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A qualitative evaluation of the spin and recovery characteristics of the Yakovlev Yak-52 airplane

Robert D. Moreau

To the Graduate Council:

I am submitting herewith a thesis written by Robert D. Moreau entitled "A qualitative evaluation of the spin and recovery characteristics of the Yakovlev Yak-52 airplane." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Ralph Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Bill Lewis, Fred Stellar

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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And recommend its acceptence:

Fred Stellar

Accepted for the Council:

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A QUALITATIVE EVALUATION OF THE SPIN AND RECOVERY CHARACTERISTICS OF THE YAKOVLEV YAK-52 AIRPLANE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Robert D. Moreau
December 2001

DEDICATION

This thesis is dedicated to:

Ann

Who Makes My World Possible

ACKNOWLEDGMENTS

There is no question that my time at the University of Tennessee Space Institute has been the high point of my educational career and one of the most enjoyable journeys that I have had the pleasure of undertaking. For that I owe everyone my heartfelt thanks. In particular I would like to thank Dr. Ralph Kimberlin, Dr. Bill Lewis and Professor Fred Stellar for opening up an exciting new world and keeping my stumbles to a minimum.

ABSTRACT

With the demise of the former Soviet Union many aircraft types which were previously unknown have become commonplace to western pilots. One such type is the Yakovlev Yak-52 unlimited aerobatic training airplane. The relatively low acquisition cost makes it accessible to pilots with a wide range of experience and proficiency. A qualitative evaluation was made of the spin and recovery characteristics of the Yak-52 airplane. Twenty-eight stalls and fifty-two spins were conducted over a nine-month period at both forward and aft centers of gravity. The spin modes included normal erect, accelerated and flat spins as well as inverted spins. At the forward center of gravity the airplane was equipped with a data acquisition system. Normal erect recoveries were found to be easy and precise within one half-turn requiring minimal control forces. Accelerated and flat spins resulted in high rates of rotation and high control forces with recoveries for aft centers of gravity requiring up to four turns. As this is starkly different from the characteristics found in most western training airplanes it is vitally important that pilots of the Yak-52 airplane be made fully aware of these characteristics before attempting such maneuvers.

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CHAPTER 1

INTRODUCTION

Purpose

The objective of this investigation was to examine the spin and recovery characteristics of the Yakovlev Yak-52 airplane qualitatively. The information collected during this investigation is intended for the education and training of western pilots regarding the unique spin characteristics of this Soviet designed airplane, especially when compared to more familiar U.S. designs on which western pilots have been trained.

Background

With the collapse of the former Soviet Union in the early nineteen nineties many types of aircraft, which were formerly unknown in the west, have become readily available. One such example was the Yakovlev Yak-52 airplane (Figure 1-1).

Figure 1-1 Standard Production Yakovlev Yak-52

The Yak-52 was built as an aerobatic trainer capable of performing unlimited class maneuvers. Available at a cost not only far below that of equivalent western aerobatic airplanes, it is available at a cost below that of most general aviation airplanes of only minor to modest capabilities. Consequently, the Yak-52 is increasingly found in the hands of pilots with little or no aerobatic flight training, or whose experience is on airplane types, which offer characteristics that are quite different, particularly with regard to spins and recovery techniques. The inevitable results are accidents, often fatal, resulting from the inability of pilots to recover from uncontrolled flight (Figure 1-2).

Figure 1-2 Fatal Yak-52 Accident Resulting From Inability To Recover From Flat Spin

Scope of Tests

The evaluation of the spin and recovery characteristics of the Yak-52 airplane consisted of 15 hours of testing over a nine-month period. The evaluation included an examination of the stall characteristics, the characteristics of the incipient stage of the spin, the characteristics of the fully developed stage of the spin, and the associated characteristics during recovery from a spin. This was accomplished during the course of 28 stalls and 52 spins. The tests were conducted within the limits of the Yak-52 Flight Manual.[1]

Method of Tests

Although the Yak-52 is licensed in the Experimental-Exhibition category of the Federal Aviation Regulations (FAR's) and does not come under the rules of FAR Part 23, which governs the certification of light aircraft, the tests were conducted with guidance from AC 23-8A.[2] Procedures were also applied during the investigation from the USNTPS Fixed Wing Stability and Control Flight Test Manual.[3]

The takeoff gross weights were within a range of 2596 pounds to 2842 pounds. The tests were conducted at both a forward center of gravity (CG) of 18% MAC and an aft center of gravity of 25% MAC (Table 1-1). During the forward CG tests a data acquisition system, type AVS-18H, was utilized for one series of tests (Appendix A). A yaw string was installed on the forward upper windscreen with sideslip markings calibrated for the idle power condition. Chase aircraft or ground observers were utilized for safety support and for a backup with data collection.

Table 1-1 Test Day Conditions

Weather Conditions	Takeoff Weight Range (lbf)	Center of Gravity (Percent MAC)	Starting Hp (Feet)
Day VFR	2596-2662	18	7000
Day VFR	2776-2842	25	7000

CHAPTER 2

AIRCRAFT DESCRIPTION

History

The Yakovlev Yak-52 airplane (Figure 2-1) was designed as an unlimited aerobatic trainer by the OKB Yakovlev (Yakovlev Design Bureau). It was a two-seat development of the single-seat Yakovlev Yak-50 competition aerobatic airplane (Figure 2-1, lower right). Intended as a replacement for the Yakovlev Yak-18 airplane then in service with the air force (VVS – Voenno Vozduschnogo Sil) and of the aero clubs of DOSAAF (Dobrovolnoe Obshchestovo Sodiestviya Armii, Aviatsii Flotu – Voluntary Association for the support of the Army and Aviation Fleet) in the former Soviet Union, the Yak-52 has also seen service with the Romanian and Vietnamese air forces. Production began in 1978 at the Aerostar S.A. aircraft factory located in Bacau, Romania, which continues to this day. To date there have been 1,800 Yak-52 airplanes delivered.

Construction

The construction of the Yak-52 is of conventional design utilizing a tandem seat, two-place, dual controlled, single-engine, low-wing monoplane design. The airframe is of all metal, semi-monocoque design. It is stressed for a g loading of 7 positive and 5 negative during normal aerobatic operation. It is covered with 2024T3 aluminum with varied

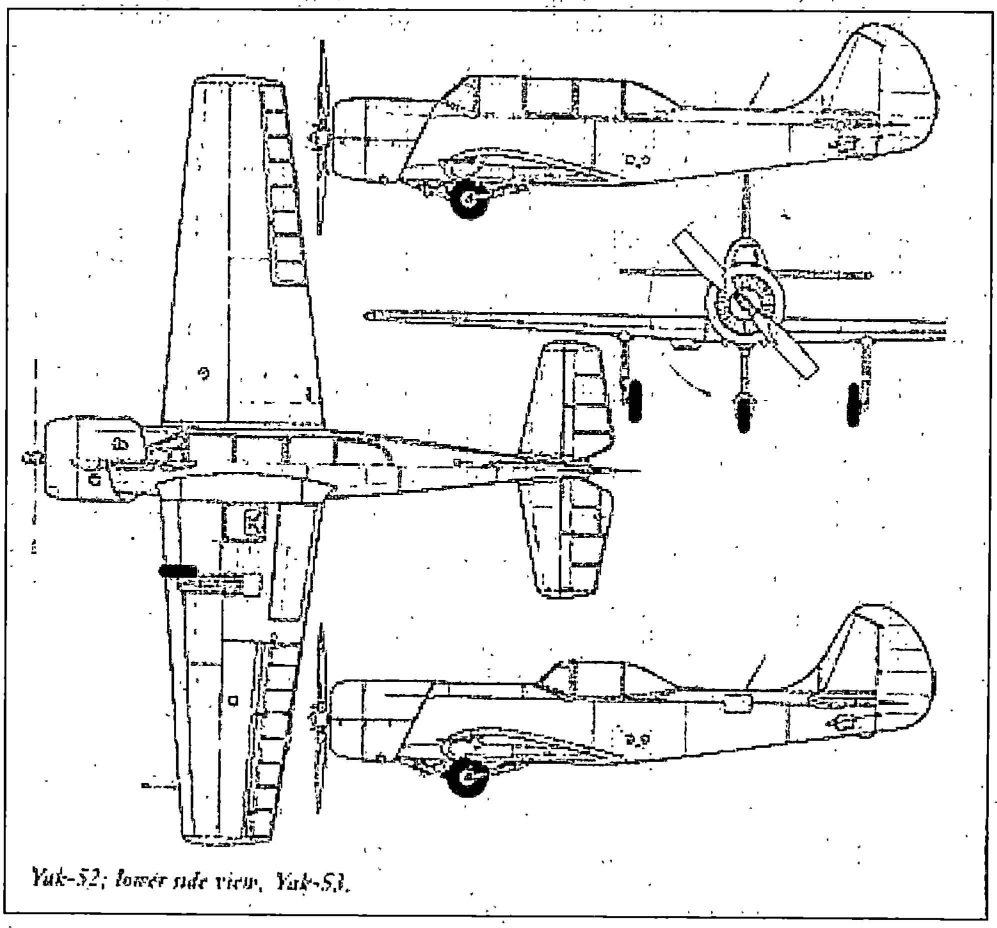

Figure 2-1 Yakovlev Yak-52 Three View and Yak-50 Series Side View

thickness along the length of the fuselage and wingspan. The wings are of a single spar stressed skin design with a slotted aileron and a split-type landing flap. The tail section has a trapeze form. It consists of a vertical unit and a horizontal unit. The vertical unit includes the fin and rudder. The horizontal unit includes two, separated stabilizer panels mounted onto a single-piece spar and two elevators.

Flight Controls

The reversible flight controls consist of two Frise-type slotted ailerons, two elevators and a single rudder. All flight control surfaces are of aluminum frame construction covered with fabric. Each control surface is 100 percent mass balanced. The aileron surfaces are actuated by dual control sticks utilizing bell cranks and pushrods. The elevators are actuated by dual control sticks utilizing a combination of pushrods and control cables. The rudder is actuated by dual rudder pedal quadrants utilizing control cables. Standard production airplanes are equipped with a centering spring device for the control stick acting in both the longitudinal axis and the lateral axis. The purpose of this device is to return the control stick to the centered, or neutral, position when released by the pilot.

Powerplant

The Yak-52 is powered by a single 360 horsepower Ivchenko M-14P nine-cylinder air-cooled radial engine of 6.3 to 1 compression ratio. A two-bladed variable-pitch wooden propeller, type V-530TA-D35, is connected to the engine via a reduction gear unit. The engine utilizes 100LL grade aviation fuel and W100 grade aviation oil. The engine oil system allows for inverted flight through the use of a cooler bypass line from the oil supply tank directly to the engine. This limited inverted flight duration based upon the temperature of the oil.

Aircraft Systems

The fuel system consists of two wing-mounted fuel tanks located forward of the main spar and just outboard of the wing root area, each with a capacity of 18.6 gallons. These tanks feed a collector tank located in the center fuselage area with a capacity of 1.5 gallons. Fuel is fed from the collector tank to the engine via non-return valves, two engine-driven pumps and a carburetor. This system allows for inverted flight. The standard production Yak-52 does not incorporate a hydraulic system. A pneumatic system is utilized to actuate the landing gear, flaps, brakes and engine starting. System pressure is 750 pounds per square inch with the air supply being stored in two separate bottles, a main bottle of 0.16 cubic foot capacity and an emergency bottle for landing gear extension of 0.09 cubic foot capacity. The supply bottles are normally charged by an engine-driven air compressor, type AK-50T, with the capability to utilize an exterior connector. The landing gear consists of a tricycle type design with the main gear retracting forward into exterior up locks, which leaves the main wheels fully exposed. The nose gear retracts rearward into an exterior up lock in a similar manner. When retracted the main and nose wheels are in alignment and located such that a landing could be accomplished on the retracted landing gear with minimal damage to the airplane.

Test Aircraft Modifications

The Yak-52 utilized for this investigation (Figure 2-2) differed from a standard production Yak-52 due to several modifications. The airflow shutters were removed from the forward engine cowling and a large spinner was installed to facilitate improved airflow into the engine compartment. The standard wheels and tires were replaced and the pneumatic brakes were replaced with hydraulic brakes actuated by the toe portion of the rudders pedals. The stick centering springs were removed and spades added to the ailerons for reduced stick forces in roll. A lightweight alternator of 35-amp capacity replaced the engine-driven generator. A transponder and encoding altimeter were installed. The airspeed indicators were replaced with units indicating knots instead of kilometers per hour.

Anthropometric Data

Pertinent cockpit evaluation points and anthropometric data were determined using the Federal Aviation Administration's Human Factors Design Guide.[4] Of particular interest were the functional reach and functional leg length measurement data. At 79cm and 94cm, respectively, both were found to be in excess of the length limit for the 5th percentile female pilot (Appendix B).

1	Aileron Spades
2	Western Wheels And Hydraulic Brakes
3	Spinner

Figure 2-2 Yak-52 Modifications From Standard Production Configuration

CHAPTER 3

THEORY

Background

Over the years much has been written about the various methods developed to predict the spin recovery characteristics of an airplane. The intent of this chapter is to examine some of these theories relative to the physical design of the Yak-52 airplane. Because these theories are by no means absolutely definitive in nature, any conclusions derived should be treated as generalizations.

Inertia Yawing Moment Parameter

The relative mass distribution is defined by a parameter known as the Inertia Yawing Moment Parameter (IYMP). It is a parameter describing the relative mass distribution of the airplane along the X-axis and Y-axis, sometimes referred to as the most important single factor in determining spin characteristics. An airplane rotating in a spin is like a gyroscope with the associated inertia moments created about all three axes. At the same time aerodynamic forces and moments are acting on the airplane due to its movement through the air. For the spin to be in equilibrium the inertia forces and moments must be equal to and opposite in sign to the aerodynamic forces and moments. For an airplane to recover from a spin this equilibrium must be broken through the use of some control or combination of controls that will create the greatest moments opposing the spin.

The IYMP is calculated by:

$$IYMP = I_X - I_Y / mb^2$$

Where

- I = respective axis moment of inertia
- m = airplane mass
- b = wingspan

For values close to zero the mass distribution is approximately balanced along the wings and the fuselage. For such airplanes the rudder is the primary recovery control. For those airplanes with a positive value the mass is distributed more along the wings than the fuselage and the elevator is the primary recovery control. For those airplanes with a negative value the mass is distributed more along the fuselage than the wings and the ailerons are the primary recovery control. The zero range is generally accepted to be from -50×10^{-4} to 50×10^{-4}.[5] The value for the Yak-52 airplane is -135.4×10^{-4}.

Relative Density

The relative-density factor (μ) is a parameter, which describes the density of the airplane relative to the density of the air in which it is flying. It is calculated by:

$$\mu = m/\rho Sb$$

Where

- m = airplane mass
- ρ = air density
- S = wing area
- b = wing span

Airplanes with a relatively high value of μ, greater than 6, normally require more rudder and elevator effectiveness for spin recovery than airplanes with lower values. For the Yak-52 airplane at the test pressure altitude of 7000 feet the value of μ is 9.43.[6]

Tail Damping Power Factor

Tail Damping Power Factor (TDPF) dates to work done by the NACA as far back as the 1930's. It is a measure of the damping provided by the exposed vertical surface area at the tail. It is derived from values for both the fuselage side area directly below the horizontal surfaces, known as the Tail Damping Ratio (TDR) and of the rudder area unshielded by the horizontal surfaces at spin angles of attack, known as the Unshielded Rudder Volume Coefficient (URVC). The calculation of the TDR is by:

$$TDR = S_F L^2 / S(b/2)^2$$

Where

- S_F = surface area directly below the horizontal tail surfaces
- L^2 = length from the center of S_F to the CG
- S = wing area

- b = wing span

The URVC is calculated by:

$$URVC = S_R L / S(b/2)$$

Where

- S_R = the rudder left unshielded by the horizontal tail surfaces at spin angle of attack, which was assumed to be 45 degrees for this calculation
- L = length from the center of S_R to the CG
- S = wing area
- b = wing span

If there is an area of rudder both above and below the shielded portion at spin angles of attack then the two areas and their respective lengths to the CG would be added together before the division by S(b/2). The value of the TDPF is found by:

$$TDPF = TDR \times URVC$$

For the Yak-52 airplane the TDPF value is 137.5×10^{-6}.[5]

Empirical Results

The values for TDPF, IYMP and μ for the Yak-52 are plotted empirically against known characteristics for other airplanes (Figure 3-1). It should be noted that the origin of this graph involved airplanes from the 1930's and 1940's, which had markedly different mass

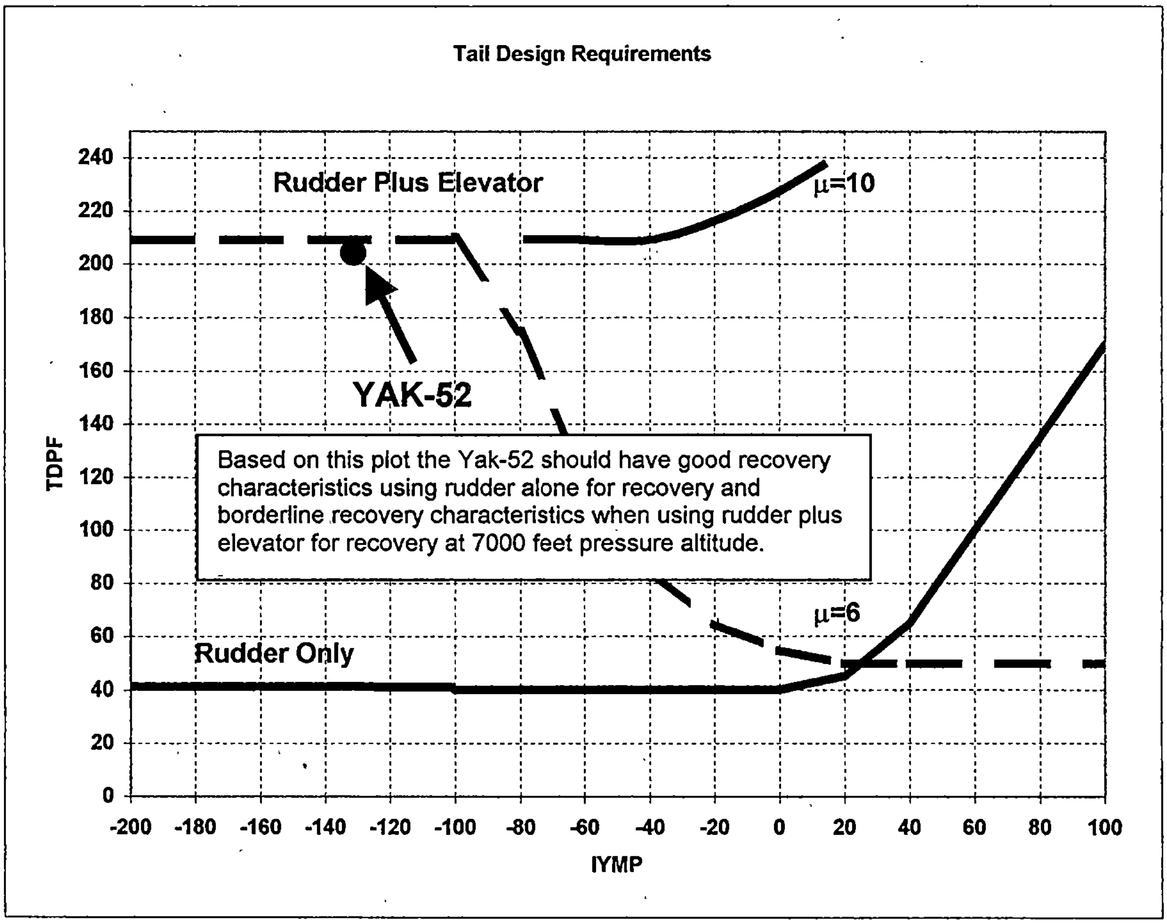

Figure 3-1 Tail Design Requirements

characteristics than post 1940's general aviation airplanes, and has been shown to be extremely limited in value for the prediction of spin recovery characteristics. It is presented here for informational purposes because it continues to appear in much of the available literature. The IYMP is actually the component that has a useful degree of predictive value, as it predicts what the primary control for recovery should be. The plot of the Yak-52 indicates an airplane with satisfactory spin recovery characteristics for the rudder only condition, where the plot is above the solid dividing line.[5] When the elevator is used along with the rudder the plot falls just below the dashed dividing line for satisfactory recovery characteristics. Reliance on the predictive value of the TDPF should not be taken as an absolute. To do so would lead to the conclusion that an airplane with a T-tail configuration would yield the highest possible value for a TDPF and, hence, the most satisfactory of spin recovery characteristics. There is, however, at least one documented case where just such a configuration was unrecoverable from a spin.[8]

Fuselage Shape

The shape of the aft fuselage cross section is another criterion used to predict an airplane's spin recovery characteristics.[7] It is based on a British study which examined the various shapes found along the length of the fuselage and assigned positive or negative values based on location and the effects of the fuselage shape to the overall spin moments. For the Yak-52 airplane the aft fuselage most closely resembles an elliptical shape with a value of +2.1. This means that the aft fuselage provides an anti-spin moment and is stabilizing. The forward fuselage shape is circular indicating a neutral contribution to the recovery from a spin.

Nose Length/Tail Length Ratio

Another predictor of spin recovery characteristics is that provided by Dr. Ralph Kimberlin of the University of Tennessee Space Institute, namely the nose length/tail length ratio.[8] According to the study no airplane with a value of 0.4 or less exhibited any spin recovery problems. Ratios of 0.41 to 0.5 were mixed. All airplanes in the study with values above 0.5 had spin recovery problems. The value for the Yak-52 airplane is 0.41. In general, the longer the tail length, the lower the spin angle of attack and the higher the rotation rate.[6]

Aileron Effects

As previously mentioned in the section that describes the IYMP, the mass distribution of the Yak-52 is primarily along the fuselage. The empirical data indicates that the aileron should be the primary control for spin recovery. Unlike modern general aviation airplanes, which have predominantly neutral mass distributions, the Yak-52 more closely resembles advanced training and fighter airplanes of the 1930's and 1940's in terms of mass distribution. This means studies conducted during that time period are of more direct relevance to the spin and recovery characteristics of the Yak-52. One such study utilized scale models made with similar mass distributions. These models were then placed in the NACA free-spinning tunnel to determine the effects of large downward deflections of the outboard aileron and of normal angular deflections of the ailerons upon recovery characteristics.[12] In general, for airplanes with a fuselage dominant mass distribution, it was determined that when normal aileron angular deflections were applied at the same time that rudder was applied the recovery characteristics were favorable and were adverse if applied against the spin. It also indicated that applying aileron against the spin without rudder application, as would be the case for an accelerated spin entry or a pilot miss-control situation, would not result in a recovery. This study did not examine the effects on rotation rate due to aileron usage.

CHAPTER 4

FLIGHT TEST RESULTS

Overview

A series of stall and spin tests of the Yak-52 airplane were conducted over a period of nine months. These tests were conducted at a forward center of gravity of 18% MAC and an aft center of gravity of 25% MAC. The results of these tests are presented in the following sections.

Stalls

Normal one G stalls were performed. The deceleration rate was 1 knot per second. Although the standard production Yak-52 was equipped with an SSKUS-1 Stall-Dive Warning System, the test airplane was not so equipped. As the airplane decelerated the stick force was relatively light and constant at 2.5 lbf until 2 knots prior to the stall break where a slight lightening to 1.5 lbf was noticed, when measured with a model 916A Stick Force Indicator. The stall occurred at 64 knots in the clean configuration. The airplane remained fully controllable in all axes throughout the approach to the stall. There was no airframe buffet noted prior to the stall break. When referencing the slip/skid ball on the right instrument panel for coordinated flight there was a sharp drop of the left wing to approximately 30 degrees angle of bank (AOB). The wing drop could easily be countered by slight right rudder application. A yaw string was installed and the markings calibrated to indicate zero sideslip with the power at idle. When stalled with reference to a centered yaw string there was a nose drop at the stall with a hesitation in wing drop with the direction of drop either left or right. In either case relaxing backpressure on the stick could effect an immediate recovery. Recovery was made within 300 to 400 feet of altitude loss at idle power or little loss of altitude with prompt application of power.

Accelerated stalls were performed both left and right. Again, the airplane was controllable in all axes up to the stall break with a sharp left wing drop noted when performed with the ball centered. Performed at various G loadings producing a variety of stick forces there was in all cases a noticeable lightening of stick force just prior to the break. Again, no airframe buffet was noted. Immediate recovery was obtained with relaxed backpressure and slight rudder application to counter the wing drop.

Incipient Spins

The incipient spin phase is defined as that portion where a pronounced yawing motion is identifiable to the point where the mode of the spin is identifiable.[9] It is also sometimes defined as the period of transition from horizontal to vertical of the flight path vector. For the Yak-52 this was on average 1.5 turns in duration. The spin entry used was from the one G stall condition followed by full rudder application in the desired direction of spin. At any point within the first turn of the spin, recovery could be effected by relaxing the stick backpressure, centering the ailerons (if any had been applied) and applying opposite rudder. The recovery would occur within 0.25 to 0.50 turns. Altitude loss depended on the pitch attitude at the time of spin stoppage, but on average from entry to level flight resulted in approximately a 600-foot loss.

One turn incipient spins were performed with the landing gear and flaps extended. No differences were noted with the exception that there was a recovery delay as the flaps had to be retracted immediately upon spin stoppage to avoid an over speed during recovery.

Developed Spins (Forward CG)

Fully developed spins in the following modes were examined; normal left and right; accelerated left and right; flat left and right; and inverted. The exact definition of spin modes varies in the available literature and from country to country. Therefore, the following definition convention is used for accelerated and flat spins; an accelerated spin refers to a steady state spin in which aileron against the spin is held with a resulting increase in rotation rate and a flat spin refers to a steady state spin in which the angle of attack averages more than 60 degrees, even if this is achieved through the use of increased engine power. Entry for the normal spin was full aft stick and full rudder in the desired direction. For the accelerated spins full aileron against the spin was applied during the incipient stage. For the flat spin entry full power was applied during the incipient stage and held to initiation of recovery, as was full aileron against the spin. The inverted spin was entered from an inverted one G stall followed by full rudder applied in the desired direction. Data for these modes at the forward center of gravity position are presented in Table 4-1. These data were obtained via the AVS-18H Data Acquisition System (Appendix A).

Developed Spins (Aft CG)

The same series of spin modes was examined at an aft center of gravity of 25% MAC. The data was manually estimated, as the AVS-18H was not installed for these tests. The rotation rates were estimated to be similar to those observed at the forward center of gravity of 18% MAC. The pitch angles were 10 to 15 degrees less nose down than those observed at the forward center of gravity. The pitch oscillations also appeared to be half their forward center of gravity values.

Recovery Techniques

The recovery techniques utilized were those as specified in the Yak-52 Flight Manual.[1] For the normal spin this consisted of full opposite rudder followed by moving the stick to slightly forward of neutral. The accelerated and flat spin recoveries shared a common technique. The power was promptly reduced to idle in the case of the flat spin. Full opposite rudder was applied followed by full forward stick and full aileron with the spin. The inverted recovery was full opposite rudder followed by full aft and centered stick. No recoveries were attempted utilizing power only.

One alternative recovery technique was attempted, the so-called Beggs/Muller emergency recovery.[10] This consists of reducing the power to idle if not already there, full rudder

Table 4-1 Spin Data; Forward Center of Gravity

Mode	Left Normal	Left Accelerated	Left Flat*	Right Normal	Right Accelerated	Right Flat*	Inverted
Average Pitch Attitude	-60°	-55°	-35°	-60°	-55°	-30°	-45°
Fully Developed Rotation Rate	102°/s	165°/s	111°/s	126°/s	160°/s	143°/s	145°/s
Recovery Rotation Rate	-	240°/s	192°/s	-	218°/s	228°/s	-
Average Pitch Oscillation	±15°	±20°	+20°/-70°	±20°	±10°	±15°	±15°
Number Of Turns To Recovery	0.50	1.25	1.00	0.75	1.25	1.75	0.75

* As Defined In Reference 8

against the spin and completely letting go of the control stick. This technique worked well for the normal spins with recovery affected within 0.5 to 1.0 turns. However, when attempted for recoveries on the accelerated and flat spins no signs of recovery were observable through 6,000 feet of altitude loss. This technique is *not* an acceptable method for emergency spin recovery for the Yak-52 airplane.

Control Forces

Rudder and stick control forces during the spins were estimated after calibrating the evaluator's feet and hands with the use of a hand-held force gauge and leg and arm press weight machines. The force values are presented in Table 4-2.

Turns To recovery

The numbers of turns to recovery from initial recovery control inputs for the forward center of gravity case are presented in Table 4-1. For the aft center of gravity case the situation was quite different. The normal spin still recovered within 0.5 to 1.0 turns, but the accelerated and flat spins took considerably longer, averaging 3.0 to 3.5 turns to spin stoppage at a center of gravity of 25% MAC. The inverted spin remained at about 1.0 turn.

Altitude Loss

The altitude loss per turn, regardless of mode, remained remarkably similar at 400 to 500 feet per turn. Following spin stoppage the altitude loss ranged from 300 feet for a normal

Table 4-2 Control Forces During Recovery (LBF)

Spin Mode	Stick Force FWD CG	Stick Force AFT CG	Rudder Force FWD CG	Rudder Force AFT CG
Normal	7-10	10-15	30-35	35-40
Accelerated	35-45	65-75	160-170	185-195
Flat	40-45	75-85	180-190	195-205
Inverted	5	7-10	30-35	35-40

spin to a maximum of 700 feet for a 1.0 turn spin where it was necessary to retract the flaps after spin stoppage.

Data Analysis

Normally, the Euler transformations could be used to calculate detailed attitude plots given either the angular velocities or the attitude rates and some valid reference attitude information to start with using the following equations:

$$p = d\phi/dt - d\psi/dt \sin\theta$$

$$q = d\theta/dt \cos\phi + d\psi/dt \sin\phi \cos\theta$$

$$r = d\psi/dt \cos\phi \cos\theta - d\theta/dt \sin\phi$$

Where

- p, q, r = body axis rates
- $(d\phi, d\theta, d\psi)/dt$ = body attitude rates

However, as explained in detail in Appendix A the attitude data was not usable, hence this process was not possible in this case. However, the data provided by the AVS-18H Data Acquisition System provided good insights into the character of the various spin modes of the Yak-52 airplane. The spin modes are reviewed here in the same order that the data plots for rates, control deflections, and Y-axis magnetic vectors are presented in Appendix A.

Left Normal Spin

The left normal spin was initiated with full left rudder being applied at 1.9 seconds and full aft longitudinal stick being applied at 2.0 seconds (Figure A-3). The yaw rate increased smoothly with variations in pitch and roll rates until the spin was fully developed by 5.3 seconds, which corresponded to one turn. The variations in roll rate appeared to follow very closely the variations in elevator deflection. This was due to the effect of gyroscopic precession, as indicated by a change in pitch rate followed almost immediately by a change in the roll rate, a change in rotation of 90 degrees in the direction of the spin. The peak roll rate was –175 deg/sec and the peak yaw rate was –75 deg/sec. Recovery was initiated at 9.8 seconds by a rapid reversal of rudder deflection, followed by a decrease in longitudinal stick toward neutral. Aileron input was not applied as a method of recovery. An immediate decrease in yaw rate was observed. The difference between roll rate and yaw rate at the point of yaw rate decrease was 100 deg/sec. Full opposite rudder deflection was achieved at 10.5 seconds. A movement toward neutral rudder deflection occurred at 10.9 seconds, signifying the end of the spin. This corresponded to 0.5 turns for recovery. The rotation rate determined from the Y-axis magnetic vector was 102 deg/sec for the fully developed portion of the spin. The recovery occurred too rapidly to determine an average rotation rate for the recovery portion of the spin.

Left Accelerated Spin

The left accelerated spin was initiated with full left rudder and full aft longitudinal stick being applied at 1.5 seconds (Figure A-4). The yaw rate increased smoothly with variations in pitch and roll rates until the spin was fully developed at 4.9 seconds, which corresponded to 0.75 turns. Right lateral stick, aileron against the spin, was applied beginning at 2.0 seconds. Unlike the left normal spin where the yaw rate achieved an equilibrium value of approximately –65 deg/sec, the yaw rate for the left accelerated spin continued to increase until reaching a maximum value of –140 deg/sec at 9.4 seconds. The variations in roll rate were followed very closely by similar variations in pitch rate indicating strong coupling due to gyroscopic precession. At 9.0 seconds the yaw rate increased to the point where it exceeded the roll rate. Recovery was initiated at 9.8 seconds by a rapid reversal of rudder deflection followed by a rapid reversal of lateral stick to aileron with the spin, 10.5 seconds. Longitudinal stick was moved forward of neutral to a nose down position, also at 10.5 seconds. The yaw rate remained relatively stable to 10.2 seconds with a slow decrease to 11.3 seconds. There was a rapid increase in roll rate from 10.5 to 11.7 seconds. It is worth noting that there was not a rapid decrease in yaw rate until the roll rate exceeded the yaw rate by approximately 90 deg/sec. The maximum roll rate was –220 deg/sec. A movement towards neutral rudder occurred at 12.0 seconds along with a rapid reversal in both lateral and longitudinal stick, indicating the end of the spin. This corresponded to 1.25 turns for recovery. The rotation rate determined from the Y-axis magnetic vector was 165 deg/sec for the fully developed portion of the spin and 240 deg/sec for the recovery portion of the spin.

Left Flat Spin

The left flat spin was initiated with full left rudder being applied at 1.5 seconds along with longitudinal stick movement toward full aft and right lateral stick, aileron against the spin (Figure A-5). Although not indicated on the plots, the engine power was increased to approximately 90 percent by 2.3 seconds. The yaw rate increased steadily to a maximum value of approximately –70 deg/sec. The variations in pitch and roll rates were large and corresponded with variations in aircraft attitude. Due to wide variations in pitch and roll rates and attitudes it cannot be categorically stated that a fully developed spin was ever achieved, although the incipient stage appears to have ended at 4.9 seconds. The spike in the rudder deflection plot peaking at 5.3 seconds corresponded to the pilot's foot slipping on the rudder pedal. Between 6.0 and 7.5 seconds the pitch attitude oscillated and reached a point of –110 degrees from the horizontal. Recovery was initiated at 7.5 seconds by a rapid reversal of rudder and the immediate reduction of engine power to idle. Reversals of longitudinal stick toward neutral and lateral stick, aileron with the spin, were initiated at 7.9 seconds. At the point of rudder reversal the yaw rate was already rapidly decreasing and continued to decrease throughout the recovery. Rudder and stick movement toward neutral occurred at 8.6 seconds, indicating the end of the spin. This corresponded to 1.0 turn to recovery. The rotation rate determined from the Y-axis magnetic vector was 111 deg/sec for the fully developed portion of the spin and 192 deg/sec for the recovery portion of the spin.

Right Normal Spin

The right normal spin was initiated with full right rudder and full aft longitudinal stick being applied 1.1 seconds (Figure A-6). The yaw rate increased smoothly with variations in pitch and roll rates. The spin was fully developed at 4.5 seconds, which corresponded to 1.25 turns. The peak roll rate was 170 deg/sec and the peak yaw rate was 75 deg/sec. Recovery was initiated at 9.0 seconds by a rapid reversal of rudder a reversal of longitudinal stick toward neutral. Aileron was not applied as a method of recovery. An immediate decrease in yaw rate was observed. The difference between yaw rate and roll rate at the point of yaw rate decrease was 90 deg/sec. A movement toward neutral rudder occurred at 10.2 seconds, indicating the end of the spin. This corresponded to 0.75 turns to recovery. The rotation rate determined from the Y-axis magnetic vector was 126 deg/sec for the fully developed portion of the spin. The recovery was too rapid to determine an average rotation rate for the recovery portion of the spin.

Right Accelerated Spin

The right accelerated spin was initiated by reaching full right rudder and full aft longitudinal stick at 2.3 seconds (Figure A-7). Left lateral stick, aileron against the spin, was applied beginning at 2.3 seconds. The yaw rate increased smoothly with variations in pitch and roll rates until the spin was fully developed at 4.5 seconds, which corresponded to 0.75 turns. The variations in pitch and roll rates between 4.5 to 10.5 seconds again appear to indicate strong coupling due to gyroscopic precession. At 7.5 seconds the yaw rate exceeded the roll rate. Recovery was initiated at 10.5 seconds by a rapid reversal of rudder deflection followed by a rapid reversal of lateral stick to aileron with the spin and longitudinal stick to well forward of neutral. The yaw rate showed a modest decrease from the maximum value achieved of 135 deg/sec to 120 deg/sec. There was a rapid increase in roll rate to a peak value of 230 deg/sec. A marked decrease in yaw rate did not occur until the roll reached a value of 190 deg/sec, a difference of 70 deg/sec from the yaw rate. A movement toward neutral controls occurred at 12.8 seconds, indicating the end of the spin. This corresponded to 1.25 turns for recovery. The rotation rate determined from the Y-axis magnetic vector was 160 deg/sec for the fully developed portion of the spin and 218 deg/sec for the recovery portion of the spin.

Right Flat Spin

The right flat spin was initiated with full aft longitudinal stick and right rudder being applied at 2.3 seconds (Figure A-8). Although not indicated on the plot the engine power was increased to approximately 90 percent at 2.6 seconds. Left lateral stick, aileron against the spin, was applied beginning at 3.4 seconds. The yaw rate increased smoothly with variations in roll and pitch rates until the spin was fully developed between 4.5 and 5.3 seconds. The yaw rate continued to increase until it reached a maximum value of approximately 135 deg/sec at 9.0 seconds, where it also exceeded the roll rate. Again, the pitch and roll rate variations appear to be strongly coupled due to gyroscopic precession. Recovery was initiated by a rapid reversal of rudder deflection at 9.8 seconds, with no corresponding decrease in yaw rate. The lateral stick was also reversed, aileron with the spin, at 9.8 seconds. The longitudinal stick was reversed to a point well forward of neutral beginning at10.5 seconds. There was a rapid increase in roll rate beginning at 9.8 seconds, which continued to a maximum value of 230 deg/sec at 12.0 seconds. There was no decrease in yaw rate observed until 11.7 seconds, which corresponded to the roll rate value exceeding the yaw rate value by 70 deg/sec. A movement toward neutral controls occurred at 12.8 seconds, indicating the end of the spin. This corresponded to 1.75 turns to recovery. The rotation rates determined from the Y-axis magnetic vector was 143 deg/sec for the fully developed portion of the spin and 228 deg/sec for the recovery portion of the spin.

Inverted Spin

The inverted spin was initiated with full forward longitudinal stick and right rudder being applied 2.3 seconds (Figure A-9). The roll rate increased smoothly with variation in pitch and yaw rates until the fully developed stage appears to have been reached at 5.6 seconds, corresponding to 1.0 turn. Thereafter, wide variations were observed in all three rates with maximum values for yaw and roll being 90 deg/sec and –155 deg/sec, respectively. Recovery was initiated by a rapid reversal in rudder deflection at 10.5 seconds along with a rapid movement toward neutral of longitudinal stick. An immediate decrease of yaw rate was observed with the reversal of rudder deflection. The difference between the yaw rate and roll rate at 10.5 seconds was 90 deg/sec. This was done by using the absolute values for the yaw rate and roll rate to correct for the opposite sign in the data as a result of the airplane being inverted.

Data Summary

The data indicates that the Yak-52 airplane is capable of being easily spun with pro-spin control application. It also is evident that aileron applied against the spin has a strong effect on the yaw rate resulting in large rate increases. The data indicates that if the roll rate is 70-90 deg/sec greater than the yaw rate when recovery controls are applied there are enough anti-spin aerodynamic moments generated to have an immediate effect to decrease the yaw rate and terminate the spin. During the accelerated and flat spin modes the data indicates that aileron with the spin must be applied to achieve the requisite roll rate to yaw rate differential of 70-90 deg/sec before there are enough anti-spin aerodynamic moments generated to effect recovery. This relates well to results determined from previous studies, which indicate the connection between airplane mass distribution and aileron usage for spin recovery. Further testing with the ability to acquire accurate attitude, angle of attack, and sideslip data to facilitate detailed mathematical modeling of the Yak-52 spin dynamics is recommended.

FAR Part 23 Comparison

Although this test program was not intended to determine the acceptability of the Yakovlev Yak-52 airplane to meet FAR Part 23 certification criteria and a full-up spin test matrix was not performed, a limited comparison is presented.[11]

FAR 23.221(c)(1) defines the requirement for the number of turns following initiation of recovery controls for an aerobatic airplane to be 1.5 additional turns. For normal erect and inverted spins and accelerated spins at forward center of gravity, the Yak-52 met this requirement. However, the right flat spin at forward center of gravity did not. The left flat spin was terminated due to wide oscillations and was not determined. For accelerated and flat spins at aft center of gravity the Yak-52 characteristic of 3 to 4 additional turns to recovery clearly did not.

The table in FAR 23.143, items (a) and (b), define the control force limits allowable during temporary application. The limits for a stick-controlled airplane are 60 pounds in pitch and 30 pounds in roll. For the rudder pedal the force limit is 150 pounds. Clearly, Table 4-2 shows several conditions where these limits were exceeded, with the aft center of gravity condition generating the greatest levels.

By comparison, a Pitts S2B aerobatic airplane (Figure 4-1) that is certified under FAR Part 23 exhibits 1.5 turns to recovery for accelerated and flat spins at an aft center of gravity with a stick force of 27 pounds. No figure was quoted for rudder pedal force but was estimated to be approximately 50 to 55 pounds (M. Heiner, Chief Test Pilot, Aviat Aircraft, June 10, 2001).

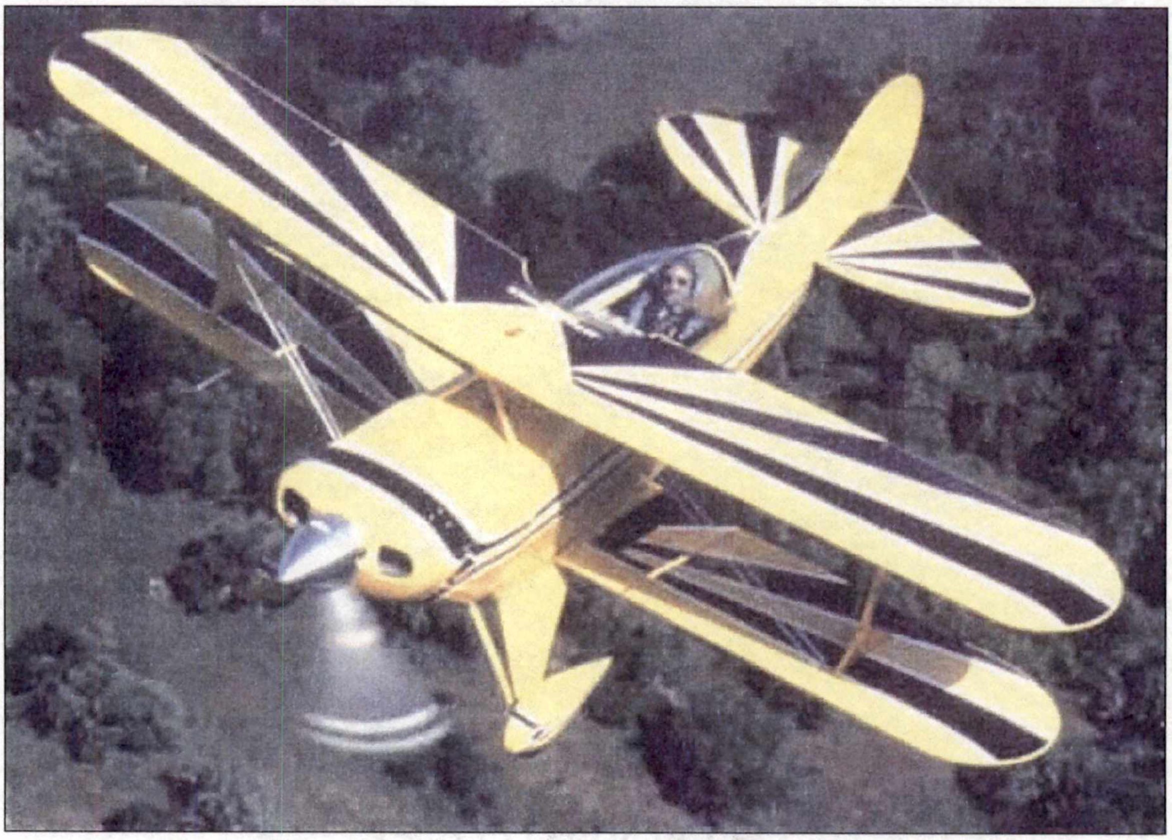

Figure 4-1 Pitts S2B

CHAPTER 5

CONCLUSIONS

General

The Yakovlev Yak-52 airplane is an unlimited aerobatic airplane easily capable of being spun. The recovery characteristics for normal and inverted spins, regardless of center of gravity position, are quick, precise and predictable. However, there is a marked contrast in the recovery characteristics for the accelerated and flat spin modes, which is aggravated by an aft center of gravity position.

Conclusions

A qualitative evaluation was made of the spin and recovery characteristics of the Yakovlev Yak-52 airplane. Based on this evaluation a number of conclusions about these characteristics can be made.

The Yak-52 has no pre-stall airframe buffet warning. The stalls and incipient stage spins are easily recovered with relaxed longitudinal control, neutral lateral control and slight opposite rudder.

The Yak-52 is easily spun with pro-spin control applications of aft longitudinal control and rudder in the direction of spin. Although the IYMP indicates a mass distribution that is fuselage dominant, which would normally indicate the need for aileron as the primary recovery control, the data indicates this to be dependent on the state of aileron usage during the spin. If the ailerons are held neutral throughout the spin the Yak-52 recovers well with rudder as the primary recovery control. This is indicated by the immediate reduction in yaw rates for both the right and left normal spin and inverted spin data when recovery rudder is applied. When a normal spin is aggravated by the application of aileron against the spin it is evident that the yaw rate is accelerated and the Yak-52 becomes dependant on aileron applied with the spin as the primary control for recovery, which is consistent with the theoretical studies. The predictive value of the TDPF technique is not upheld by the data. The data indicates a correlation between the yaw rate and roll rate, with a differential of 70 to 90 degrees per second greater roll rate than yaw rate being necessary for recovery to occur.

The center of gravity has a marked effect on the spin recovery characteristics of the Yak-52. At aft CG the control forces increase to extremely high values. These values exceed the permitted values as outlined in FAR Part 23. At aft CG the number of turns to recovery for the accelerated and flat spin modes exceed the permitted 1.5 turns by 2.0 to 2.5 additional turns.

The Beggs-Mueller emergency spin recovery technique does not work for accelerated or flat spins in the Yak-52.

The control travel distances for the stick grip and rudder pedals exceed the normal values for the 5th percentile female pilot.

Recommendations

Due to a lack of pre-stall airframe buffet, the Yak-52 should not be flown without the SSKUS-1 Stall-Dive Warning System installed and operating. Based on the high control forces and the number of turns to recovery for the accelerated and flat spins, especially at an aft center of gravity position it is reasonable to conclude that few western pilots will have experienced similar characteristics. This would be particularly true for pilots whose experience is limited to airplanes certified to FAR Part 23 standards.[11] Because of these factors it is recommended that current and future pilots of the Yak-52 airplane be made aware of these characteristics and approved recovery techniques so as to avoid accidents. It is recommended that spins be limited to the normal spin mode only.

It is recommended that the training emphasize the high control forces involved as well as the necessity to hold the proper recovery controls for an extended period of up to 4 turns before the airplane responds. Although written information on this subject is important, due to the disorienting effects of the high rotation rates and the unfamiliar control forces encountered it is highly recommended that in-flight training be obtained. The shortcomings of the antropometrics for female pilots approaching the 5th percentile should also be stressed if the when applicable, with such pilots prohibited from flying the Yak-52 airplane.

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REFERENCES

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APPENDICES

APPENDIX A

AVS-18H DATA ACQUISITION SYSTEM

AVS-18H Data Acquisition System

Background

The AVS-18H Data Acquisition System was installed in the Yak-52 airplane for the purpose of recording data during the different spins modes at a forward center of gravity of 18 percent mean aerodynamic chord (MAC). The University of Tennessee Aviation Systems Department developed this system for the United States Army Flight Concepts Division at Fort Eustis, Virginia. The original purpose of the design was to provide a cost effective solution for helicopter dynamic response flight testing. Permission was kindly given to use this system briefly for this spin evaluation.

System Components

The AVS-18H utilizes Miniature Electro-Mechanical System (MEMS) technology. It is totally portable. The attitude and heading reference system (AHRS) is mounted in a travel case along with a self-contained battery power source, making the AVS-18H independent of the host aircraft electrical system. The AHRS can acquire up to 14 parameters at a maximum rate of 60 samples per second. Control positions are measured using rotary potentiometers operated via spring-loaded cable reels. Light cables are attached to the flight controls via Velcro straps. For the Yak-52 this involved only three such devices, for longitudinal stick displacement, lateral stick displacement and rudder pedal displacement. The AVS-18H was mounted in the rear cockpit (Figure A-1).

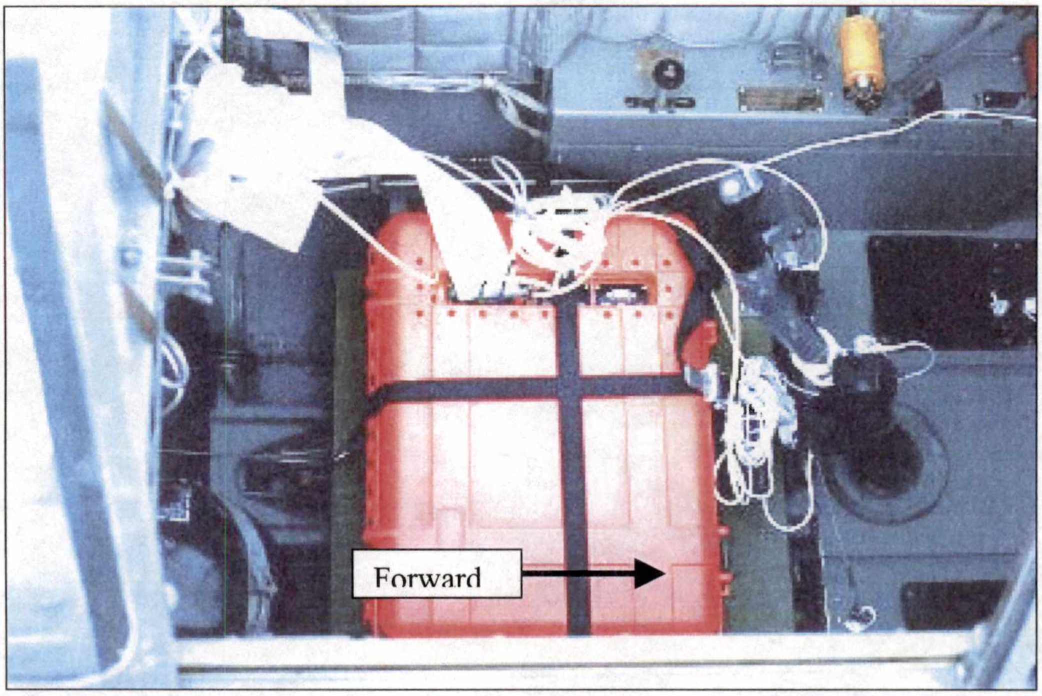


Figure A-1 AVS-18H Data Acquisition System Installation

Data Recording

Flight control positions and data from the AHRS were recorded into a laptop computer mounted in a protective box installed on the rear cockpit turtle deck behind the normal seat position (Figure A-2). A multifunction I/O card was installed in an open PCMCIA slot on the laptop computer and was connected by cable to the AVS-18H. Although the maximum scan rate for the AHRS was 60 data frames per second, the actual rate set for this test was 13.3 data frames per second. This rate was a function of the clock speed of the computer used. The run time for each data recording was set at 30 seconds. This resulted in an even 400 data frames per run.

To activate each recording run a standard mouse control was connected to the computer via an extension cord and secured on the left sub-panel in the forward cockpit. To prevent the cursor from moving away from the start prompt on the computer screen the track ball was removed from the mouse and the rollers within the mouse were secured to prevent accidental movement due to aircraft vibrations.

Although the AVS-18H recorded 17 parameters the relevant data for this test centered on determining the exact points of control inputs, primarily rudder, and the number of turns from the point of initial recovery control input to the point where the spin stops. For any type of certification effort under FAR Part 23 these would be the required data points. Of secondary concern was determining turn rates and pitch and roll oscillations.

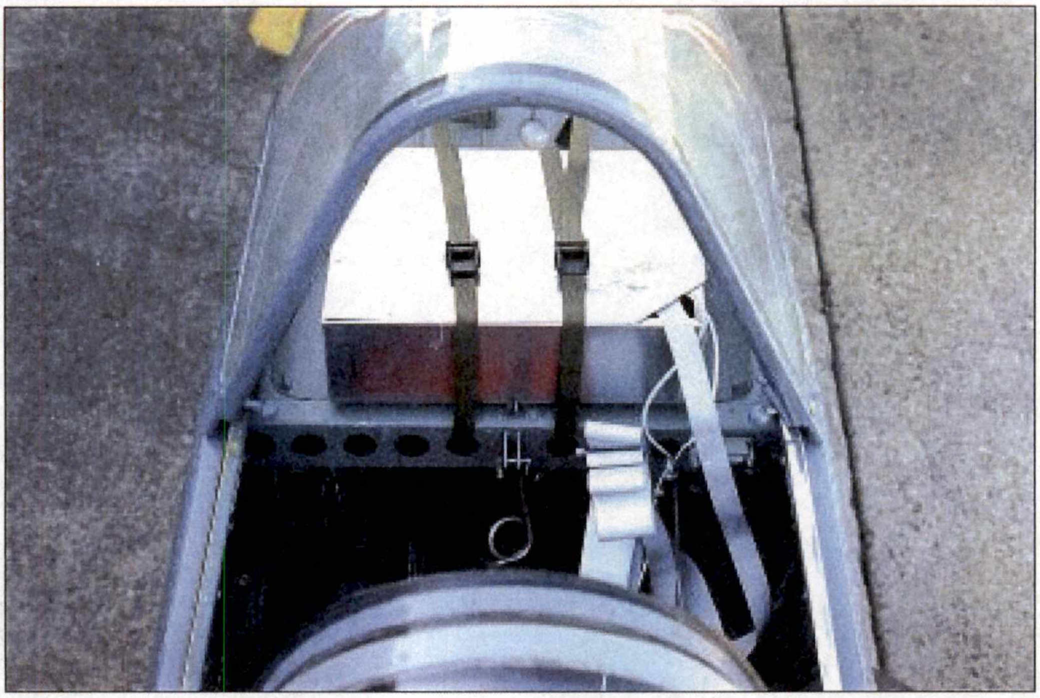


Figure A-2 Laptop Computer Box

Parameters

The parameters of interest from the AHRS portion of the AVS-18H were attitude angles, angular velocities, accelerations, and magnetic vectors are presented in Table A-1. The angular velocity, or rate, limits of ± 200°/sec and the attitude limits of ± 180° for roll and yaw and ± 90° for pitch resulted in the inability of the AVS-18H to present valid indications for the attitude angles. This was mainly due to the roll rate limit being repeatedly exceeded. When these values were exceeded the algorithms used for determining the attitude angles were frozen at their current values and did not begin updating until the rate values returned below the limit values. At this point the attitude angle values began to update starting from the previously frozen values. Unless the AVS-18H unit was returned to what is called the "zero,zero,one" condition of steady heading, straight and level flight for a period of thirty seconds, the attitude data continued to be in error. This resulted in many sharp cliffs for the attitude data rendering it useless for computational purposes.

The rate data remained valid throughout each spin maneuver even though the actual rates sometimes exceeded the limit values. This was due to the nature of the rate values being direct sensor data information as opposed to the attitude values being derived computational information from the rate data. This was also due to the fact that the stated limits for the rate sensor readouts were somewhat arbitrarily set by the manufacturer and have a considerably wider range of actual useful data (R. Lees, Customer Support, Crossbow Technology, Inc, October 25, 2001).

Table A-1 AVS-18H AHRS Parameter Ranges

PARAMETER	RANGE
Roll Angle	±180°
Pitch Angle	±90°
Yaw Angle	±180°
Roll Rate	±200°/sec
Pitch Rate	±200°/sec
Yaw Rate	±200°/sec
X-axis Acceleration	±10g
Y-axis Acceleration	±10g
Z-axis Acceleration	±10g
X-axis Magnetic Vector	±1gauss
Y-axis Magnetic Vector	±1gauss
Z-axis Magnetic Vector	±1gauss
Case Temperature	°C
Time Tick	0.79μsec/tick

The AVS-18H AHRS provides separate magnetic vector readouts through the use of three flux valves, one aligned along each of the three axes. Since the orientation of the magnetic field remains fixed with respect to the earth at any given location a flux valve, which is rotating within that field, will experience two maximum voltages and two null voltages for each complete rotation. The only exception to this is if the alignment of the flux valve perfectly coincides with the axis of rotation. During a spin it is possible for the flux valves aligned along the X-axis and Z-axis to experience rotation which is perfectly aligned. For the X-axis this would mean a pure rolling motion with no rotation about the other two axes. In a spinning maneuver this would most likely occur during recovery if the X-axis were perfectly vertical. For the Z-axis this would be possible if the spin was totally flat with an angle of attack of 90 degrees. For this to occur on the Y-axis the aircraft would have to be rotating only about the Y-axis with the Y-axis aligned vertically, a near impossibility. For this reason the flux valve aligned along the Y-axis was chosen for data plotting. The resulting data is in the form of a repeating wave. The number of turns can be graphically determined simply by counting the number of waves, or fractions thereof, between any two points of time. The rate of rotation of the aircraft can be determined by noting the time in seconds between any two peaks or troughs, which corresponds to 360 degrees of rotation. The end result is a simple and precise method for determining rotation rates and numbers of turns.

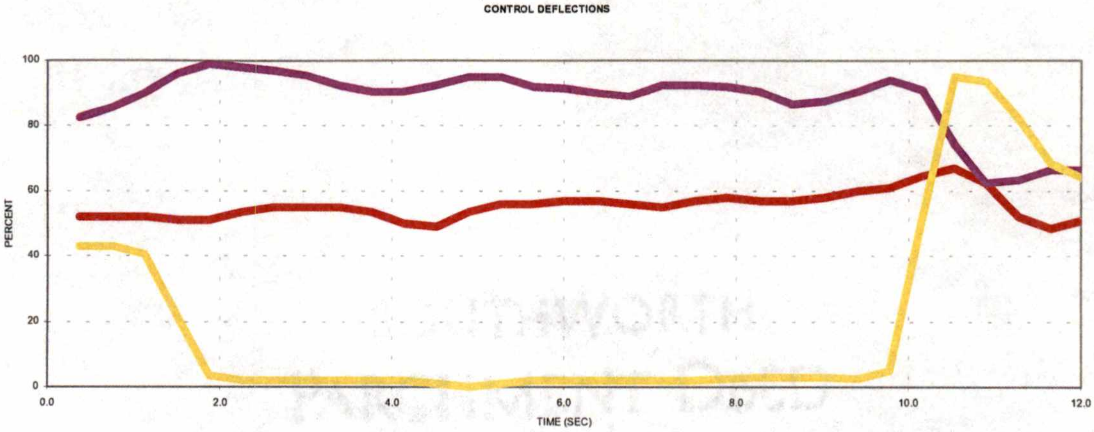
Other parameters of interest were the control position readouts provided by the rotary potentiometers connected to the controls. Table A-2 presents the legend for the control deflection and rate portions of the spin data plots (Figures A-3 through A-9), which also include the Y-axis magnetic vectors.

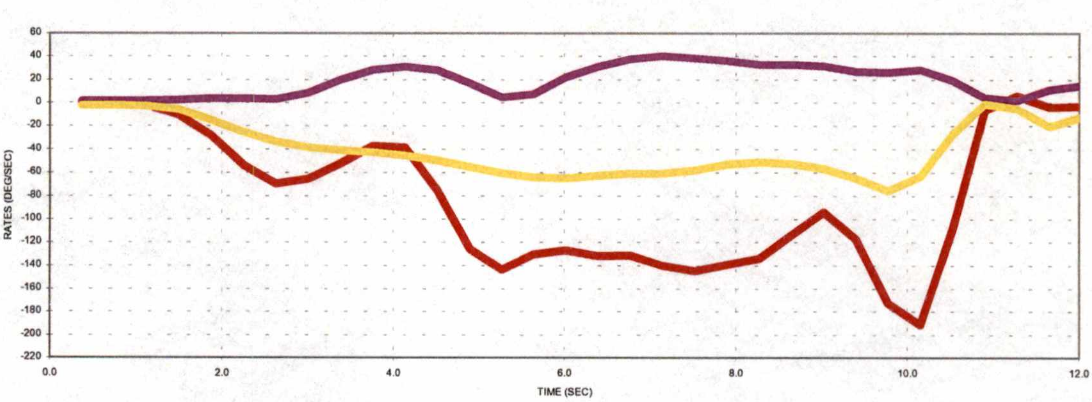
Summary

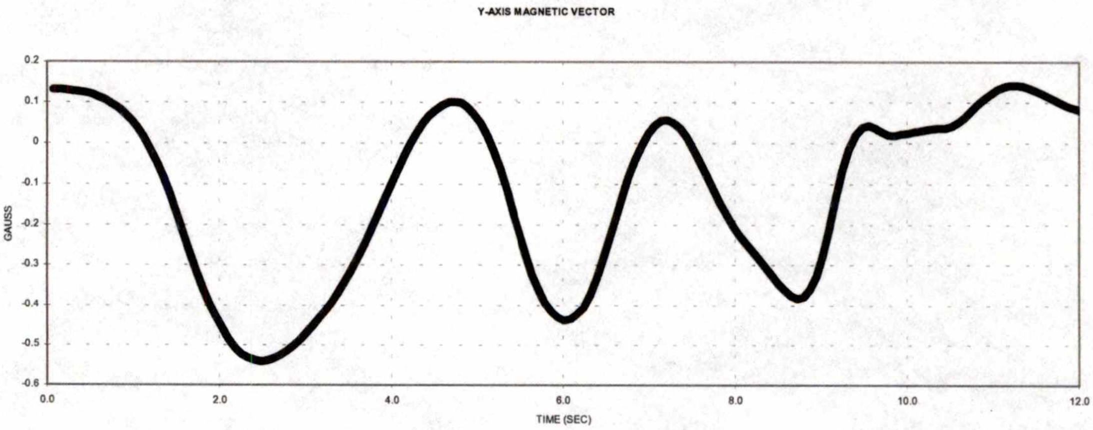
Although not originally designed for aircraft spin testing, the AVS-18H Data Acquisition System provides a low-cost platform from which to gather the precise turn data necessary for FAA certification purposes as well as rate and control data to aid in defining the characteristics of different spin modes, while at the same time reducing test pilot workload by eliminating some of the traditional methods of manual data recording. The addition of the ability to acquire data for 360 degrees of attitude in all axes, angle of attack, and sideslip would be a significant improvement for the AVS-18H system.

Table A-2 Rate and Control Deflection Plot Legend

RATE/DEFLECTION	COLOR	CONTROL MOVEMENT PERCENT	STICK/RUDDER DISPLACEMENT	CONTROL SURFACE ANGLES
Pitch Rate/ Elevator Deflection		0-100	34.4cm	Elevator $\pm 25^{\circ}$
Roll Rate/ Aileron Deflection		0-100	28cm	Aileron 22^{0} Up 16° Down
Yaw Rate/ Rudder Deflection		0-100	42.2cm	Rudder $\pm 27^{\circ}$

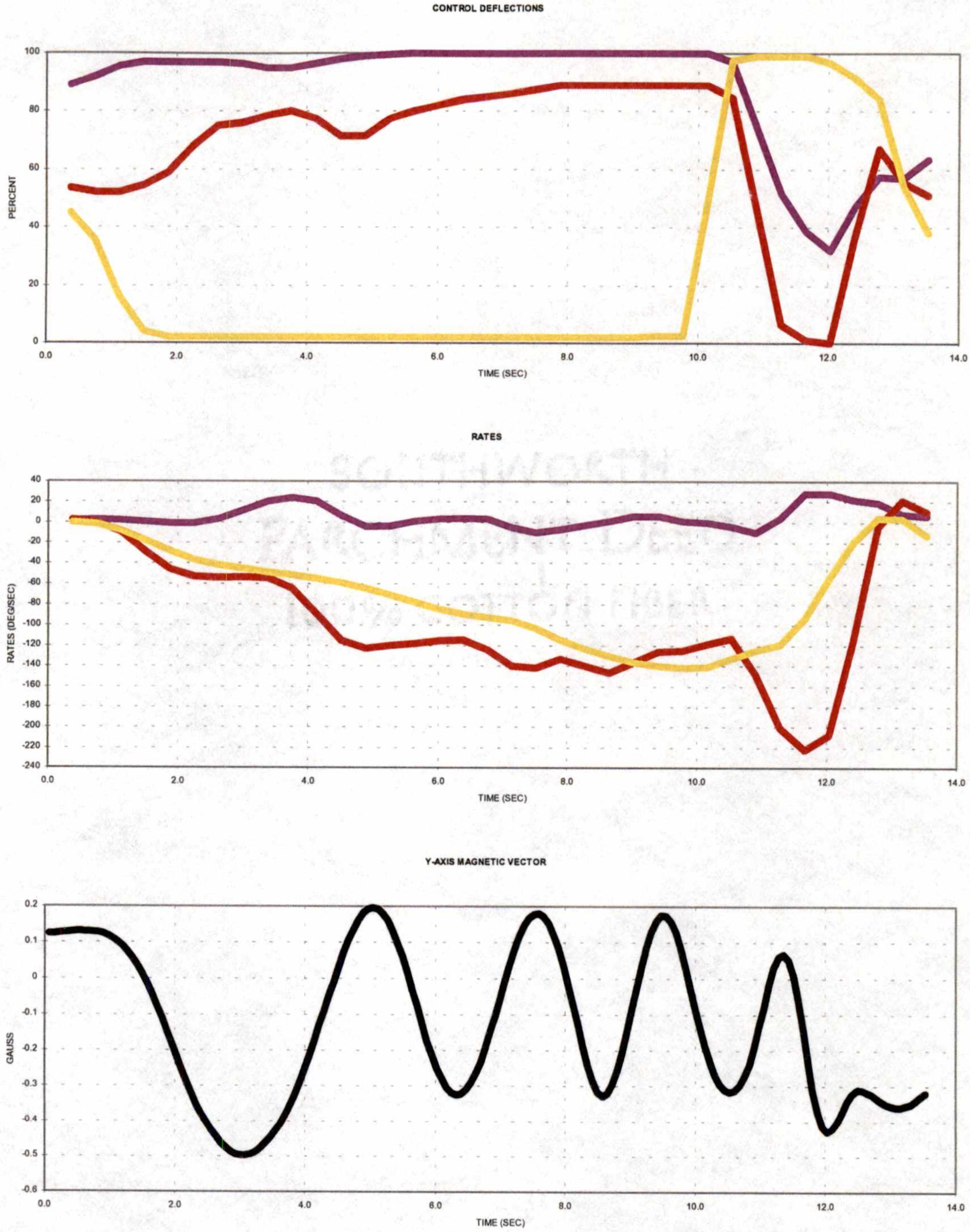






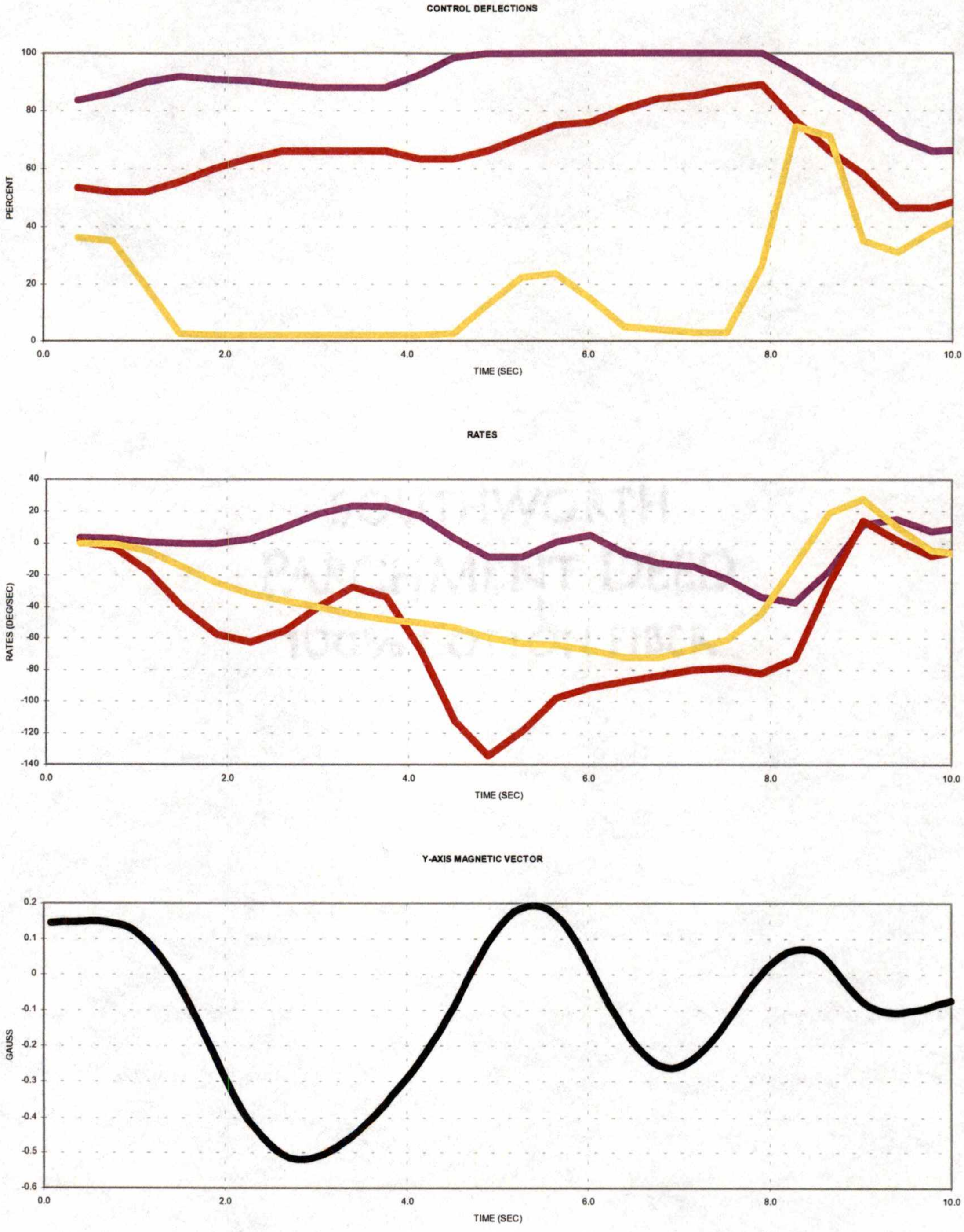
Aircraft: Yak-52 / Registration: N120NS / CG: 18% / TOW: 2662lbs / Pilot: R. Moreau / Location: Tullahoma, TN / Date: 4-27-01

Figure A-3 Left Normal Spin Data



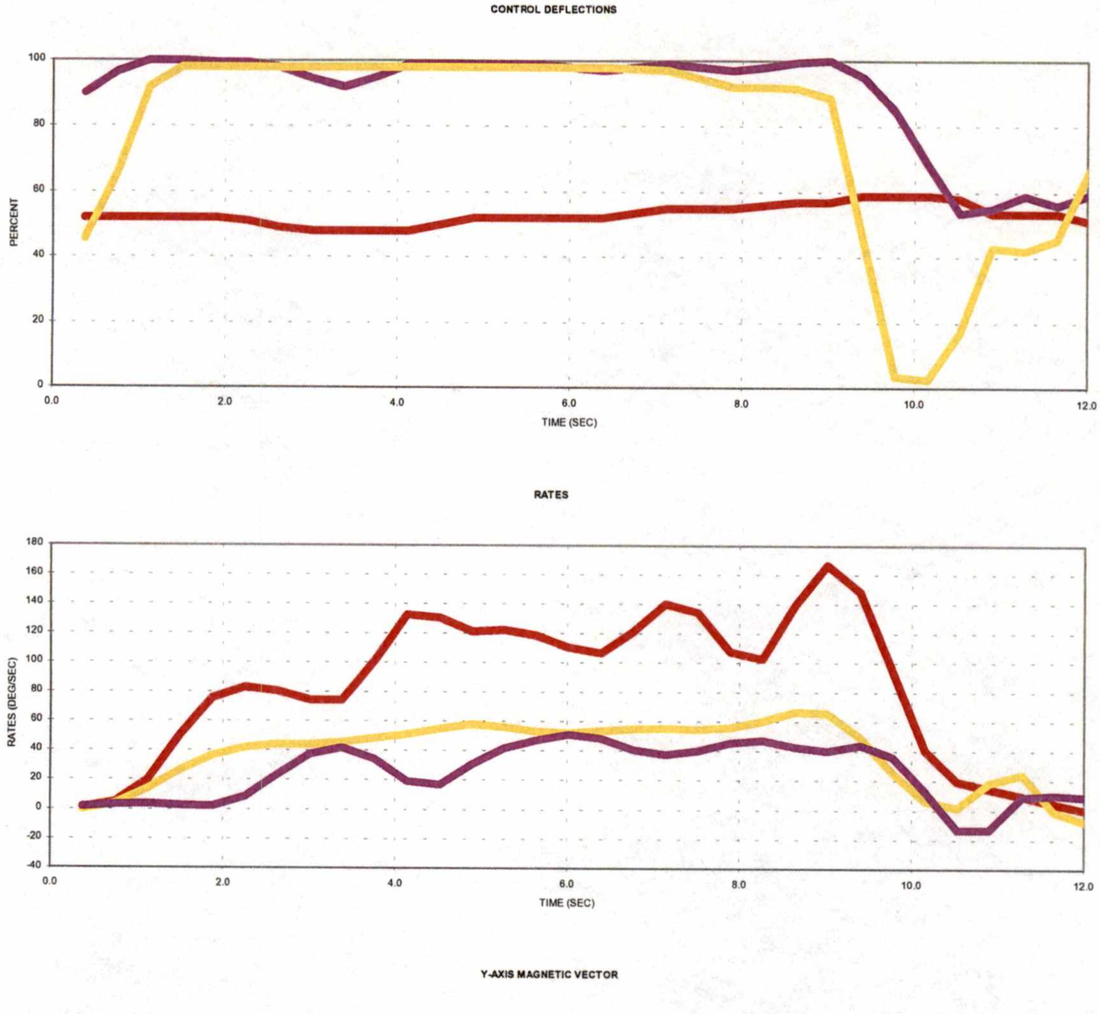
Aircraft: Yak-52 / Registration: N120NS / CG: 18% / TOW: 2638lbs / Pilot: R. Moreau / Location: Tullahoma, TN / Date: 4-27-01

Figure A-4 Left Accelerated Spin Data



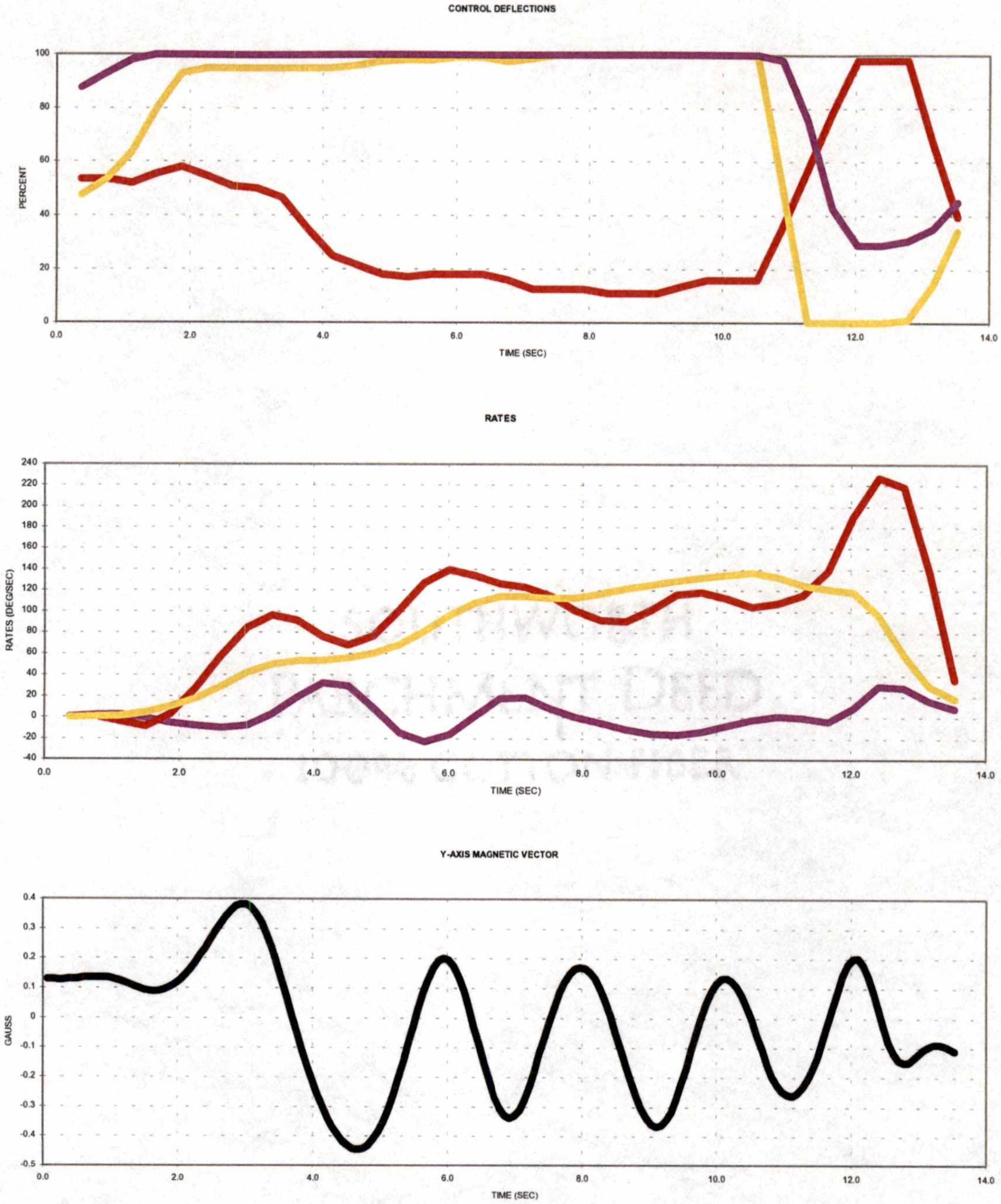
Aircraft: Yak-52 / Registration: N120NS / CG: 18% / TOW: 2605lbs / Pilot: R. Moreau / Location: Tullahoma, TN / Date: 4-27-01

Figure A-5 Left Flat Spin Data



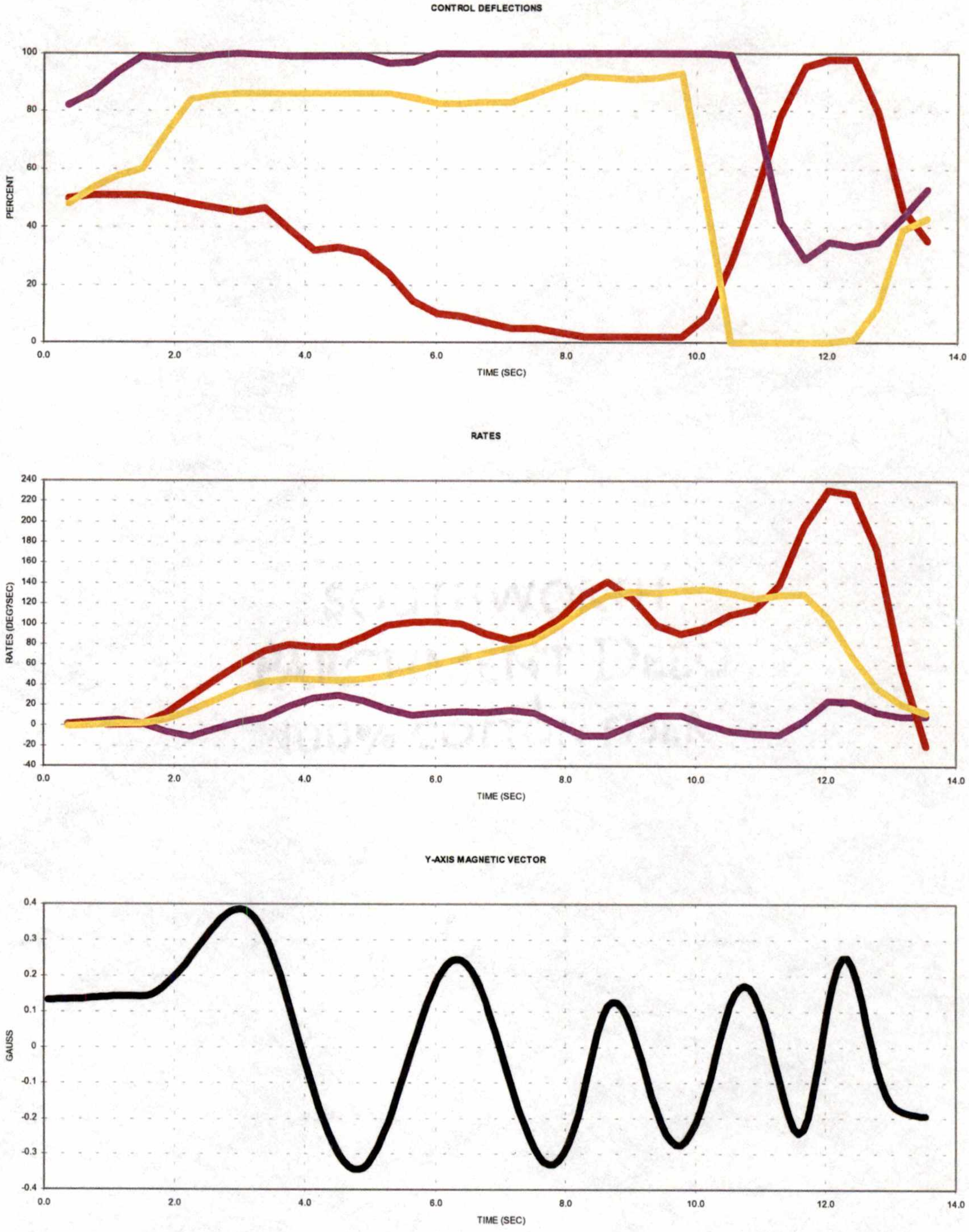
Aircraft: Yak-52 / Registration: N120NS / CG: 18% / TOW: 2662lbs / Pilot: R. Moreau / Location: Tullahoma, TN / Date: 4-27-01

Figure A-6 Right Normal Spin Data



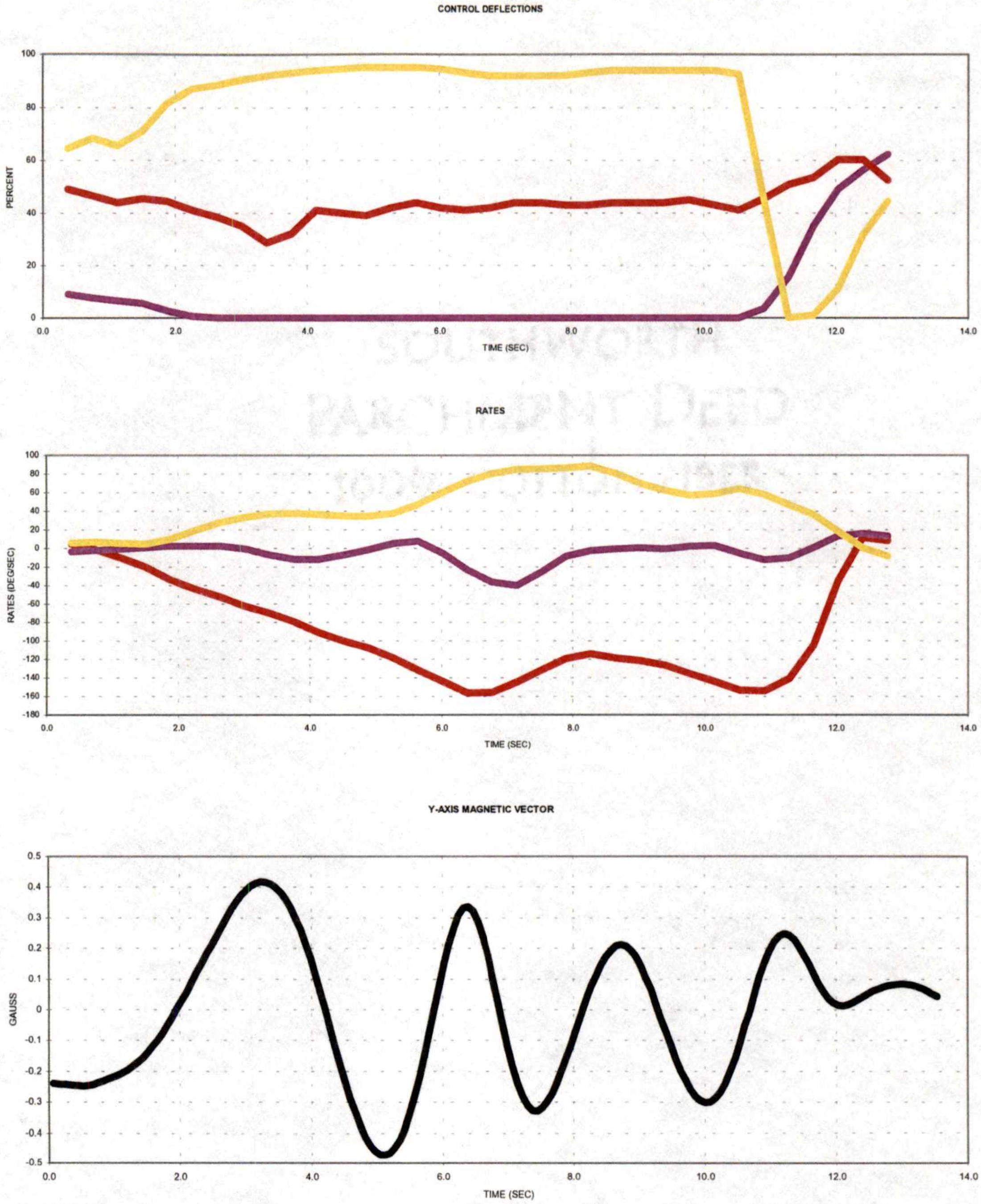
Aircraft: Yak-52 / Registration: N120NS / CG: 18% / TOW: 2629lbs / Pilot: R. Moreau / Location: Tullahoma, TN / Date: 4-27-01

Figure A-7 Right Accelerated Spin Data



Aircraft: Yak-52 / Registration: N120NS / CG: 18% / TOW: 2596lbs / Pilot: R. Moreau / Location: Tullahoma, TN / Date: 4-27-01

Figure A-8 Right Flat Spin Data



Aircraft: Yak-52 / Registration: N120NS / CG: 18% / TOW: 2662lbs / Pilot: R. Moreau / Location: Tullahoma, TN / Date: 4-27-01

Figure A-9 Inverted Spin Data

APPENDIX B

YAK-52 COCKPIT EVALUATION

Yak-52 Cockpit Evaluation

Background

The Yak-52 flight controls were evaluated for their anthropometric characteristics. The evaluation was conducted in daylight conditions inside a hanger located at the Aerocountry Airport (TX05), McKinney, Texas. The evaluator was wearing normal summer flight clothing consisting of flying summer coveralls, flying summer gloves, and running shoes. The evaluator was seated on a Strong seat-pack parachute, type 7463-406019, fitted with a 26-foot para-cushion seat. The evaluator's anthropometric measurements are presented (Table B-1).

Table B-1 Evaluator's Anthropometric Measurements

DIMENSION	MEASUREMENT	PERCENTILE
Weight	235lbs.	NA
Height	188cm	95-99
Shoulder Width	51.2cm	50-95
Trunk Height	64.7cm	95-99
Sitting Height	95.8cm	50-95
Sitting Eye Height	95.8cm	95
Functional Reach	87.5cm	95-99
Popliteal Height	47.0cm	95-99
Buttock-Leg Length	117.0cm	95-99
Buttock-Knee Length	62.0cm	50-95
Functional Leg Length	124.0cm	50-95
Knee Height	60.0cm	95

The measurement criteria used for this evaluation was based on those as specified in the FAA's Human Factors Design Guide [4].

Seat

The pilot seat was fixed to the airframe with no provision for either vertical or longitudinal adjustment. The seat was a bucket type designed to house a seat-pack type parachute, which forms the cushion for the pilot. Vertical adjustment was only available through the use of cushion inserts of varying thickness and number to achieve the proper eye height. For male pilots approaching the 95th percentile in sitting height, this can be problematical during negative G flight as the canopy-head clearance may be eliminated.

Control Stick

The control stick was tall by western standards with a height of 67cm. It moved through a longitudinal arc of 44^0 and a lateral arc of 28.2^0. At the hand grip the length of travel was 34.4cm longitudinally and 28cm laterally. With the stick placed in the full forward position and either full left or full right position the handgrip was at a functional reach 79cm. This was at the 50th percentile for male pilots but beyond the 5th percentile for female pilots.

Rudder Pedals

Rudder pedal adjustment was evaluated for operational sense, location and functionality. The rudder pedals were adjustable 10.1cm fore or aft via an adjustment knob located between the rudder pedals. Clockwise rotation of the knob extended the pedals while counter clockwise rotation retracted the pedals. By western standards the pedal location was too far aft, resulting in the knee position being relatively high. This was, however, a design point for the unlimited aerobatic mission and is designed to mitigate the physiological effects of high G maneuvers, as the airplane has no provision for the use of an anti-G suit. The rudder pedals were evaluated for movement. The travel was measured at 42.2cm. This range resulted in a functional leg length requirement of 94cm with the pedals adjusted to the full aft position. This was beyond the 5^{th} percentile for female pilots.

VITA

Robert D. Moreau was born in New York on February 23, 1954. He graduated high school from Monterey High School, Lubbock, Texas in the spring 1971. He entered enlisted service with the United States Air Force in the fall of 1971. He served as a North Vietnamese interpreter with the Air Force Security Service in Southeast Asia until his separation in 1974. After attending several colleges he received a Bachelor of Science in Aeronautics from Embry-Riddle Aeronautical University. He was employed by Federal Express in 1980. Serving in a number of capacities including instructor, check airman and FAA designated examiner, he is currently serving as an acceptance test pilot on the Boeing MD-11 and MD-10. He began his studies at the University of Tennessee Space Institute in the fall of 1999. After completing his Master's Degree in Aviation Systems he will be expanding his duties at Federal Express to include engineering flight test and certification issues.