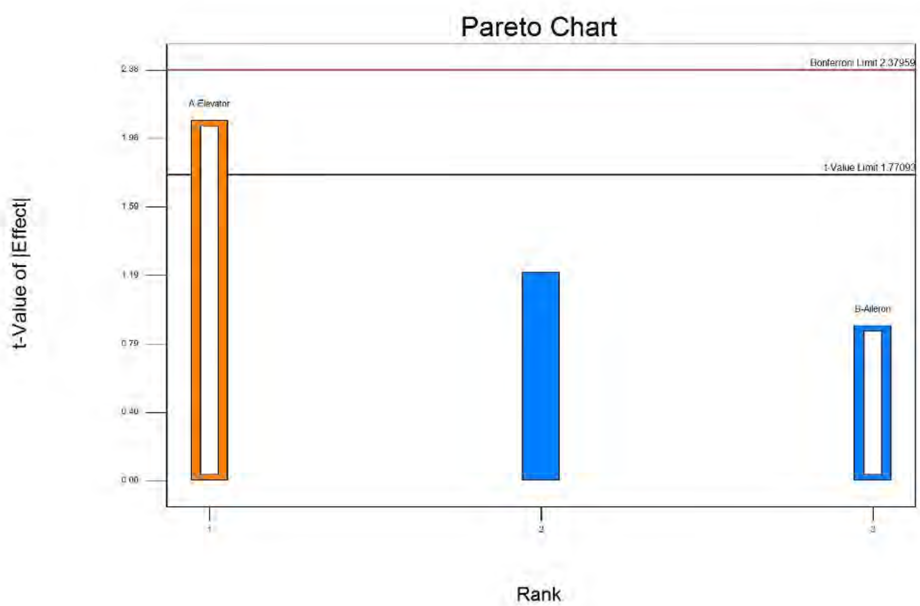


Figure 83: EA.seq Model Pareto Chart

Table 50: EA.seq Model ANOVA

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Block	16728.45	1	16728.45			
Model	48585.74	2	24292.87	2.82	0.0959	significant
A-Elevator	*36709.84*	*1*	*36709.84*	*4.27*	*0.0594*	
B-Aileron	*7844.90*	*1*	*7844.90*	*0.91*	*0.3571*	
Residual	1.119E+005	13	8607.05			
Cor Total	1.772E+005	16				

Table 51: EA.seq Model Fit Statistics

Std. Dev.	92.77	R-Squared	0.3028
Mean	1367.65	Adj R-Squared	0.1955
C.V. %	6.78	Pred R-Square	-0.1944
PRESS	1.917E+005	Adeq Precisior	5.280

Table 52: EA.seq Model Coefficient Statistics

Factor	Coefficient Estimate	df	Standard Error	90% CI Low	90% CI High	VIF
Intercept	1363.84	1	22.69	1323.65	1404.02	
Right Spins	-33.39	1				
Left Spins	33.39					
A-Elevator	58.41	1	28.28	8.32	108.50	1.02
B-Aileron	-27.00	1	28.28	-77.09	23.09	1.02

Table 53: EA.seq Model Equation (Coded Factors)

Final Equation in Terms of Coded Factors:

Altitude Loss	=
+1363.84	
+58.41	* A
-27.00	* B

Table 54: EA.seq Model Equation (Actual Factors)

Final Equation in Terms of Actual Factors:

Altitude Loss	=
+1363.83547	
+1.16827	* Elevator
-0.27003	* Aileron

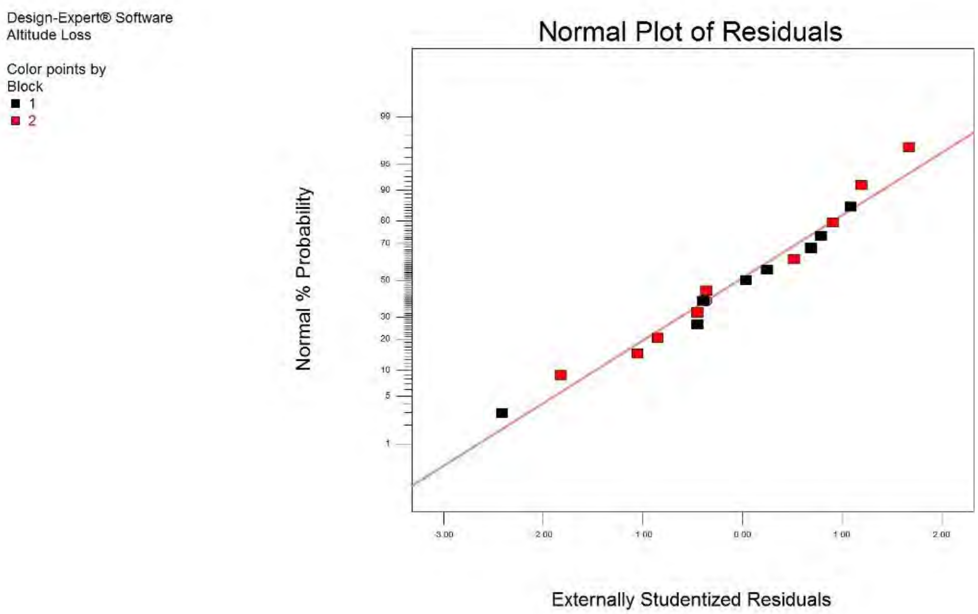


Figure 84: EA.seq Model Normal Plot of Residuals

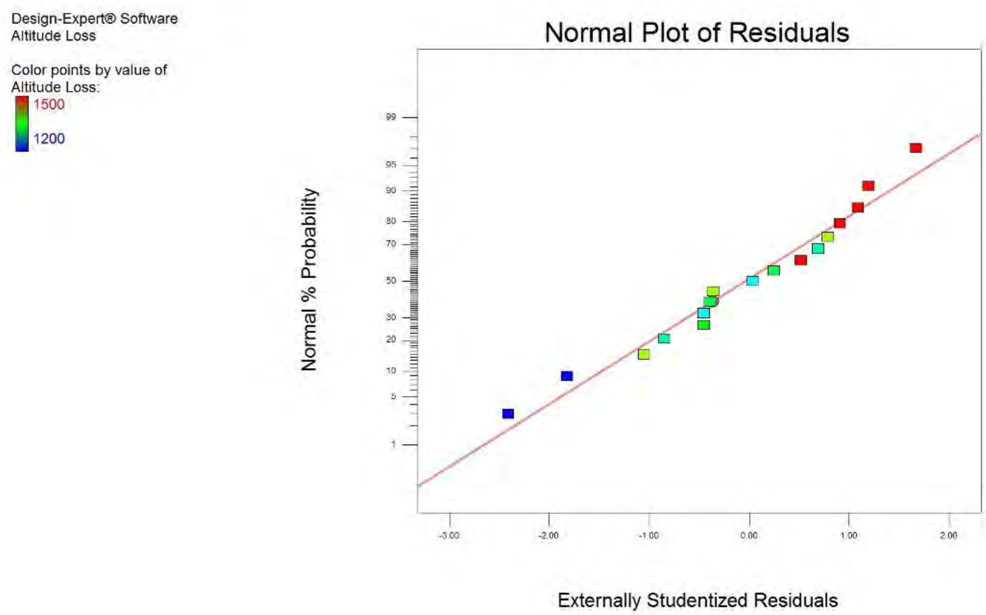


Figure 85: EA.seq Model Normal Plot of Residuals

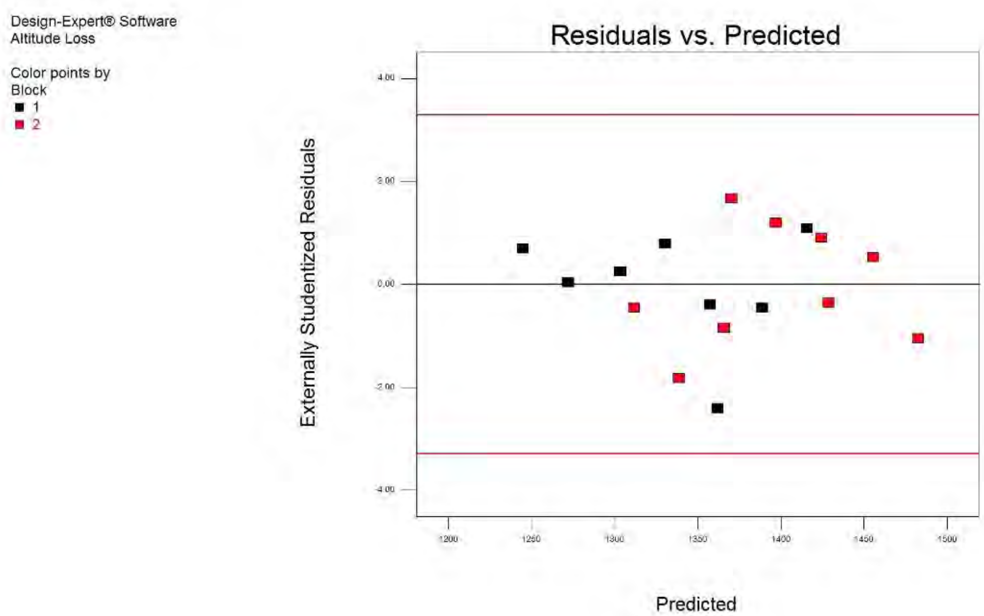


Figure 86: EA.seq Model: Residuals vs. Predicted

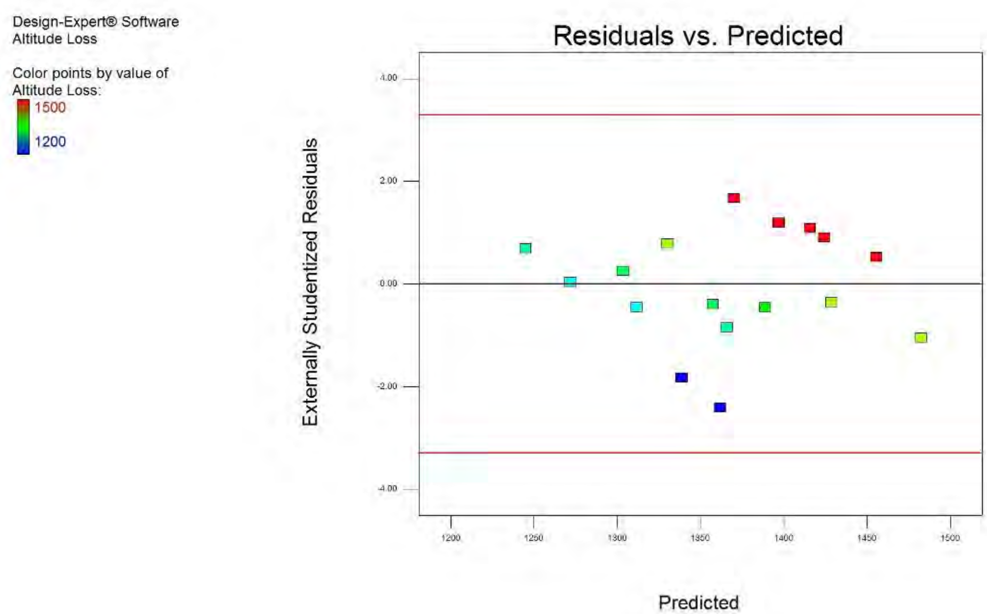


Figure 87: EA.seq Model: Residuals vs. Predicted

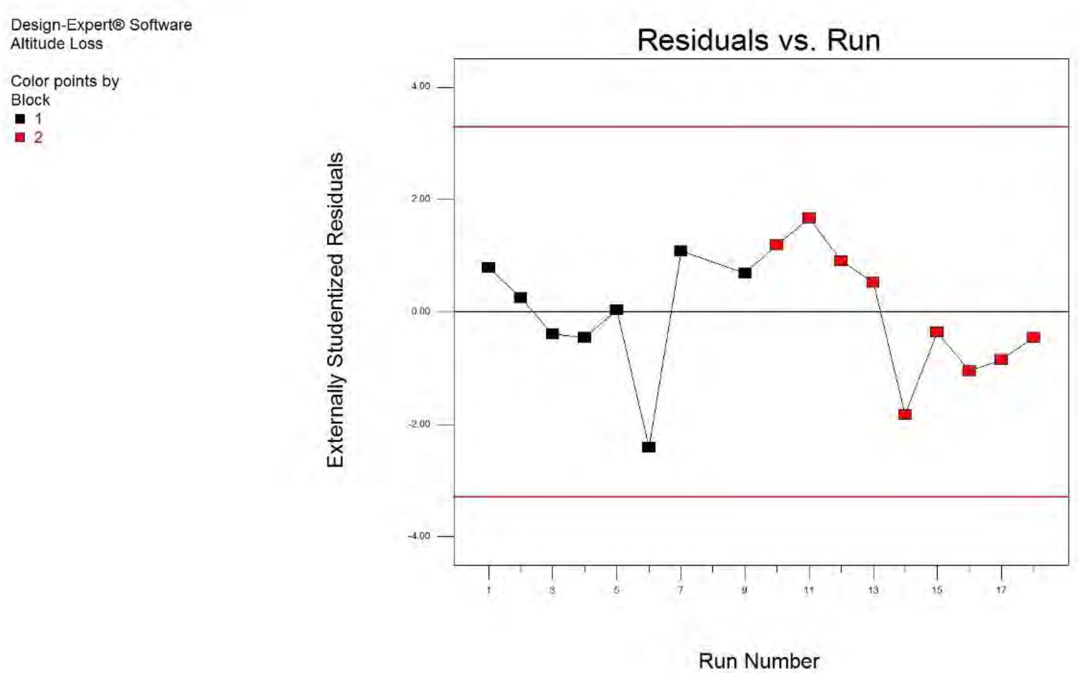


Figure 88: EA.seq Model: Residuals vs. Run

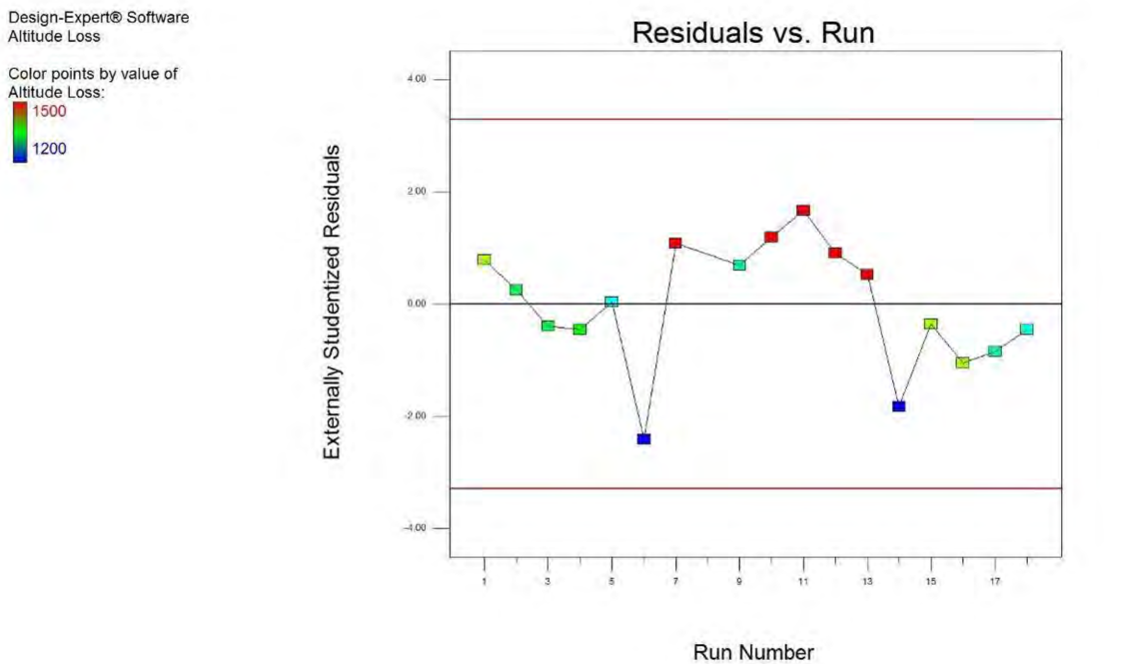


Figure 89: EA.seq Model: Residuals vs. Run

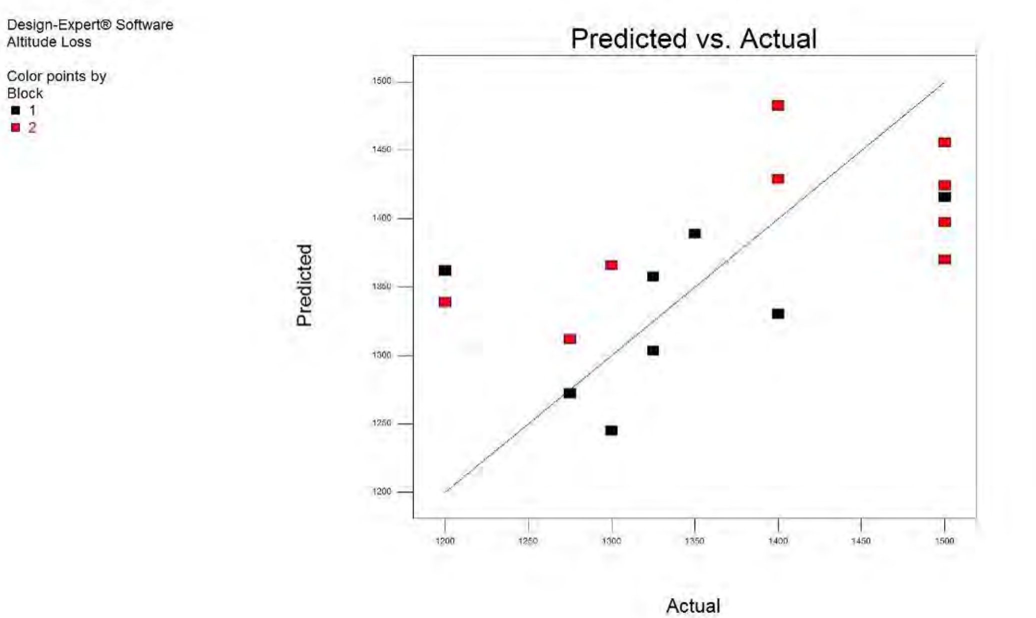


Figure 90: EA.seq Model: Predicted vs. Actual

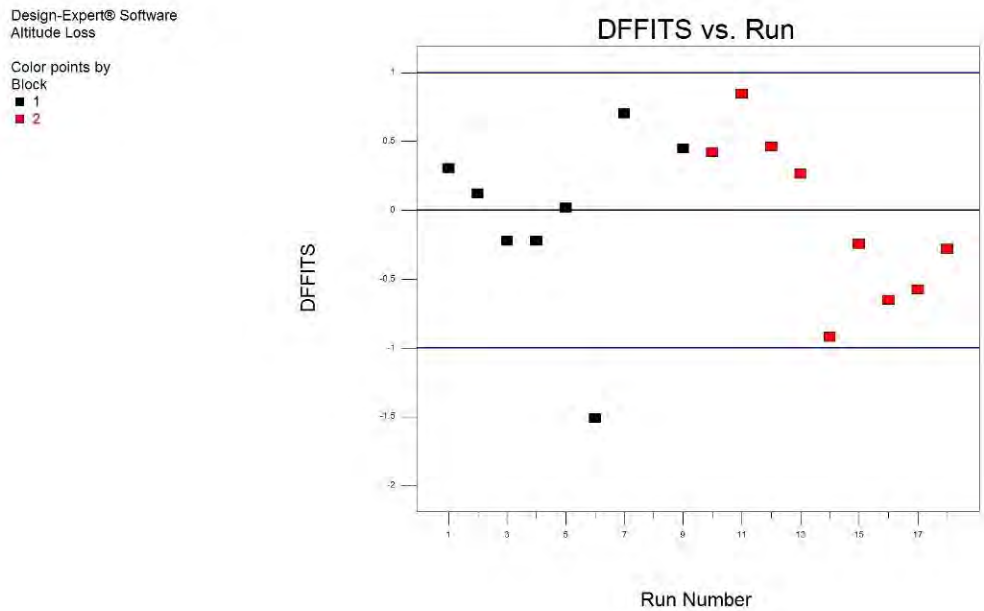


Figure 91: EA.seq Model: DFFITS vs. Run

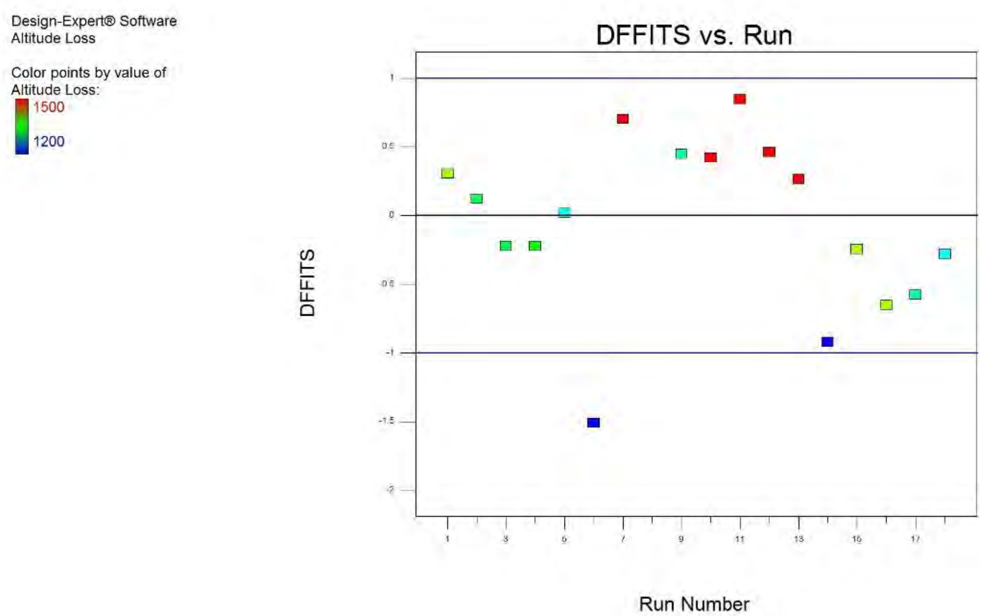


Figure 92: EA.seq Model: DFFITS vs. Run

Table 55: EA.seq Model Summary of Residuals

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residual	Externally Studentized Residual	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	1400.00	1330.45	69.55	0.128	0.803	0.791	0.024	0.303	3
2	1325.00	1303.45	21.55	0.196	0.259	0.250	0.004	0.123	5
3	1325.00	1357.45	-32.45	0.247	-0.403	-0.390	0.013	-0.223	1
4	1350.00	1388.86	-38.86	0.196	-0.467	-0.453	0.013	-0.223	7
5	1275.00	1272.04	2.96	0.247	0.037	0.035	0.000	0.020	8
6	1200.00	1361.86	-161.86	0.282	-2.059	-2.410	0.416	-1.510 *	4
7	1500.00	1415.87	84.13	0.295	1.080	1.088	0.122	0.703	2
9	1300.00	1245.03	54.97	0.295	0.706	0.691	0.052	0.447	9
10	1500.00	1397.22	102.78	0.111	1.175	1.194	0.043	0.422	10
11	1500.00	1370.22	129.78	0.204	1.568	1.673	0.158	0.847	11
12	1500.00	1424.23	75.77	0.204	0.915	0.909	0.054	0.460	12
13	1500.00	1455.64	44.36	0.204	0.536	0.521	0.018	0.264	13
14	1200.00	1338.81	-138.81	0.204	-1.677	-1.820	0.180	-0.922	14
15	1400.00	1428.63	-28.63	0.316	-0.373	-0.361	0.016	-0.245	15
16	1400.00	1482.64	-82.64	0.278	-1.048	-1.052	0.106	-0.653	16
17	1300.00	1365.81	-65.81	0.316	-0.858	-0.849	0.085	-0.577	17
18	1275.00	1311.81	-36.81	0.278	-0.467	-0.452	0.021	-0.281	18

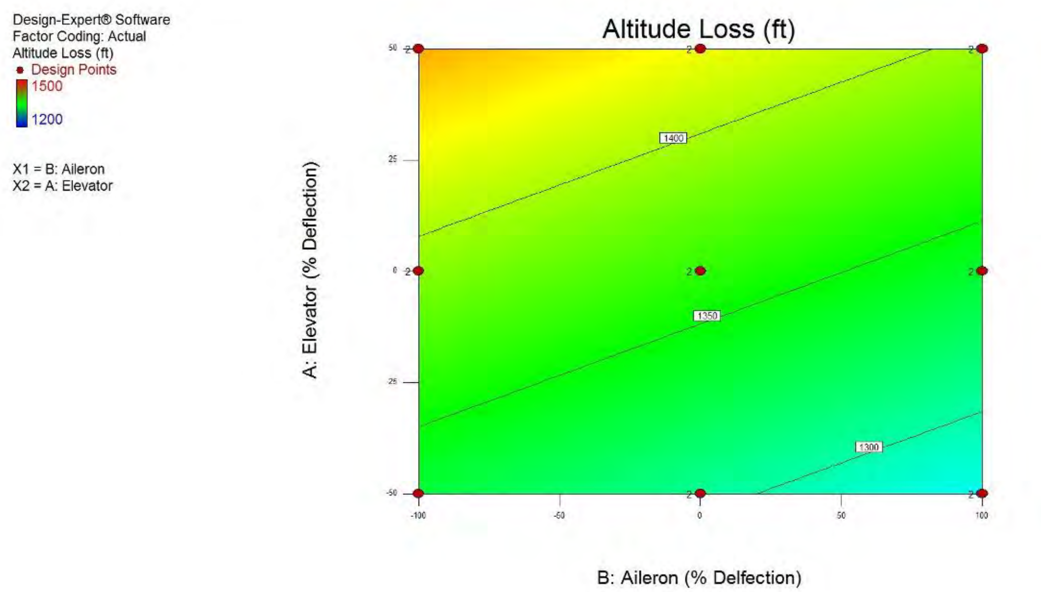


Figure 93: EA.seq Model Contour Plot; Aileron, Elevator, Altitude Loss

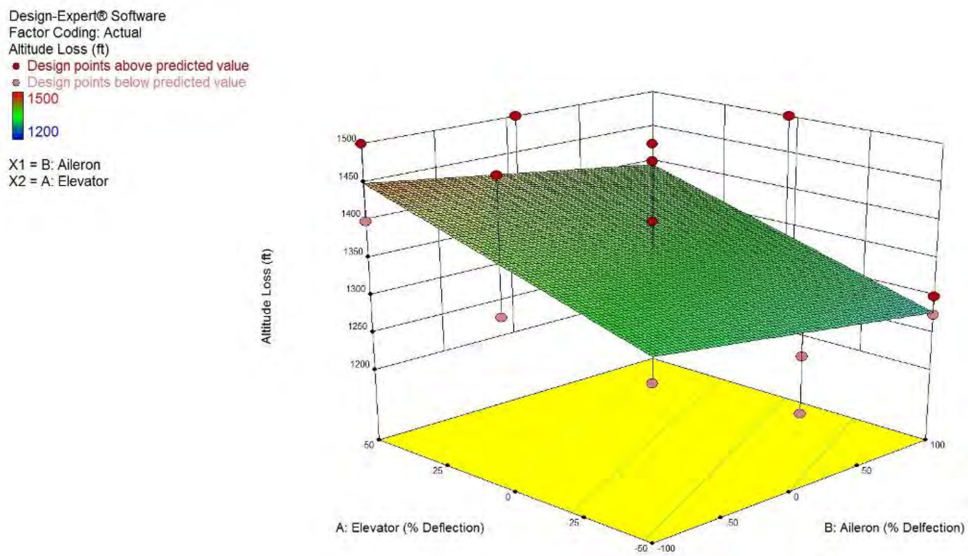


Figure 94: EA.seq Model 3D Plot; Aileron, Elevator, Altitude Loss

Bibliography

[1] J. Lowery, Anatomy of a Spin, Long Beach, CA: Airguide Publications, Inc, 1981.

[2] Federal Aviation Administration, *Advisory Circular 23-8C Flight Test Guide for Certification of Part 23 Airplanes*, Oklahoma City, OK: U.S. Department of Transportation, 2011.

[3] R. Stowell, The Light Airplane Pilot's Guide to Stall/Spin Awareness Featuring the PARE Spin Recovery Checklist, Ventura, CA: Rich Stowell Consulting, 2007.

[4] G. Beggs, Spins in the Pitts Special, Odessa, TX: Gene Beggs, 2001.

[5] M. C. Love, Spin Management & Recovery, New York, NY: McGraw-Hill, 1997.

[6] Federal Aviation Administration, *61-67C Stall and Spin Awareness Training*, Oklahoma City, OK: U.S. Department of Transportation, 2007.

[7] Federal Aviation Administration, FAA-H-8083-25A Pilot's Handbook of Aeronautical Knowledge, Oklahoma City, OK: U.S. Department of Transportation, 2008.

[8] R. M. Herrington and P. E. Shoemacher, "AF Technical Report No. 6273 Flight Test Engineering Manual," United States Air Force, Air Research and Development Command, Air Force Flight Test Center, Edwards Air Force Base, CA, 1953.

[9] Federal Aviation Administration, FAA-H-8083-3A Airplane Flying Handbook, Oklahoma City, OK: U.S. Department of Transportation, 2004.

[10] American Champion Aircraft Corporation, *Pilot's Operating Manual, Super Decathlon (8KCAB) 1990 & Up*, Rochester, WI: American Champion Aircraft Corporation, 1990.

[11] P. Scott, The Shoulders of Giants A History of Human Flight to 1919, New York, NY: Perseus Books, 1995.

[12] S. B. Anderson, "A Historical Overview of Stall/Spin Characteristics of General Aviation Aircraft," Vols. 16, No.7, p. 9, 7 July 1979.

[13] M. W. McFarland, The Papers of Wilbur and Orville Wright, New York, NY: McGraw-Hill, 2001.

[14] O. Wright, How We Invented the Airplane An Illustrated History, New York: Dover Publications, Inc, 1988.

[15] O. Lilienthal and G. Lilienthal, Birdflight As The Basis Of Aviation, Hummelstown, PA: Markowski International Publishers, 2001.

[16] A. Price, World War II Fighter Conflict A Comparative Study on the Evolution of Aircraft and Tactics: Great Britain, USA, Germany, USSR, Japan, France, Italy, London: Madonald and Jane's, 1975.

[17] H. H. Hurt, Aerodynamics for Naval Aviators, United States Navy, Naval Air Systems Command, 1965.

[18] R. Stowell, Emergency Maneuver Training Controlling Your Airplane During A Crisis, Ventura, CA: Rich Stowell Consulting, 1996.

[19] W. H. McAvoy, "Piloting Technique For Recovery From Spins," National Advisory Committee for Aeronautics, 7, 1936.

[20] A.E.B, "Parke's Dive," *Flight,* vol. IV, no. 192, pp. 787-789, 31 August 1912.

[21] M. J. Anderson and P. J. Whitcomb, DOE Simplified Practical Tools for Effective Experimentation, Boca Raton, FL: CRC Press, 2007.

[22] W. F. Adams and M. J. Anderson, "Optimal Experimental Design with R," *Technometrics,* vol. 54, no. 2, pp. 198-205, May 2012.

[23] A. Marino, R. Fauci, R. Donelli and A. Schettino, "Hypersonic Laminar-Turbulent Transition Experiment Design: From wind tunnel model definition to MDOE Approach," *American Institute of Aeronautics, Inc,* p. 19, 2010.

[24] M. J. Anderson and P. J. Whitcomb, "Practical Aspects for Designing Statistically Optimal Experiments," *Journal of Statistical Science and Application*, vol. 2, no. 3, pp. 85-92, March 2014.

[25] S. J. Milton and J. C. Arnold, Introduction to Probability and Statistics Principles and Applications for Engineering and the Computing Sciences, 4th ed., New York, NY: McGraw-Hill, 2003.

[26] C. Bertoni, "In Pursuit of Optimal Weld Parameters," *Welding Design and Fabrication*, p. 22, 8 Dec 2014.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
17-09-2015	Master's Thesis	Oct 2014- Sept 2015

4. TITLE AND SUBTITLE	
Evaluation of Control Inputs on the Spin Recovery of the 8KCAB Super Decathlon	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Courtney Allen, Civilian, DAF	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way, Building 640 WPAFB OH 45433-7765	AFIT-ENV-MS-15-S-035
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
Intentionally Left Blank	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

14. ABSTRACT
The current Federal Aviation Administration (FAA) response to stall/spin related accidents is prevention through pilot awareness training and encouraging stall proof aircraft design features. Aircraft have an inherent capability to spin. The controls that influence spin recovery have yet to be quantitatively analyzed in a regression analysis. This thesis presents the regression modeling and validation process for the evaluation of control inputs on the spin recovery of the 8KCAB Super Decathlon. The regression models in this thesis explore the control inputs for factors of: rudder, elevator, and aileron. Additionally, this thesis explores the timing of the control inputs factors for sequenced as well as simultaneous application. The research presented is of interest to general aviation pilot community with limited exposure to spins and variations of spin recovery methods. Aircraft spins have become taboo and avoided by all but the most experienced pilots and researchers. The research here is focused on the evaluation of control inputs on spin recovery qualities. While this research is limited to the 8KCAB super decathlon type aircraft, the aircraft is a good representation of the general aviation community.

15. SUBJECT TERMS
Spin Recovery, Super Decathlon, Design of Experiments, Regression Analysis

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Dr. John M. Colombi, AFIT/ENV
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)*
U	U	U	UU	236	(937) 255-6565, x 3347 (johncolombi@afit.edu)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18