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Date 10 March 1995

THE SUITABILITY OF THE T-45A GOSHAWK AS A FLEET OUT-OF-CONTROL FLIGHT AND SPIN TRAINER

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Joseph S. Wascavage

May 1995

DISCLAIMER

The flight test results contained within this thesis were obtained during a United States Department of Defense sponsored Naval Air Systems Command project. The discussion of the data, conclusion and recommendations presented are the opinion of the author and should not be construed as an official position of the United States Department of Defense, the Naval Air Systems Command or the Naval Air Warfare Center, Aircraft Division, Patuxent River, MD.

DEDICATION

This thesis is dedicated to my wife, Betty,

whose devotion and support made the time available for this research,

to my sons Joseph and Andrew,

and to my best friend who passed away on August 21 in the year 1994,

my Father,

SEMPER FI.

ACKNOWLEDGMENTS

I would like to express my gratitude to my fellow Naval Air Warfare Center Aircraft Division, Patuxent River, T-45A teammates for their engineering expertise and support during the T-45A High Angle-of-Attack flight test program. I would especially like to recognize Mr. Pat Perusse for producing the data time histories and Mr. Steve Cricchi for his assistance in data analysis. Their help make this task an enlightening and enjoyable one.

I would also like to commend both the contractor and government technical personnel for successful completion of the highest risk flight testing that can be conducted, a high angle-of-attack program. All personnel did so in the utmost professional manner and adhered to the fundamental aspects of a flight test program:

1. Have Fun.
2. Collect Reasonable Data.
3. Complete the flight test program with the same amount of people and airplanes you started with.

ABSTRACT

This project evaluated the T-45A Goshawk airplane for its potential use as an out-of-control flight and spin trainer.

This project was a United States Department of Defense sponsored project. The project utilized assets provided to McDonnell Douglas Aerospace by the Department of the Navy, Naval Air Systems Command.

The process for conducting high angle-of-attack flight testing used a methodology of controlled buildup. The test program was segmented into four distinct phases. The first was flying qualities evaluations up to airplane stall. The second phase was bank-to-bank rolls building up to full longitudinal, lateral and directional control inputs. Third, was sustained aggravated longitudinal, lateral and directional control inputs. The last phase involved spin entry and recovery demonstrations.

The T-45A Goshawk is not a suitable replacement as an out-of-control and spin training airplane. Upright spins do not stabilize and the undesirable propensity to transition into inverted spins does not allow for detailed spin mode demonstration. Inverted spins do display stabilized spins, but the transitory nature between three separate inverted spin modes and the exactness required for spin recovery make it impractical for spin demonstrations.

It is recommended that consideration be given to installing a powered rudder in the T-45A airplane to preclude rudder lock out and assist in inverted spin recovery.

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GLOSSARY

AC	Alternating Current
AOA	Angle-of-Attack
ARI	Aileron to Rudder Interconnect
BUFS	Backup Fuel System
CG	Center of Gravity
DC	Direct Current
DEG	Degree
FTEG	Flight Test Engineering Group
G, g	Acceleration
HAOA	High Angle-of-Attack
HYD1	Hydraulic System Number One
HYD2	Hydraulic System Number Two
kt	Knots
KEAS	Knots Equivalent Airspeed
KIAS	Knots Indicated Airspeed
lbs	pounds
MAC	Mean Aerodynamic Chord
MIL	Military Rated Thrust
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration

GLOSSARY

NATOPS	Naval Aviation Training and Operating Procedures Standardization Program
NAWCAD	Naval Air Warfare Center Aircraft Division
Nz	Normal Acceleration
OCF	Out of Controlled Flight
PLC	Public Limited Company
PMBR	Practice Multiple Bomb Rack
psi	Pounds Per Square Inch
RAG	Replacement Air Group
SDOF	Six Degree of Freedom
sec	Seconds
USNTPS	United States Naval Test Pilot School
VDC	Volts Direct Current
Vstall	Stall Airspeed
WUT	Wind up Turn
YDC	Yaw Damper Controller

INTRODUCTION

From a pilots perspective, whether civilian or military, departure from controlled flight or entering into a spin is not only disorienting but also an extremely anxious experience. During a departure from controlled flight and subsequent entry into a spin, pilots immediately fall back on the out-of-control flight and spin training that they have received to affect recovery. Training may have taken various forms including classroom instruction, flight simulator training or actual flight demonstrations of departures and spins. Student naval aviators in the training command today, are taught during ground school, the dynamics of spins. Subsequently, they are demonstrated an upright spin in a T-34C and spins and departures in the T-2C Buckeye. Out-of-control flight and spin training does not end with Navy pilots earning their "wings of gold" and becoming naval aviators. Historically, training continued for Navy pilots in either a replacement air group (RAG) where the newly winged Naval aviators learn to fly their fleet airplane. In the 1978-1979 time frame out-of-control flight and spin training for all Navy tactical pilots was delegated to two Navy squadrons VF-43 and VF-126 located at NAS Oceana, VA and NAS Miramar, CA respectively. However, in 1993 the Chief of Naval Operations decided to discontinue the out-of-control flight and spin training syllabus at VF-126 and VF-43, place the responsibility back on the RAG squadrons for the training and move all T-2C Buckeye airplanes to the training command. That decision was a result of the advancing age and attrition of the T-2C Buckeye and the requirement to fulfill its primary mission as the intermediate jet trainer at the Naval Air Training Command.

For the chosen few naval aviators, selected to attend the United States Naval Test Pilot School (USNTPS) located at NAS Patuxent River, MD, their training and education in out-of-control flight and spins was greatly expanded. While students at USNTPS, the test pilots under instruction are exposed to an in-depth evaluation of the T-2C Buckeye's spin characteristics. Demonstration and flight test evaluations include upright and inverted departures, upright and inverted spin characteristics, coupled departures and evaluation of various recovery control inputs. USNTPS instruction establishes the test pilot under instruction basic background for high angle-of-attack flight test evaluations.

In November, 1981, the Naval Air Systems Command selected the T-45A Goshawk as the replacement for the T-2C Buckeye intermediate and the TA-4J Skyhawk advanced jet training airplanes for the Naval Air Training Command, reference 1. As a part of the development of the T-45A Goshawk, the Strike Aircraft Test Directorate of the Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland was tasked to evaluate the out-of-control flight and spin characteristics of the T-45A.

This thesis represents the analysis of the out-of-control flight and spin characteristics of the T-45A Goshawk and assesses the suitability of the T-45A Goshawk as an out-of-control flight and spin training airplane.

BACKGROUND

Introduction

The first recorded spin test program conducted at the Naval Air Test Center was on the F7U-3 Cutlass airplane, figure 1, in 1955. Since then the Navy has relied on the Naval Air Warfare Center Aircraft Division (NAWCAD) Patuxent River to conduct flight testing of naval aircraft. Test evaluations conducted by the Flight Systems Department of the Strike Aircraft Test Directorate include high angle-of-attack spin and departure evaluations of current fleet airplanes as well as new airplanes under development for future fleet use. In the case of the T-45A Goshawk, the Flight Systems Department's role was to monitor contractor development and demonstration testing. With this knowledge Flight Systems focused Navy test efforts to evaluate the departure resistance of the airplane, gain a thorough understanding of the departure and spin characteristics and assess its operational usefulness as an out-of-control flight training demonstration airplane.

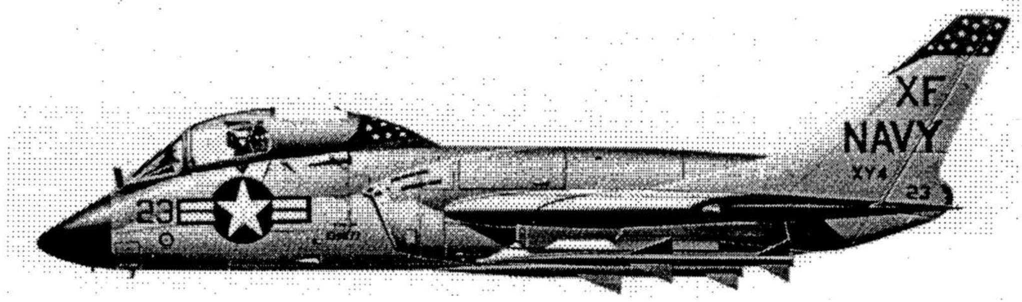

Figure 1

F7U-3 Cutlass

U. S. Navy and Contractor Flight Test Responsibilities

Contractor responsibilities during a development and demonstration flight test program are wide and varied. It is the responsibility of the contractor to demonstrate the departure characteristics, spin characteristics, effects of control inputs during the spin, as well as demonstration of a repeatable recovery technique for all spin modes. High angle of attack flight testing is extremely expensive when considering the cost of flight test instrumentation installed on the test airplane, test specialized systems, real time flight monitoring of the data, safety chase airplanes, and ground based photography coverage. As a result, the method that a contractor uses to reduce the amount of flight testing required includes many facets. Low angle of attack simulation model, usually wind tunnel derived and updated with flight test data becomes the basis of the high angle-of-attack model. This simulation model is merged with stability derivatives derived by the use of a rotary spin balance [1].

Potential spin recovery control inputs are estimated by the use of the NASA Langley Research Center's vertical spin tunnel. NASA Langley used a 15% scale model, constructed to represent the airplane with movable control surfaces, e.g., stabilator, ailerons, rudder and speedbrakes. The model is tossed into the vertical tunnel attempting to get the model to sustain a spin mode predicted by the six degree of freedom (SDOF) data. Control surfaces of the airplane are then remotely actuated

[1] Rotary spin balance is a technique in which six-component measurements are made of the aerodynamic forces and moments acting on a wind tunnel model during continuous 360 degree spinning motions at a constant angle of attack. Estimates of potential departure boundries and spin modes are also made. Additional information on this technique can be found in reference 2.

to attempt to recover the airplane from the spin. Results of these tests will dictate the starting point for spin entry and recovery control inputs for evaluating the airplane's characteristics in a piloted simulation. After a thorough simulation evaluation of all flight test maneuvers, flight testing will commence. Gradual buildup in flight control input magnitude and duration will be increased to the worst cases predicted by the simulation. Data gathered will be reduced and compared to the SDOF simulation for refinement of the simulation. Normally the maneuvers conducted by the contractor are demonstration data points of departure, spins or the buildup points to get to those extreme data points. The demonstration data points are not usually representative of fleet operational maneuvers or how student naval aviators are taught to fly. They are a precisely controlled academic exercise to understand and describe the airplane's departure and spin characteristics.

Navy flight testing of the high angle-of-attack characteristics of an airplane follows from results of the contractor's evaluation and demonstration. Test data points are flown in a manned simulator for familiarization and evaluation of predicted airplane response. Where the contractor concentrates on the academic approach to testing, i.e., identifying specific data that describe the maneuvers, the Navy test team is charged with identifying areas within the operational flight envelope where inadvertent departures or spins could be encountered. Navy test pilots and engineers evaluate the ability of the airplane to resist departures as a result of misapplied flight controls during operational maneuvers such as air combat maneuvering and acrobatics. Navy pilots evaluate departures and spins to determine the airplane characteristics and the ability of pilots to readily identify various spin modes. Various recovery flight control inputs to affect recovery are evaluated as well as the contractor recommended procedures to determine simplicity of flight control manipulation while minimizing altitude lost during the departure or spin. Lastly, an assessment is made of the operational effectiveness and safety for the airplane to be used as an out-of-control flight and spin trainer.

Navy Out-of-Control Flight Training

The T-2C Buckeye entered the United States Navy fleet inventory in 1968. For approximately fifteen years, the T-2C Buckeye fulfilled the role of the spin and out-of-control flight trainer. An enhancing characteristic of the T-2C was the ease and consistency of recovery from all departure and spin modes with various recovery control inputs. The T-2C Buckeye, a straight winged airplane, obtains steady state upright and inverted spin modes which allows investigation of airplane characteristics to various control inputs during the spin. A high speed spiral and a three axis coupled departure can also be conducted. Most importantly, recovery from the T-2C Buckeye spins and departures are immediate and consistent. The T-2C Buckeye departure and spin characteristics are demonstrated to student pilots in the training command by instructor pilots. A summary of fleet aircraft erect spin recovery control inputs, from reference 3 are listed in appendix A, table I.

For some pilots spin training continued when they entered their respective replacement air group squadrons. These squadrons are where pilots receive training in a newly assigned fleet airplane. However, these programs were initiated only in squadrons that had airplanes with acceptable spin and recovery characteristics. For example, a program was instituted in A-7 Corsair squadrons but not F-4 Phantom squadrons by virtue of the latter's unrecoverable flat spin mode. The TA-4 Skyhawk was not acceptable either, due to its extremely disorienting inverted spin mode, reference 4.

The United States Naval Test Pilot School located at the Naval Air Warfare Center, Patuxent River, MD continues to use the T-2C Buckeye as a tool for the training of test pilots and flight test engineers in out-of-control flight and spins. Flight demonstrations are conducted with instructor test pilots in the T-2C Buckeye. Spin modes and departures include erect incipient, oscillatory and non oscillatory spins and inverted spins, inertia coupled departures and recoveries. Effects of flight control positions during the spin and recovery are demonstrated addressing the tendency to enter into a progressive spin. Lastly, the physiological cues are addressed and the difficulty in assessing the nature and characteristics of the spin while relying on the outside visual references and the 'seat of the pants' feel. It is imperative that the pilot place trust and reliance on the cockpit flight instruments. Upon successful completion of the demonstration phase of the out-of-control flight characteristics of the T-2C Buckeye, test pilots and engineers develop test plans and conduct departure and spin evaluations. Departure resistance during normal flight operations, misapplied flight control inputs, and airplane characteristics leading to spin entry are investigated as are the effects of various control inputs during the spin. Recovery techniques are evaluated to determine which control inputs are the easiest for the pilot to perform and recover the airplane rapidly and consistently while minimizing altitude lost.

Due to 42 tactical airplanes lost due to departure or out-of-control flight conditions from July 1971 to July 1975, the Chief of Naval Operations called a conference to assess new methods for training to avoid accidents and to evaluate NATOPS flight characteristics sections for all tactical aircraft. A specific recommendation was for "CNO provide T-2 aircraft to type commanders for use as spin demonstrators", reference 5.

As a result of this meeting, the task of training Navy tactical aviators in the recognition and characteristics of out-of-control flight and spin training, was given to two squadrons; VF-126 on the west coast located at NAS Miramar and VF-43 on the east coast located at NAS Oceana. VF-126 commenced T-2C spin training in 1978 and VF-43 in 1979. As such, the T-2C Buckeye fulfilled the roll as the fleet out-of-control flight and spin demonstration training airplane. Due to the late introduction of the T-45A into the training command, T-2C assets were required at the training command to maintain pilot training requirements. As a result of the advancing age, attrition, and as its primary mission as a intermediate undergraduate jet flight trainer for training student naval aviators in the training command, a decision was made by CNO to discontinue T-2C spin training programs and revert to RAG groups providing this training. Training discontinued at VF-126 in May 1993 and at VF-43 in September 1993 in order to provide the T-2C Buckeye assets to the Naval Air Training Command.

Aircraft Losses: July 1971-October 1993

Since out-of-control flight training applied only to tactical airplane Naval aviators, discussion and analysis will be limited to tactical airplanes. Tactical airplanes for the purpose of this discussion are all Navy fighter and attack aircraft as well as two seat trainer versions of these models. In analyzing airplane losses due to departure from controlled flight, accidents fell into four categories of flight maneuvers, i.e., air combat maneuvering, acrobatics, navigation or level flight and takeoff and landing. Two other factors noted during the analysis of the accident data were aircraft losses due to a material failure on the airplane and departures or spins that were encountered during specific flight tests where high angles of attack were not expected to be encountered. Relevant data for this evaluation were considered to be those departures where sufficient altitude was available for recovery, where no material failure occurred, and eliminated from consideration of relevancy was the category of takeoffs and landings.

As stated earlier, 42 tactical airplanes were lost due to departure or out-of-control flight conditions from July 1971 to July 1975. Data of aircraft lost were not available for the period July 1975 through December 1976. A review of naval safety center data over the period of January 1977 through October 1993 reveals for all Navy aircraft types a total of 304 incidents of loss of controlled flight by Naval pilots. Of these, 136 tactical aircraft were lost as a result of unrecovered spins and out-of-control flight. A summary of tactical airplanes lost is shown in appendix A, table II. Total tactical airplanes lost are presented as a function of calendar year in figure 2.

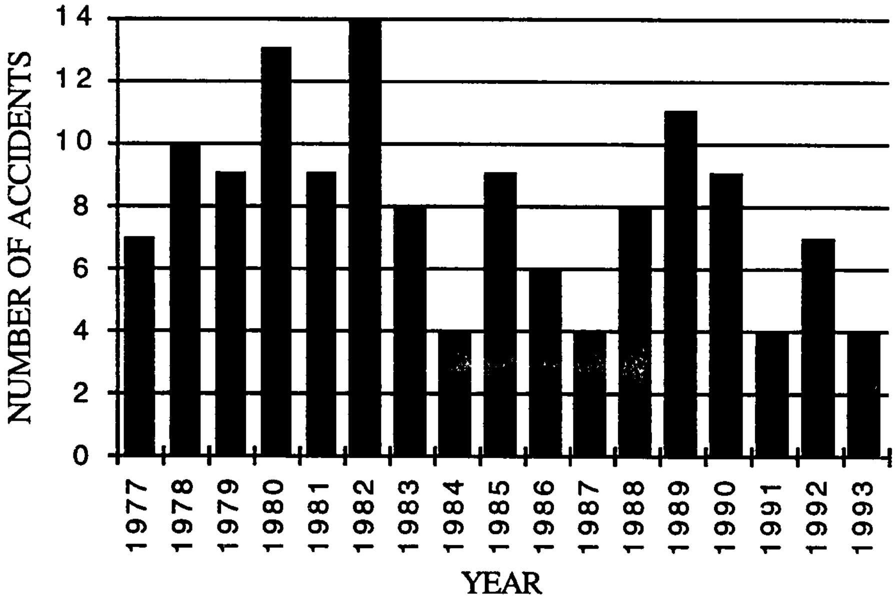

Figure 2
Summary of Tactical Airplane Losses (1977-1993)

For the years 1971 to 1975 an average of approximately 10 aircraft per year were lost. Training in out-of-control flight and spin at VF-43 and VF-126 commenced in the 1978-1979 time frame. Figure 2 shows a significant decrease in tactical aircraft lost starting in 1983. Allowing for a transition time for all fleet pilots to have completed the out-of-control and spin training syllabus at least twice by 1982, the average rate of aircraft lost decreased from approximately 10 per year to approximately 7 per year after 1982. Granted there is a sudden increase in aircraft lost in 1989, but the important trend is that aircraft lost annually due to out-of-control flight and spin had a declining trend. With the cost of tactical aircraft approaching $40 million dollars per aircraft, the decreasing aircraft loss trend translates into approximately $120 million dollars saved per year. Cost of providing the out-of-control flight training for the Navy was unavailable. However, the U. S. Air Force "approximate yearly cost (FY80) for all T-37", reference 6, student and instructor spin training was approximately $2 million dollars. This translates into a very cost effective method of training pilots in out-of-control flight and spin characteristics.

T-45A Goshawk as an Out-of-Control Flight and Spin Trainer

The service life and attrition of the inventory of T-2C Buckeyes restricted the availability of these airplanes. T-2C Buckeye's primary mission as an intermediate undergraduate jet flight trainer for training student naval aviators in the naval training command has made the airplane unavailable for fleet out-of-control and spin demonstration.

The Unites States Navy developed the T-45A Goshawk at the NAWCAD Patuxent River as replacement to the T-2C Buckeye for the Naval Air Training Command. As a part of the development program, the T-45A Project Office and the Flight Systems Department at the Strike Aircraft Test Directorate were tasked to evaluate the T-45A Goshawk's out-of-control flight and spin characteristics.

The flight test consisted of upright and inverted spins attempts, with various symmetric and asymmetric store loading. Also, susceptibility to enter spins and out-of-control flight from flight conditions of nose high pitch attitudes up to 90 degrees and zero airspeed were investigated, as well as an assessment of the capability of the T-45A to be used as a out-of-control flight and spin training airplane.

LITERATURE REVIEW

Introduction

Research for this paper fell into three categories; 1. the military specification MIL-D-8785C, 2. pilot training and 3. airplane flight characteristics. These three areas of investigation are complimentary in that the specification attempts to give general guidelines as to the acceptable flight characteristics, and resultant airplane flight characteristics determine the suitability of the airplane as an out-of-control flight and spin trainer. Additional discussion of the need for government flight test of T-45A high angle-of-attack characteristics and student pilot training can be found in a Masters Thesis written by Joseph M. Rogers entitled "The T-45 High Angle of Attack Evaluation; The Testing of an Advanced Trainer Aircraft", reference 7.

Military Specification

The military specification, MIL-F-8785C, reference 8, is the Military Specification for Flying Qualities of Piloted Airplanes. It specifies handling qualities requirements for all flight regimes. The handling qualities requirements for out-of-control flight and spins are briefly discussed below. Additional detail may be found in reference 8.

Stall Approach, shall be easily perceptible by the shaking of cockpit controls or airframe buffeting with increasing intensity as angle-of-attack is increased.

Stall Characteristics, shall not exhibit characteristics that can not be controlled to 20-30 degrees of pitch, roll or yaw. No undesirable pitch-up tendencies are desired that impact the operational effectiveness.

Stall Prevention and Recovery, shall be possible with simple use and moderate inputs of pitch, roll and yaw cockpit controls.

Airplanes shall be resistant to departure from controlled flight, post-stall gyrations and spins. The airplane shall exhibit no uncommanded motions that can not be arrested by simple application of cockpit controls.

Recovery from post-stall gyrations and incipient spins, require a recovery technique that is easy to apply under the airplane motions encountered. A single technique shall provide prompt recovery from all gyrations and incipient spins regardless of direction of motion and tendency to enter a spin. Avoidance of spin reversal or mode change shall not be dependent on precise timing of pilot input.

Pilot Training

On March 19, 1992 an EA-6B Prowler piloted by Lt. James Hogan, stalled while maneuvering, entered a spin and crashed on the Olympic Peninsula. The resultant accident report by the Judge Advocate General blamed "complacency in Hogan's training. Hogan had been trained to get out of spins at flight school, but had lost the skill after being assigned to his squadron", reference 9. This event is an example of the inherent danger involved in aviation since the time of the Wright brothers.

> In 1910 "thirty seven pilots were killed and it was axiomatic that a crash always followed a stall. No one knew how to recover from a spin until Eddie Stinson reasoned it out and demonstrated spin recovery in 1916." (Christy, 10)

Once pilots' fears of entering a spin were alleviated as a result of Eddie Stinson's flight tests, military pilots were trained to use the spin to their benefit.

> "Starting with operation of World War I fighters, many aircraft and lives have been lost due to stall and spin accidents; however, stalls and spins were also sometimes used to escape from an opponent. Due to its low Lift-to-Drag ratio, a spinning aircraft could lose altitude more rapidly and more safely ... as compared to his pursuer who risked structural failure in attempting to follow in a high speed dive". (Anderson, 11)

Eddie Stinson benefited general aviation in much the same manner as he did military aviators, but not as a result of adversarial pursuit during aerial battle. Their benefit was in saving their own lives as well as their passengers.

> "If a pilot lost control or found himself in or above clouds with fuel near exhaustion, he deliberately stalled the airplane and applied full rudder to enter a spin. A spin was a known condition, and a safe way to lose altitude without gaining excessive airspeed". (Christy, 10)

The operational environment of today's military tactical aircraft is such that they are frequently flown to the edges of their maneuvering flight envelope in an attempt to gain an advantage over an opponent in air combat maneuvering. Donald House and Alexander Money, reference 4, classify combat aircraft pilots into two categories, as "those who have departed controlled flight, and those who will". This perspective of pilots and their experiences is not unique to the United States. A similar perspective is held by the Military School of Advance Aeronautics, Leningrad, Russia.

> Ensuring flight safety with the maximum use of aircraft maneuverability during training of cadets is possible in two ways. The first - teach them to fly so that they would never enter into conditions of stalling and spin. Alternate method - show the cadets the conditions of stalling and spin with training in both entry into them and in recovery in all possible variations. (Rayevskiy, 12)

The application of spin training for pilots and complete knowledge of an airplane's departure and spin characteristics are essential for modern day combat pilots. The combat pilot must use the airplane to its full potential during air-to-air combat engagements so that full concentration and attention may be placed on the adversary. It is implied that the training a pilot receives and retention of those skills plays a major role in determining the success of recovery from out-of-control flight. Three pilot factors relating to the success of spin training for pilots were identified by House and Money in reference 4. They are: properly identifying the motions of the aircraft, proper use of controls, and the concept that a pilot's perception of time passage during the spin is quicker than actually occurs. These factors are key to the understanding of the need for training on a recurring basis for all tactical pilots. The pilot must understand and be able to recognize the different spin modes exhibited by his aircraft. Once the spin mode has been identified, the proper recovery controls must be applied until the airplane has recovered, and not rely on an estimation of the duration of time that recovery controls have been applied.

> The training provided in the USAF flying schools is designed to foster confidence, instill discipline, develop motor skills, and most importantly ingrain and develop situational awareness while transitioning the neophyte student into the maximum performance arena of military aviation. (Uptegraph, 6)

The corollary to the two types of pilots mentioned earlier are the two types of instructor pilots identified by Rayevskiy, reference 12. "Pilots, who earlier fulfilled flights for stalling and spin are supporters of the matter, would want to teach cadets this. Those who did not earlier deal with a similar condition, object to this instruction, relying on the requirements of providing flight safety".

Airplane Flight Characteristics

Departure and spin characteristics are as varied as there are types and models of aircraft. They are too numerous to detail here but the respective Naval Flight Manuals for current fleet aircraft are included in the reference section in references 13 through 18. These flight manuals detail the flight characteristics for each of the aircraft types. Examples of airplanes that are departure resistant and exhibit excellent departure characteristics are the F-14, F-5E, the F-15A and F-16A, reference 11. The A-7 airplane is not spin prone, but it is prone to violent departures in roll and yaw in the same direction. Modifications to the same model aircraft can have a drastic effect. The F-4E, with the addition of wing leading edge slats reduced the adverse yaw, increased departure resistance, increased controllability with the rudders and aileron, and recovered more rapidly. (reference 11) The current spin and departure trainer, the T-2C Buckeye (reference 18) exhibits excellent departure characteristics and spin modes that include erect incipient spins, erect oscillatory and non-oscillatory spins and inverted spins and inertia coupled departures. The key to the success of the T-2C Buckeye or any airplane as a departure and spin trainer is summarized by J. A. Nial in reference 19. Those criteria are: repeatable and predictable spin characteristics and spin entry and recovery should not be complicated. The airplane characteristics should not confuse the pilot, have reasonable rotation rates, buffet levels and control forces. Incorrect application of controls should not hazard the airplane and recovery should be consistent and well defined. Adequate pilot restraint, and engines that are not adversely affected are also desired. Aircraft structural loads should not be exceeded and spin and recovery characteristics should not change with configuration and center of gravity.

METHODOLOGY

Introduction

The purpose of this evaluation was to examine the out-of-control flight, departure and spin characteristics of the T-45A Goshawk and to determine the airplane's potential to fulfill the requirements of a fleet out-of-control flight and spin trainer. The evaluation was directed by the author as a result of tasking from the Naval Air Systems Command, Washington, D.C. to the Naval Air Warfare Center Aircraft Division, Flight Test Engineering Group (FTEG), Patuxent River, Maryland. The test preparation and conduct was carried out by the Flight Systems Department of the Strike Aircraft Test Directorate of FTEG.

Description of Test Airplane and Test Equipment

T-45A Goshawk

The T-45A Goshawk is a tandem-seat, land or aircraft carrier based jet trainer airplane manufactured by the McDonnell Douglas Aircraft Company shown in figure 3. The T-45A has a low mounted swept wing and is powered by a non-after burning Rolls-Royce F405-RR-401 turbofan engine which produces 5,775 lbs. of thrust at uninstalled, static, sea level, standard day conditions. The airplane utilized for these tests was the first production T-45A, Navy Bureau Number (BuNo) 163599, built by the Douglas Aircraft Company, Long Beach, CA. This airplane was inducted into the flight test program in an attempt to reduce schedule duration and identified as T003 designating it as a "test" asset.

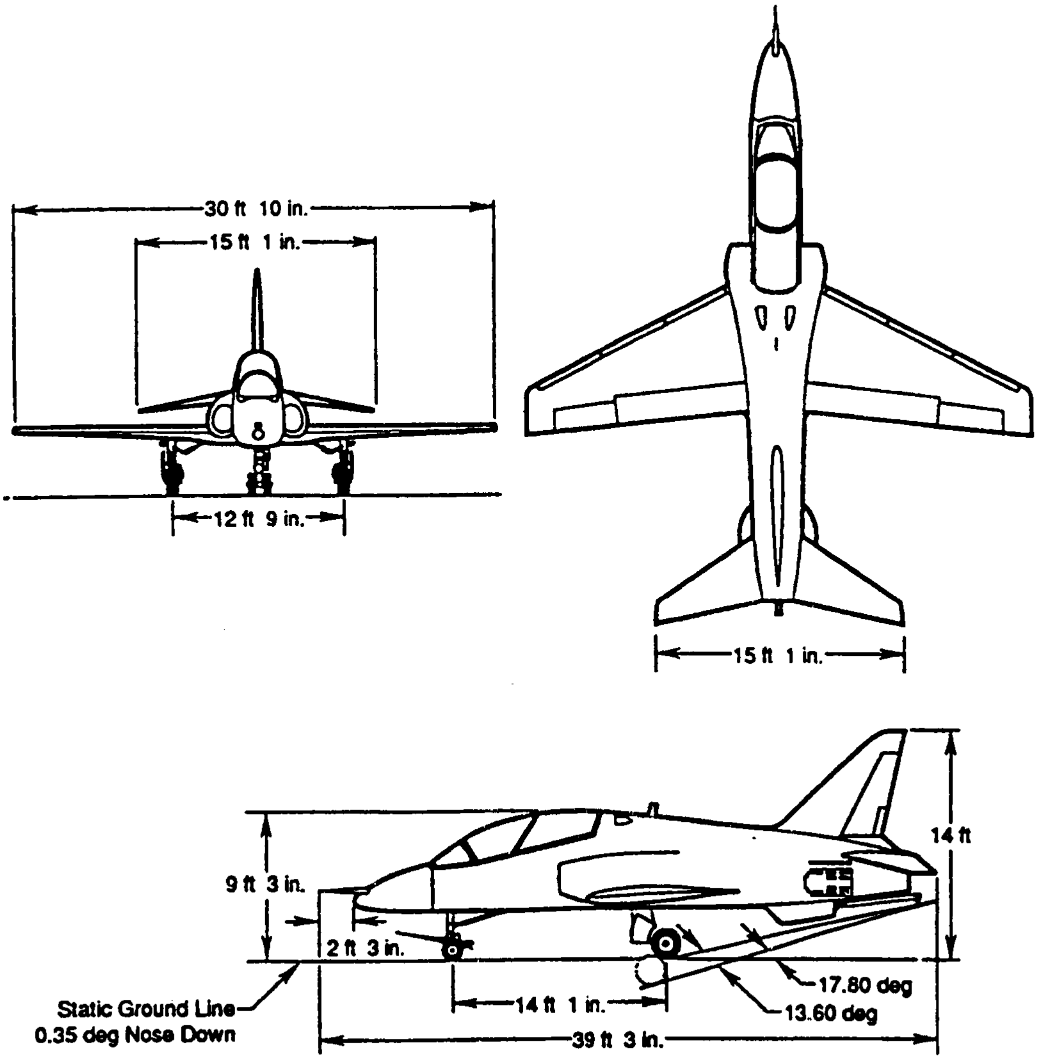

Figure 3
T-45A Goshawk

Flight Control System

The primary flight control system consisted of a hydraulically powered stabilator and ailerons and for longitudinal and lateral control respectively and a mechanical reversible rudder for directional control. The rudder also contained a rudder trim tab driven by a yaw damper or the rudder trim motor. The hydraulic actuators used for the stabilator and ailerons were of tandem design, with one cylinder connected to each of two independent hydraulic systems. Artificial feel in the longitudinal control system was provided by a spring cartridge, a bobweight, and two viscous dampers. Artificial feel in the lateral control system was provided by a spring cartridge. Rudder centering was provided by a spring cartridge. A mechanical 'no-float' mechanism in the directional control system was designed to maintain the rudder in a centered position unless it was displaced by a rudder pedal input. Since the rudder was a reversible design, rudder pedal forces felt by the pilot are directly proportional to dynamic pressure.

Control Augmentation

The test airplane was configured with a production Yaw Damper Controller (YDC). The YDC drove the rudder and rudder trim tab via commands to the electromechanical yaw damper actuator. It provided yaw damping and Aileron to Rudder Interconnect (ARI) when the airspeed was below 217 KIAS, the flaps down and the airplane airborne. With the flaps up the ARI function was removed. The YDC provided yaw damping for three seconds after the airplane touches down during landing before disengaging. For departures, out-of-control flight and spins that generate yaw rates in excess of 25 degrees-per-second the YDC functions are removed. The YDC also has additional functions of commanding the yaw damper actuator for rudder trim and schedules the speed brake to stabilator interconnect as a function of Mach number.

Power Plant

The T-45A Goshawk was powered by a Rolls-Royce, PLC produced Adour engine designated the F405-RR-401 engine. The engine was rated at 5,775 lbs. (uninstalled) at maximum thrust for a minimum engine at static, sea level standard day conditions. The engine ignition circuit was modified in the test airplane to provide redundancy and increased reliability for restarting the engine in the event the engine was shut down to clear an over temperature or a surge condition. Redundant engine ignition was accomplished by isolating each of the engine ignitors. The engine ignitors operate once the pilot has depressed the engine start button. Reliability of the ignition was achieved by providing continuous operation with the backup fuel system (BUFS) selected. BUFS was selected prior to each flight test maneuver.

Spin Recovery Parachute System

A spin recovery parachute system, designed by British Aerospace and NASA Langley was installed on the test airplane and is shown in figure 4. The parachute was an 8.66 foot flying diameter, ring slotted with an attach line length of 69.6 feet of rigging lines and risers installed into a drag chute compartment above the tail cone. The maximum deployment speed is 158 KEAS. The attach and release mechanism was contained within an arm attached to the underside of the fuselage in place of the production arresting hook. Parachute deployment was by means of a drogue parachute extracted by a bullet fired from a dual cartridge drogue gun. Primary release was via a mechanical actuator with emergency release via dual redundant electrical circuits to an explosive bolt.

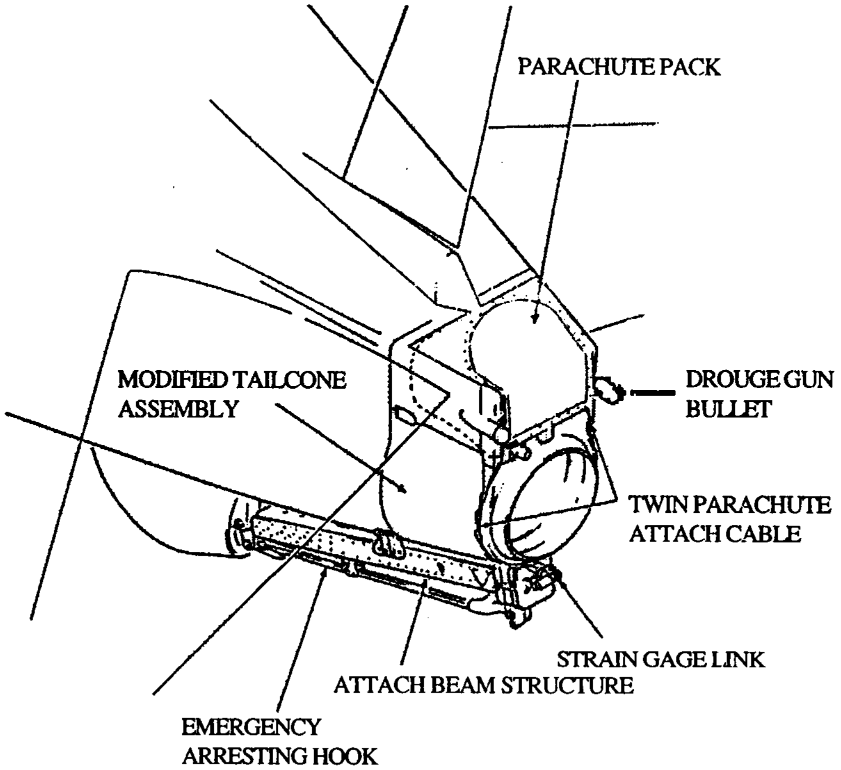

Figure 4
Spin Recovery Parachute Installation

Crew Station

The forward crew station was modified to provide additional information, controls and safety related items for the pilot. Spin displays and indicators shown in figure 5, were incorporated to the forward cockpit main instrument panel and included AOA and yaw rate indicators, full control throw position indicators, aileron and rudder position indicators, flight test airspeed indicator with an expanded scale in place of the production airspeed indicator, angle-of-sideslip indicator and flight test G-meter.

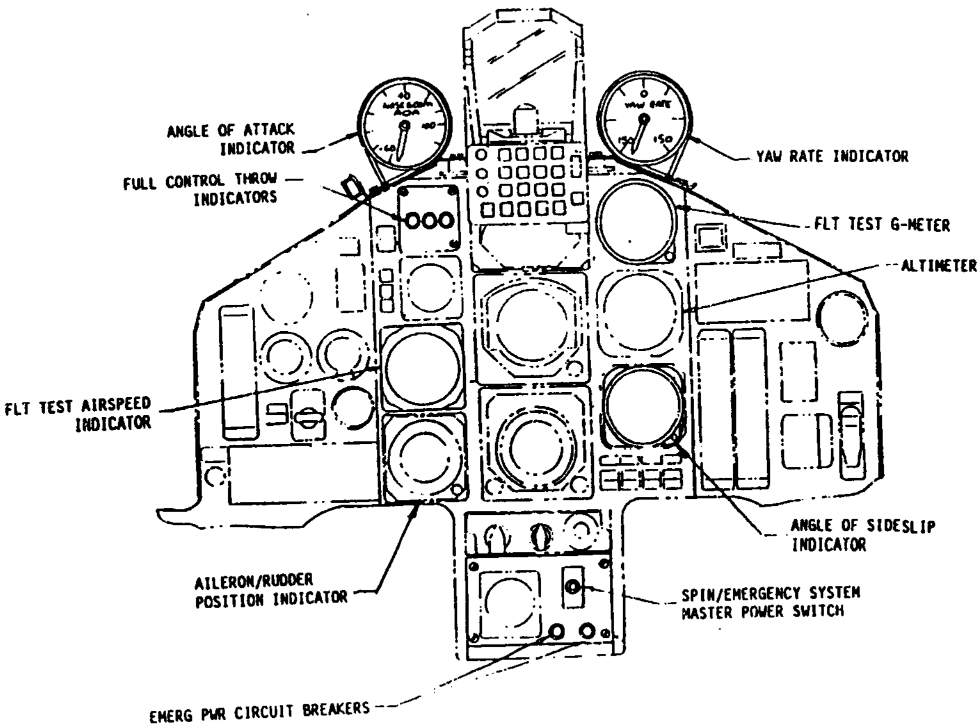

Figure 5
Forward Cockpit Main Instrument Panel Configuration

A spin recovery parachute control panel, shown in figure 6 replaces the weapons control panel. This panel was used to deploy and jettison the spin chute and display the spin chute system status to the pilot. A lateral chest restraint strap was added to the production restraint system to provide supplemental restraint. Lanyards attached to the airframe extract attach pins during the ejection sequence normalizing man-seat separation. An over-the-shoulder video camera was installed behind the forward crew station so as to record the external view and cockpit gages during the flight evaluations. Video coverage of the Heads-Up-Display was also recorded on selected flights.

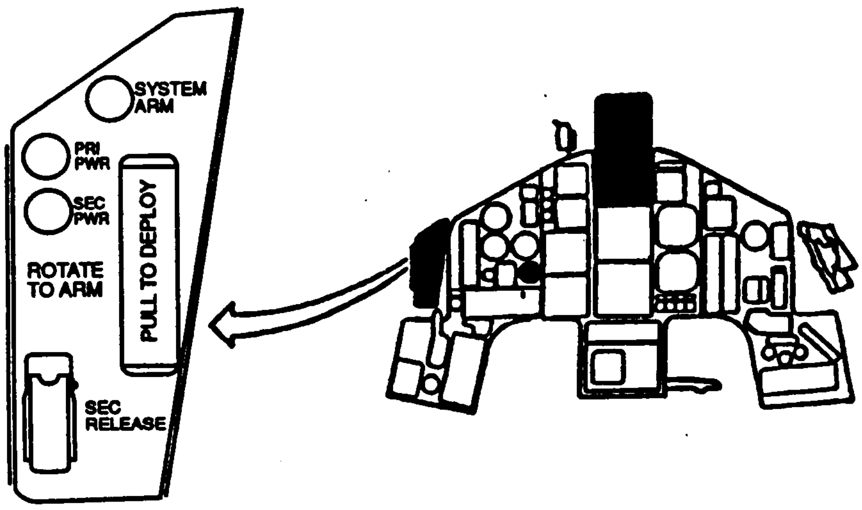

Figure 6

Spin Recovery Parachute Control Panel

Hydraulic System

The production hydraulic system as shown in figure 7, contained two separate 3000 psi systems (HYD1 and HYD2) with pressure provided by two engine driven pumps. Each system contained primary flight control accumulators and the HYD2 systems had a ram air turbine to provide system pressure in the event system pressure drops below 1500 psi. The primary flight control hydraulic system (HYD2) was modified with the addition of two fifty cubic inch accumulators in the flight control circuit. These accumulators provided for the equivalent of five full longitudinal and lateral flight control cycles after engine spool down without flow from the ram air turbine. A full control cycle is defined as starting with centered control position move the stick, full forward, full right, full aft, full left, full forward, neutral lateral while maintaining full forward stick and return the control stick to the original centered control position.

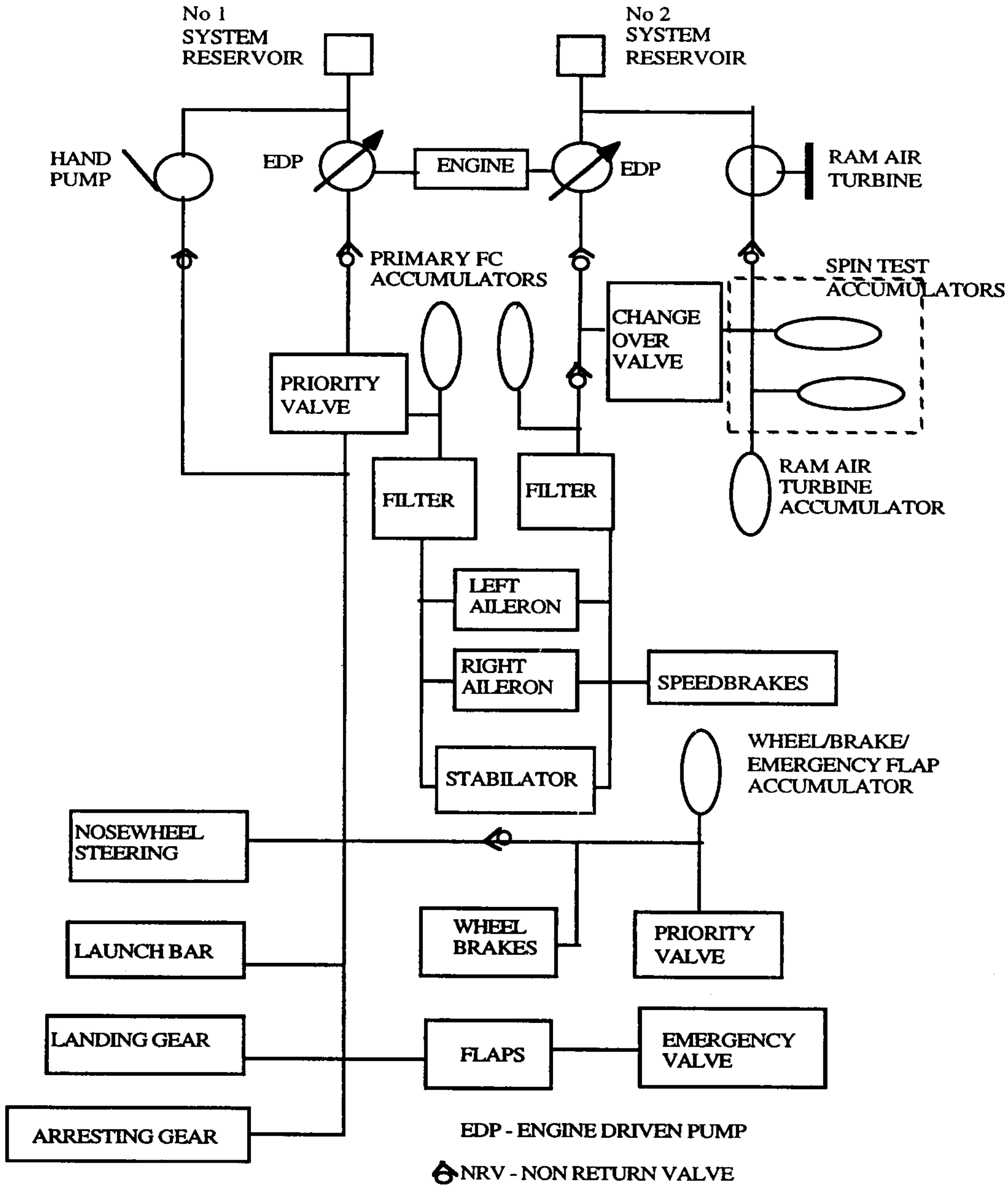

Figure 7
Hydraulic System

Electrical System

Engine driven generators provided primary Direct Current (DC) power to the Generator Bus. Alternating Current (AC) power is supplied to the AC Buses by two static inverters connected in parallel. The inverters are powered from the 28 VDC Essential Services Bus. Two 24 volt batteries provided power for the engine starting system and in the event of a generator failure they provided power for essential services for operation of the airplane. Modifications of the electrical system of the test airplane were made to provide for safety and redundancy. Redundant power sources for spin parachute deployment was completed by equally dividing the production battery bus into two independent battery busses. Each battery bus supplied power to approximately half of the production electrical systems as well as one independent circuit of the spin deployment release system.

Emergency Arresting Hook

The spin recovery parachute was attached to the airframe by an attach beam located on the bottom of the airplane located in place of the production arrestment tailhook as depicted in figure 8. The emergency arrestment tailhook, installed on the underside of the attach beam provides the capability of emergency field arrestments as required of specific in-flight emergencies.

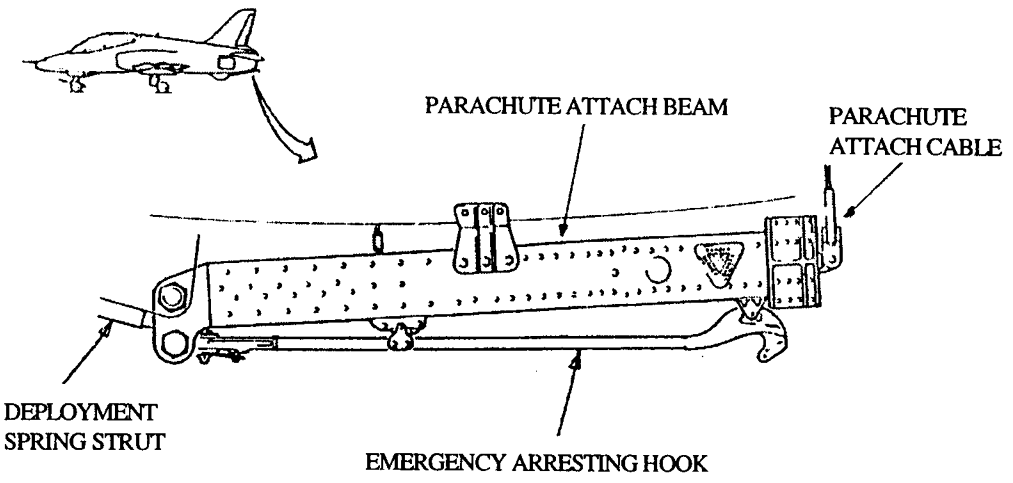

Figure 8
Emergency Arresting Hook Installation

Method of Tests

Introduction

The process for conducting high angle-of-attack flight test involved a methodology of controlled buildup from one test point to another. The entire flight test program was segmented into four separate phases. The first was flying qualities evaluations below the stall angle of attack. The second phase was bank-to-bank rolls up to full forward and full aft control stick building up in magnitude of control input. Third, were aggravated control inputs building up to full lateral and full longitudinal control inputs and held in for as long as fifteen seconds. The last phase involved spin entry and recovery high angle-of-attack demonstrations. Test configuration was the cruise configuration: gear up, flaps and slats retracted, idle power, and speedbrakes retracted. External test loadings are listed in appendix A , table III.

Flight Tests

Flight testing began on January 18, 1992 and continued until 7 April 1993 when a McDonnell Douglas Aircraft pilot encountered an inverted spin mode which did not recover using the predicted recovery controls. Deployment of the antispin chute did not assist in recovery from the spin due to it failing structurally after the design limit airspeed had been exceeded. Flight testing ceased until additional simulation updating and revised predictions of the high angle-of-attack characteristics could be completed by McDonnell Douglas Aircraft. Limited testing recommenced in August 1993 through September 1993 allowing the Navy their first evaluations of the high angle-of-attack characteristic of the T-45A airplane. This Navy evaluation was limited in scope to include upright spin attempts, misapplied controls, vertical maneuvers and operational maneuvers within the approved flight envelope since the determination was made that additional spin tunnel testing was required prior to further evaluation of the inverted spin characteristics. After additional spin tunnel testing was complete and the six degree-of-freedom simulation model and piloted flight simulation were updated and evaluated, flight testing once again commenced in August 1994 and concluded in October 1994.

Data Reduction

Data reduction was completed by the contractor. Airplane data included flight controls positions and forces and control surface positions, airspeed, altitude, normal and lateral acceleration. Airplane angles, rates and accelerations and heading were calculated using the on-board inertial navigation system, and the Standard Attitude Heading Reference System.

Data Presentation

All airplane data records were made available to the Navy by the contractor. Examples of these data from references 20 and 21 are presented in appendix B. The video coverage of the high angle-of-attack program is to be produced by the contractor into a presentation to be used by the Naval Air Training Command. The video presentation will include spin video taken from ground based cameras, over-the-shoulder video of external view and cockpit gages and video coverage of the Heads-Up-Display.

Specific Flight Test Maneuvers

Normal Stall Analysis

Stall characteristics during upright 1-g stalls to full back stick were evaluated by trimming the airplane, wings level at approximately 1.2 Vstall and applying aft stick to establishing a 1 kt/sec rate of deceleration. At stall full aft stick was applied for 5 seconds or departure. A representative time history for a normal stall is presented in appendix B, figure 1. The normal stalls were fairly benign maneuvers. As full back stick was achieved, the airplane began to slowly roll off in one direction. Sideslip excursions were minimal throughout the maneuver and roll rates during the stall rolloff were considered acceptable. Although the airplane was in heavy buffet and mild pitch bucking during full aft stick, the airplane quickly recovered from the stalled flight condition once the control stick was neutralized. Symmetric and asymmetric stores had no adverse effects on the stall characteristics.

Inverted Stall Analysis

Inverted stall characteristics were evaluated from -1 g, wings level flight and applying full forward stick and held for 5 seconds or departure. A representative time history of an inverted stall is presented in appendix B, figure 2. Inverted stalls in all loadings were characterized by a slow to moderate roll rate with light airframe buffet. The stall was defined by full forward stick since no distinct stall characteristic were observed. Once full forward stick was achieved, the nose dropped below the horizon and the airplane accelerated quickly. The airplane recovered quickly when the forward stick was reduced.

Accelerated Stall Analysis

Airplane flight characteristics were evaluated during constant Mach wind up turns (WUT). Representative time history of a 0.5M WUT are presented in appendix B, figure 3. During most WUT's, full back stick was held for approximately 5 seconds. The constant Mach WUT's were flown to buffet onset AOA, approximately 15 degrees. At that point, a mild to moderate pitch bucking motion would commence and longitudinal stick was smoothly pulled to the aft stop. Maximum AOA oscillations during the most severe pitch bucking motion were approximately ±10 deg. Once the pitch bucking motion started, lateral-directional oscillations, or wing rock, would begin. These lateral-directional oscillations were not divergent. Aileron roll control decreased but remained adequate for controlling roll angle. The airplane recovered quickly when the stick was moved forward to a neutral position.

Normal, inverted and accelerated stall characteristics were considered satisfactory as a training maneuver due to the benign flight characteristics and the rapid recoveries in all modes.

Departure Analysis

The T-45A has exhibited two departure modes resulting in negative AOA post stall gyrations, a pitch down departure and a forward stick departure. The pitch down departure occurred during rolling cross control maneuvers at speeds less than 0.5M and during recoveries from vertical maneuvers within 10 deg of vertical. The pitch down departure occurs during the post stall gyration, when high roll rate and yaw rates diverge in opposite directions. Since the directional control system is reversible, the rudder will float to full deflection as sideslip increases. The departure follows the rudder float so rapidly that it is unusable as a warning of impending departure. The pilot must immediately determine if the airplane is in a post stall gyration or a full developed spin. If the T-45A is in a post stall gyration, longitudinal and lateral controls must be held in the neutral position. The pilot will have to forcefully center the rudder requiring rudder pedal forces as much as 300 pounds. Delay in applying the appropriate recovery controls or input of lateral control stick into the yaw rate may cause entry into an inverted spin.

The forward control stick departure occurred when maneuvering at or near full forward control stick and applying lateral stick or rudder input. The sideslip increases rapidly followed by a pitch down and inverted post stall gyration as discussed above. Characteristics of the T-45A during departures show that lateral stick inputs increase the magnitude of roll and yaw rates, prolong the post stall gyration and increase the potential of spin entry. The departure evaluation assisted the development of techniques for spin entry.

In each of the departures, the rudder float and high rudder pedal forces were a result of the reversible directional control system. A power assisted or boosted directional control system would prevent both adverse airplane characteristics.

Vertical Maneuvering Analysis

High angle-of-attack flying qualities and spin susceptibility were evaluated during low airspeed vertical maneuvers. The maneuvers were entered at 350 KIAS with a 4 g Nz pull to the desired pitch attitude while allowing the airspeed to decelerate to zero airspeed. A representative time history of a 70 degrees pitch, upright vertical maneuver is presented in appendix B, figure 4. Vertical maneuvers evaluated up to approximately 80 degrees pitch attitude recovered easily using neutral controls and forcibly centering the rudder pedals without departures or incipient spins. Pitch rates encountered during these maneuvers were moderate and predictable by the pilot. Control inputs in the vertical, up to 80 degrees pitch attitude, resulted in slow airplane response but could be used to reduce pitch attitude during the recovery. Control inputs as the nose fell below the horizon did not have a significant impact on the recovery portion of the maneuver. No spins were encountered during vertical recoveries. The airplane characteristics and recovery from vertical maneuvers up to 80 degrees pitch attitude were adequate for vertical recovery training.

Vertical maneuvers within 10 degrees of the vertical both upright and inverted were not characterized by a ballistic profile but by the airplane slowing to zero airspeed. A representative time history of a vertical maneuver within 10 degrees of the vertical is presented in appendix B, figure 5. Control inputs resulted in sluggish airplane response as mentioned above. Recovery controls are the same as for the maneuvers conducted below 80 degrees pitch attitude. Vertical maneuvering within 10 degrees of vertical exhibited roll and yaw oscillations greater than those maneuvers conducted below 80 degrees. However, approximately 10% of the vertical maneuvers at pitch attitudes within 10 degrees of the vertical at airspeeds of 100 KIAS or less resulted in an inverted spin. A time history of a vertical maneuver that resulted in an incipient inverted spin is presented in appendix B, figure 6. The negative AOA incipient spins were very uncomfortable and disorienting to the pilot. The characteristics exhibited were similar to those displayed in the above section "Departure Analysis". The near vertical maneuvers propensity to enter into incipient spins and the disorientation of the pilot determined it's inadequacy as a training maneuver.

Upright Spin Analysis

The T-45A has exhibited two distinct upright spin modes at 30 degrees and 45 degrees angle-of-attack, neither of which becomes a stabilized spin.

30 Degree Angle-of-Attack Spin Mode

The 30 degree angle-of-attack spin mode was entered during the evaluations by input of full aft stick and full rudder pedal at airspeeds up to 0.5M. A time history of a vertical maneuver that resulted in an 30 degree angle-of-attack spin is presented in appendix B figure 7. The characteristics of the airplanes motion was a spiral rather than a spin with large roll rate oscillations. The pilot observed airspeeds of 150 KIAS or greater and 30 degrees angle-of-attack. Airspeed increased approximately 10 KIAS for each turn in the spiral. Recovery from this low angle-of-attack spiral mode was initiated at 180 KIAS by centering longitudinal, lateral and directional controls. If the roll rate oscillations are left to build, the airplane demonstrated, a transition into either the upright 45 degree angle-of-attack spin mode or pitched down into an inverted spin.

45 Degree Angle-of-Attack Spin Mode

The 45 degree angle-of-attack spin mode was entered from precisely timed sequence of full aft longitudinal control stick, full rudder input, and lateral control stick input at the peak roll rate. A time history of a 45 degree angle-of-attack spin is presented in appendix B figure 8. The airplane exhibited the same roll rate oscillations however, the airspeed maintained approximately 100 KIAS. If the roll rate oscillations were allowed to build, the airplane either self recovered from the spin or transitions into an inverted spin mode. If the pilot recognized the 45 degree angle-of-attack upright spin mode, distinguished by the airspeed difference from the 30 degree angle-of-attack upright spin mode, recovery controls of neutral longitudinal stick with lateral stick into the spin direction and rudder against the spin direction could be used. Recovery normally occurred within one to two turns.

Upright spins were not satisfactory to be used as a training maneuver due to the lack of a stabilized upright spin, the potential for transition into inverted spins and the inconsistent recovery control inputs between the two modes.

Inverted Spin Analysis

-25 Degree Angle-of-Attack Mode

The -25 degree angle-of-attack spin mode was entered by full aft control stick, and cross controlled aileron and rudder inputs. Departure and entry into this mode would occur as the airplane rolled through approximately 270 degrees. The motion of the T-45A was a spiral rather than a spin and could be sustained by neutralizing the rudder and longitudinal stick and maintaining full aileron input. Observed airspeed increased to 165 KIAS and completed one turn in approximately every four seconds. A time history of a -25 degree angle-of-attack spin is presented in appendix B figure 9. Recovery from this mode was to neutralize all flight controls. Neutralizing rudder required as much as 300 lb of rudder force. If the -25 degree spin is sustained, transition into the -60 degree mode could occur. Indications to the pilot of the transition are a pegged angle-of-attack indicator and airspeed decreasing to approximately 100 KIAS. The pilot must be quick to differentiate between the -25 degree and the -60 degree mode. Recovery control inputs from the -60 degree spin mode are pro-spin inputs while in the -25 degree spin mode as noted in the -60 Degree Angle-of-Attack Mode paragraph below.

-60 Degree Angle-of-Attack Mode

The -60 degree angle-of-attack developed spin mode was entered by full aileron and rudder inputs in the same direction and neutral longitudinal control stick. As the airplane rolled through approximately 270 degrees the pilot would slowly cross aileron in the opposite direction. A time history of a -60 degree angle-of-attack spin is presented in appendix B figure 10. Spin mode characteristics were mild pitch oscillations with airspeed at approximately 100 KIAS. The T-45A would complete one turn in approximately 3-4 seconds while descending about 1000 ft for each turn. The pitch oscillations did cause a transition into the -25 degree mode, noted by an increase in airspeed. Recovery from the -60 degree mode required the pilot to input aileron opposite the spin direction and slowly reduce the rudder pedal force to allow the rudder to lock into the 'no-float' mechanism. If the pilot attempted to forcefully center the rudder, or removed his foot from the rudder pedal, airloads forced the rudder beyond the neutral position. It then did not engage the 'no-float' mechanism and airplane entry into the -40 degree spin mode occurred.

-40 Degree Angle-of-Attack Mode

The -40 degree angle-of-attack spin mode could be entered into deliberately by full aft control stick, and cross controlled aileron and rudder inputs. As the airplane rolled through approximately 270 degrees the pilot would neutralize the control stick while maintaining the rudder input. A representative time history of a -40 degree angle-of-attack spin is presented in appendix B, figure 11. This mode was also entered from the -60 degree spin mode as a result of rudder float. Spin mode characteristics were similar to the -60 degree spin mode but more stabilized. Airspeeds ranged from 140-160 KIAS. Recovery was more positive using the same technique described for the -60 degree mode.

The inverted spin modes of the T-45A Goshawk were unacceptable for spin training due to the potential for transitioning into the various inverted modes, the rudder float and the associated high rudder pedal forces similar to those encountered during departures and the inconsistent recovery technique for all inverted spins.

CONCLUSIONS

The research and flight testing during this project gave a deeper appreciation into the necessity for an out-of-control flight and spin training program for the U.S. Navy. Decreases in out-of-control flight related accidents were observed during the operation of VF-43 and VF-126 flight training programs. The effectiveness of the spin training program cannot be relied upon as the sole source of the reduction of accidents since other factors, such as the removal of spin prone airplanes from the fleet occurred. However, sources mentioned in the Literature Review agree that spin and departure training is a necessary ingredient to the complete training of a tactical pilot.

The invaluable nature of the manned flight simulator with accurate aerodynamic models assisted in the preparation of the flight evaluations. The simulator allowed the pilots to fly the maneuvers while the engineers monitored the critical flight parameters gaining knowledge of airplane characteristics prior to the actual flights.

The T-45A does exhibit satisfactory flight characteristics during normal stalls, inverted stalls, accelerated stalls and recoveries from vertical maneuvers outside a +/- 10 degree cone from the vertical and could be used for training in these regimes. However, the T-45A Goshawk is not a suitable replacement to the T-2C Buckeye as an out-of-control flight and spin training airplane. The maneuvers critical to spin training did not display satisfactory characteristics. Upright spins did not display stabilized spin characteristics and the propensity to transition into inverted spins did not allow for detailed spin mode demonstration. Inverted spins did display stabilized spins, however, the transitory nature between inverted modes and the exactness of recovery inputs made it impractical for spin training and demonstrations. The high rudder pedal forces and the rudder float resulting from aerodynamic forces acting on the rudder did not allow the pilot to use the directional control system as a reliable means of recovery control. A powered rudder would allow the pilot to achieve greater advantage over the aerodynamic forces and use the rudder as a recovery control.

It is recommended that the T-45A Goshawk be utilized for stall training and recovery from vertical maneuvers up to 80 degrees pitch attitude. Consideration should be given to installing a powered rudder in the T-45A airplane to preclude rudder float and assist in inverted spin recovery. It is also recommended that future high angle-of-attack programs use a manned flight simulator for pilot proficiency, engineering training and analysis prior to the actual flight tests.

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APPENDICES

APPENDIX A

TABLES

Table I

SUMMARY OF FLEET AIRPLANE ERECT SPIN RECOVERY CONTROLS

	A-4 A-7 T-45A (1) AV-8B (3)	F-14 EA-6B	A-6	T-2 T-28	T-34	AV-8B T-45A(2)	F/A-18 TAV-8B
Rudder	Against	Against	Against	Against	Against	Neutral	Neutral
Aileron	With	With	Neutral	Neutral	Neutral	Neutral	Neutral
Elevator	Neutral	Aft	Aft	Neutral	Forward	Neutral	Forward

Notes: (1) 45 Degree Angle-of-Attack Spin Mode

(2) 30 Degree Angle-of-Attack Spin Mode

(3) Recovery controls with asymmetric stores.

APPENDIX A

Table II

SUMMARY OF TACTICAL AIRPLANE LOSSES

AIRCRAFT TYPE	TOTAL LOSSES (JANUARY 1977-OCTOBER 1993)
T/A-7	21
F-4	22
F-18	23
F-14	43
A-6	26
EA-6	12
T-2	15
AV-B	21
TA-4	25
F-8	2
A-3	2
A-4	14
TF-16	1

Table III

T-45A TEST LOADINGS

LOADING	LEFT WING STATION	RIGHT WING STATION
CLEAN	CLEAN	CLEAN
ASYMMETRICAL	PYLON/PMBR (1)	CLEAN

NOTE: (1) PMBR is a practice multiple bomb rack with six inert MK-76 (25 pound) practice bombs.

APPENDIX A

APPENDIX B

FIGURES

T-45A Airplane

Configuration: CR
Gross Weight: 13,100 lb
Speedbrakes: Retracted

Loading: Clean
CG: 18.1% MAC
Thrust: Idle

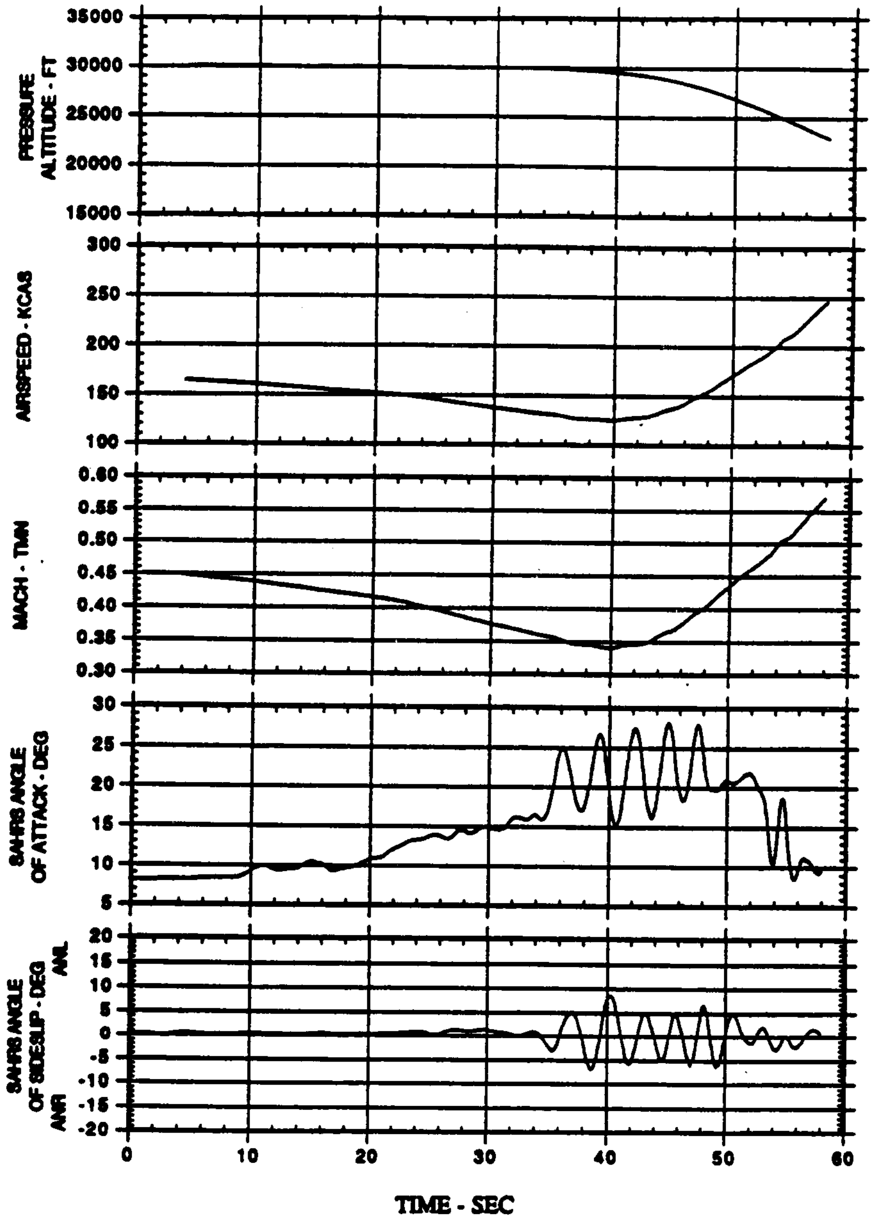


Figure 1
Normal Stall

APPENDIX B

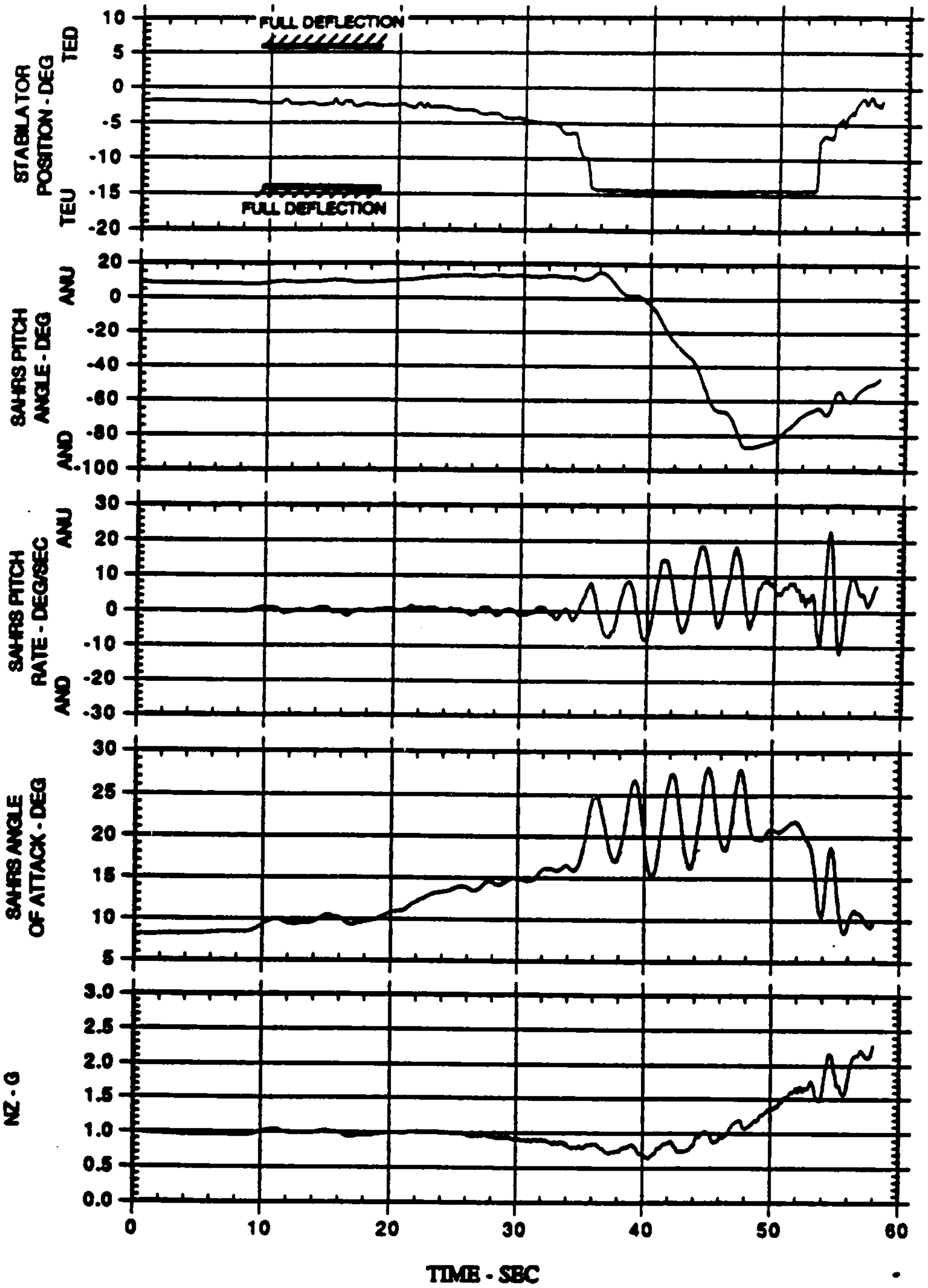
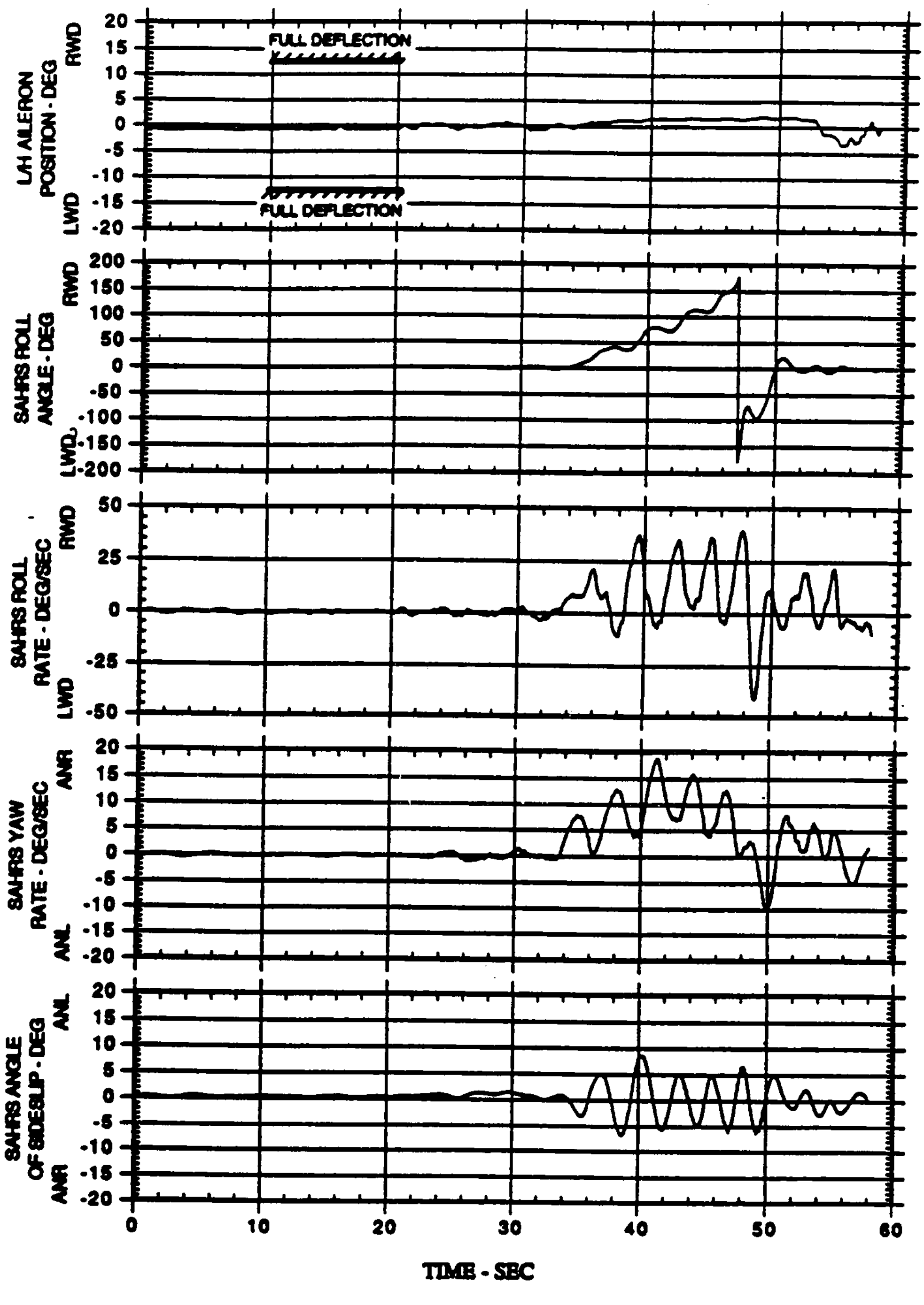


Figure 1 (Continued)

APPENDIX B



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APPENDIX B

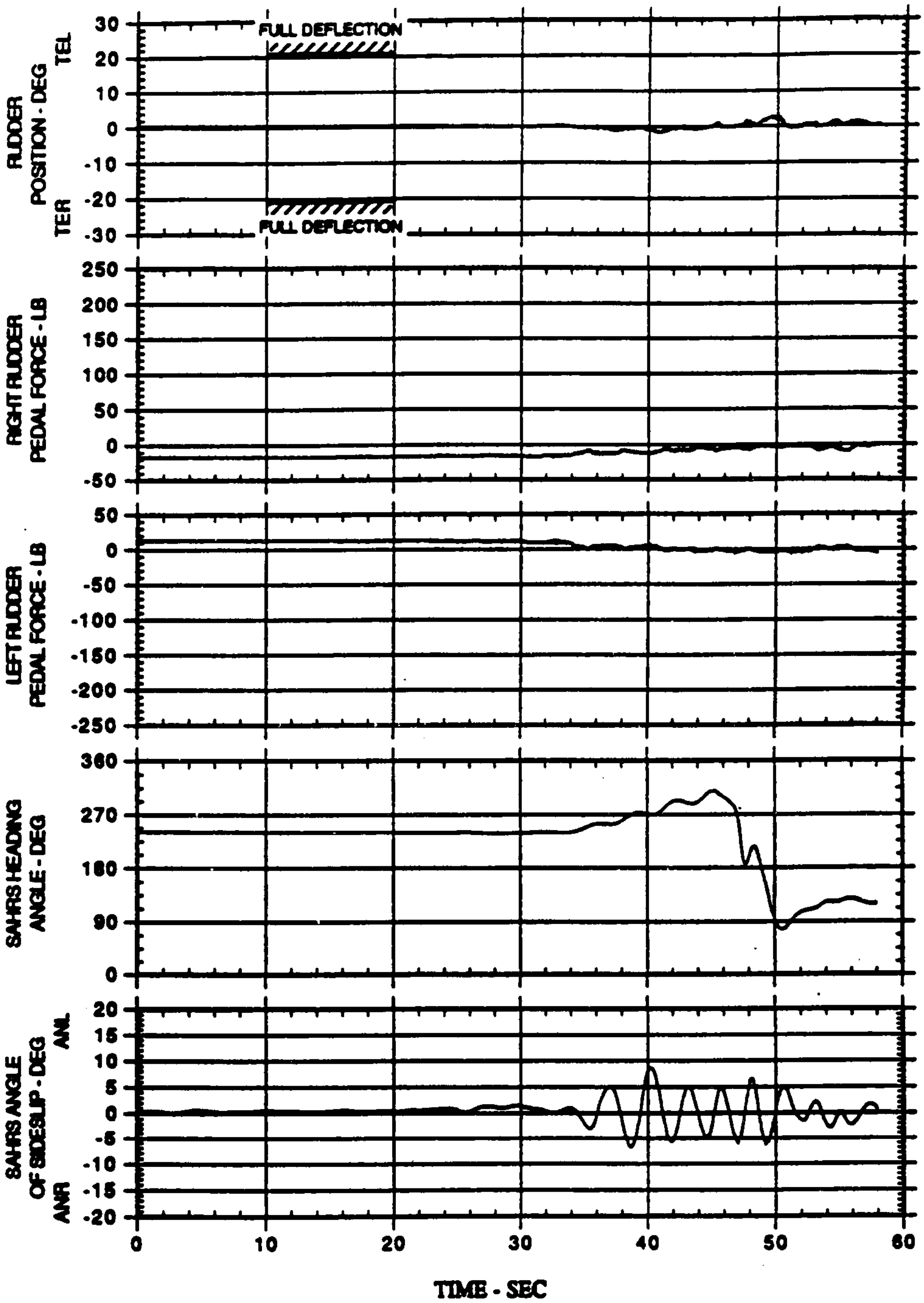


Figure 1 (Continued)

APPENDIX B

T-45A Airplane

Configuration: CR
Gross Weight: 12,700 lb
Speedbrakes: Retracted

Loading: Clean
CG: 18.3% MAC
Thrust: Idle

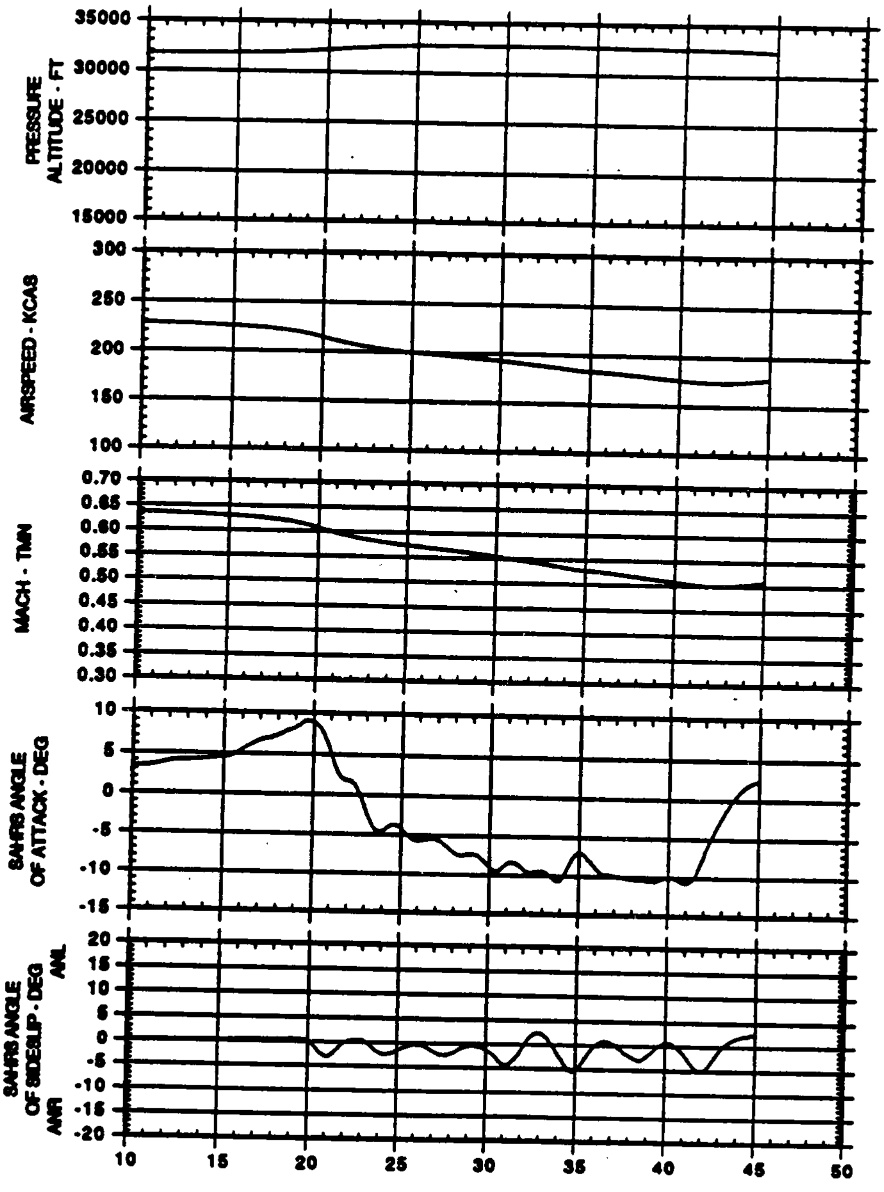
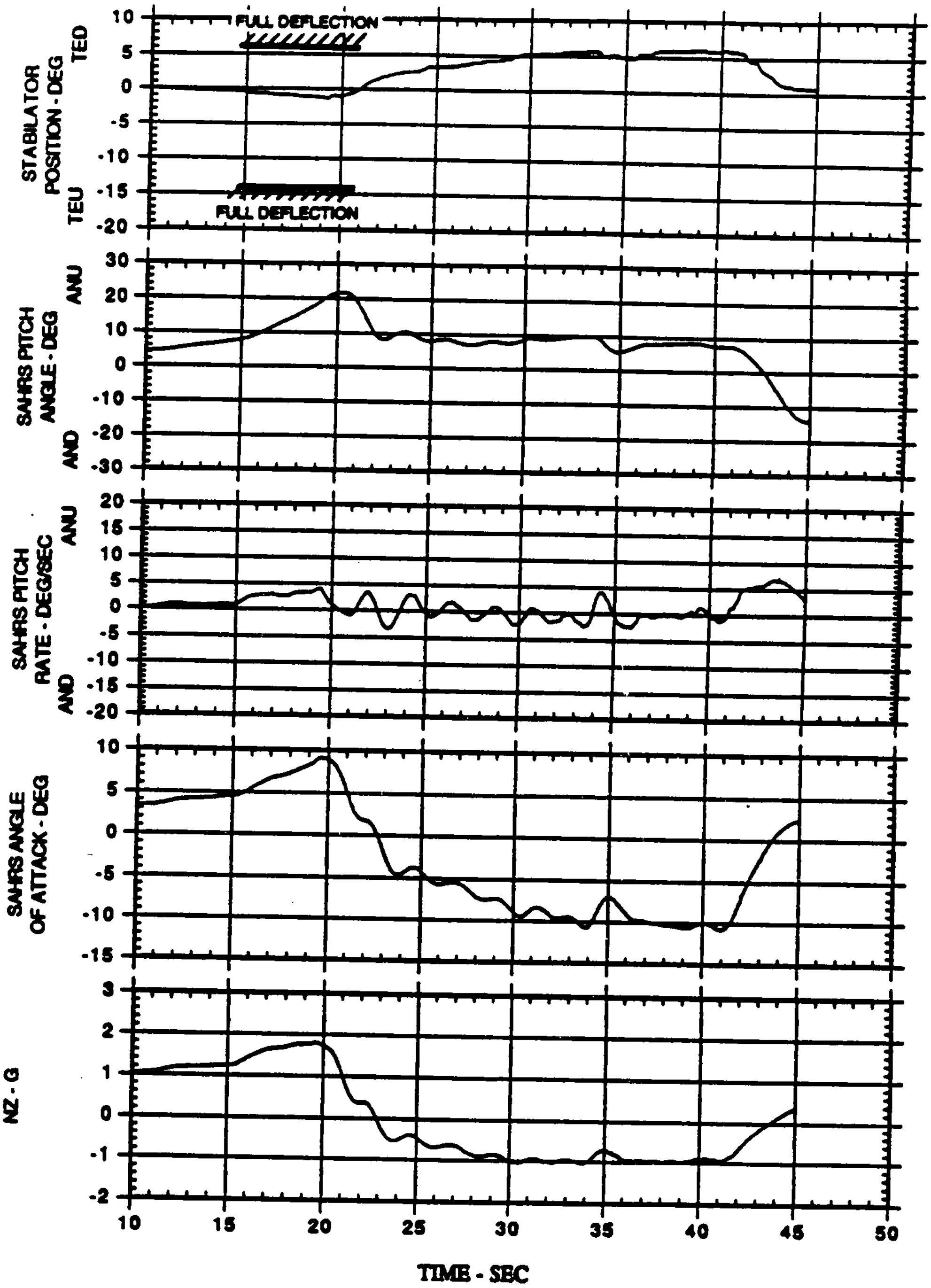


Figure 2
Inverted Stall

APPENDIX B



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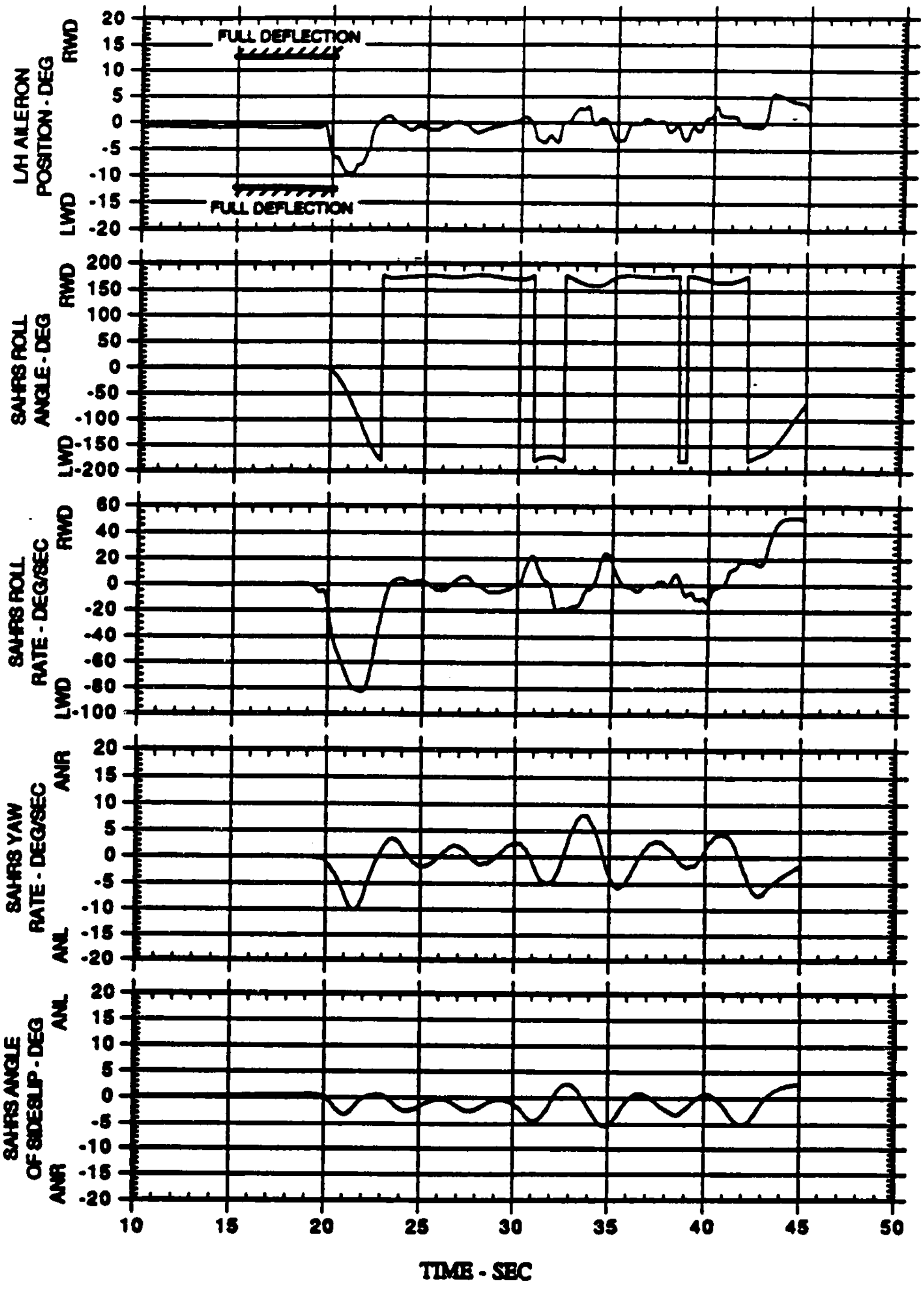
APPENDIX B



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APPENDIX B

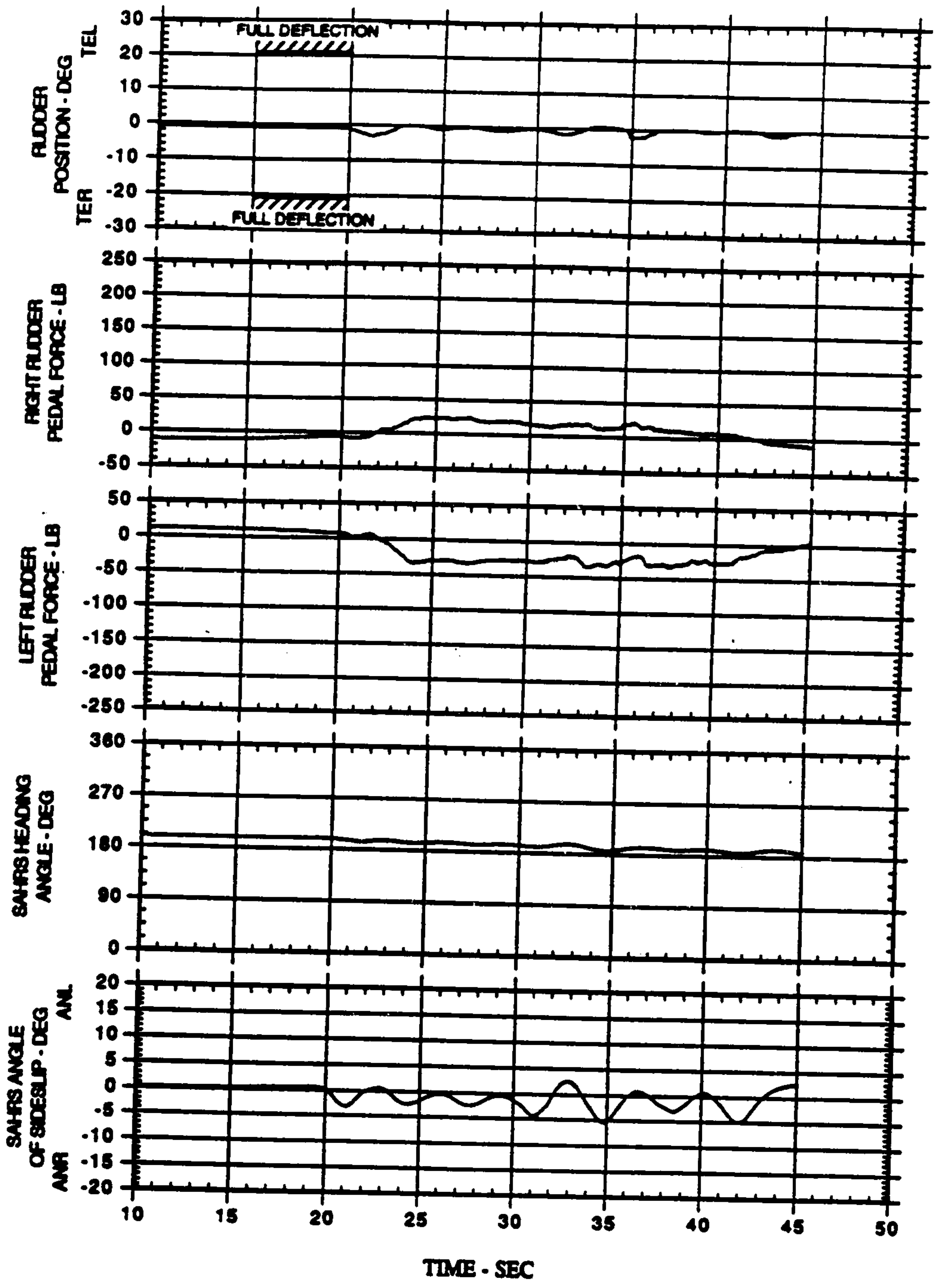


Figure 2 (Continued)

T-45A Airplane

Configuration: CR
Gross Weight: 12,500 lb
Speedbrakes: Retracted

Loading: Clean
CG: 18.8% MAC
Thrust: Idle

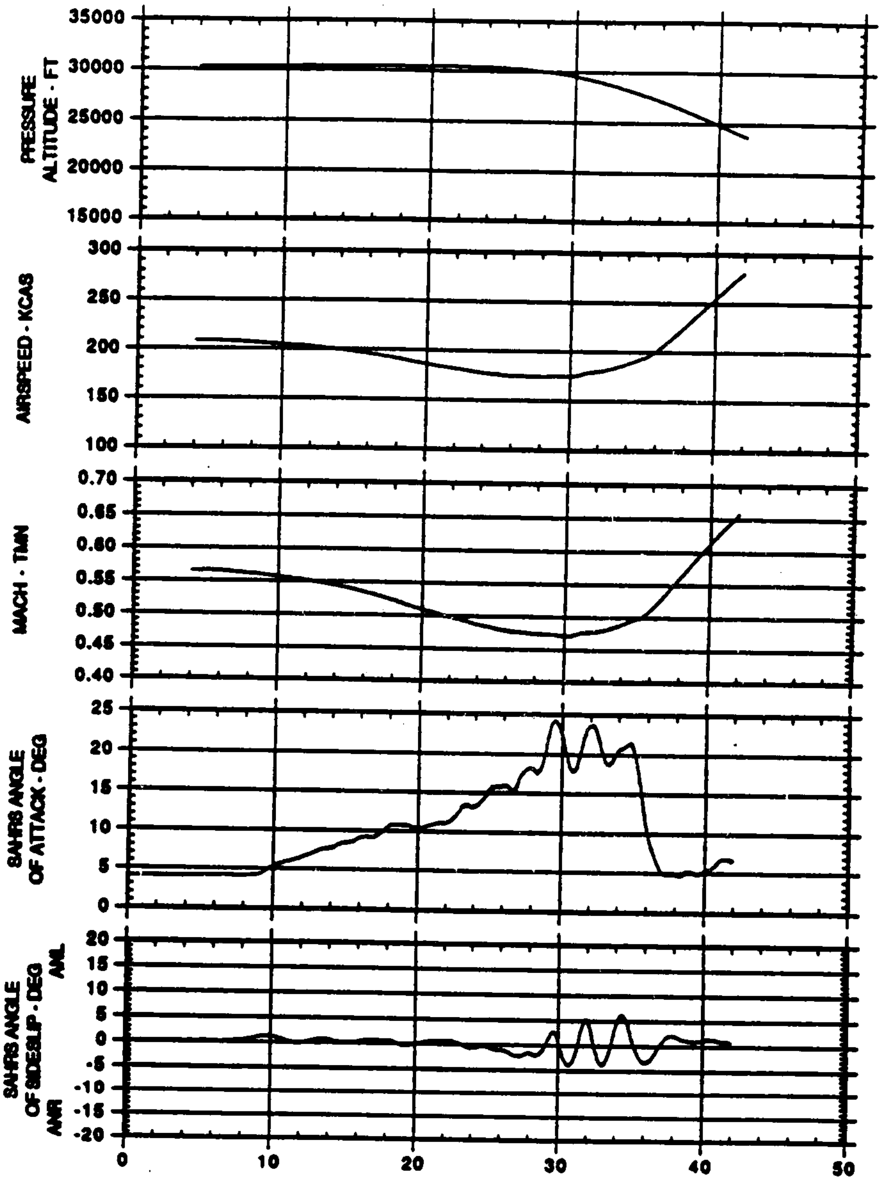


Figure 3
Accelerated Stall

APPENDIX B

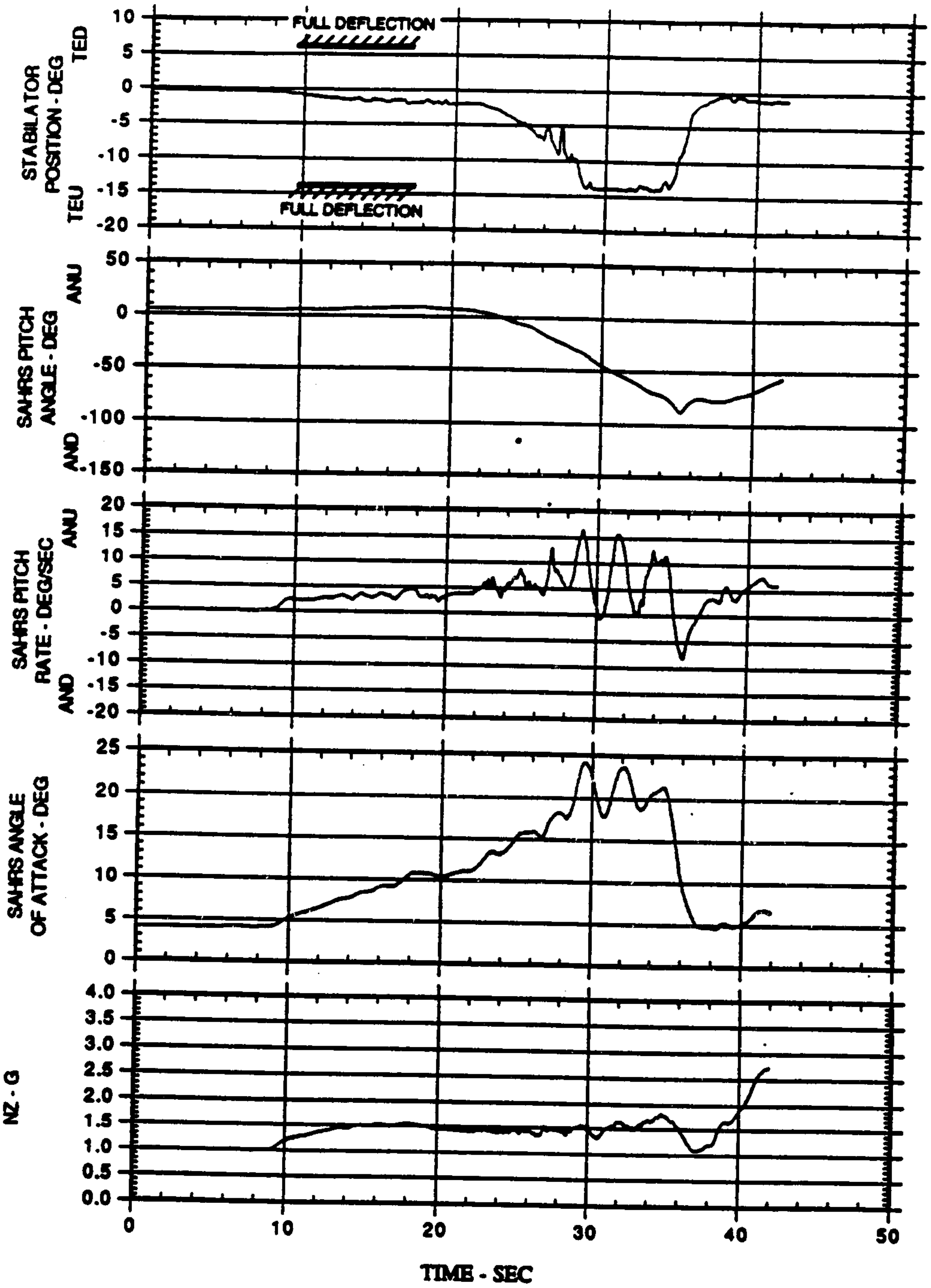


Figure 3 (Continued)

APPENDIX B

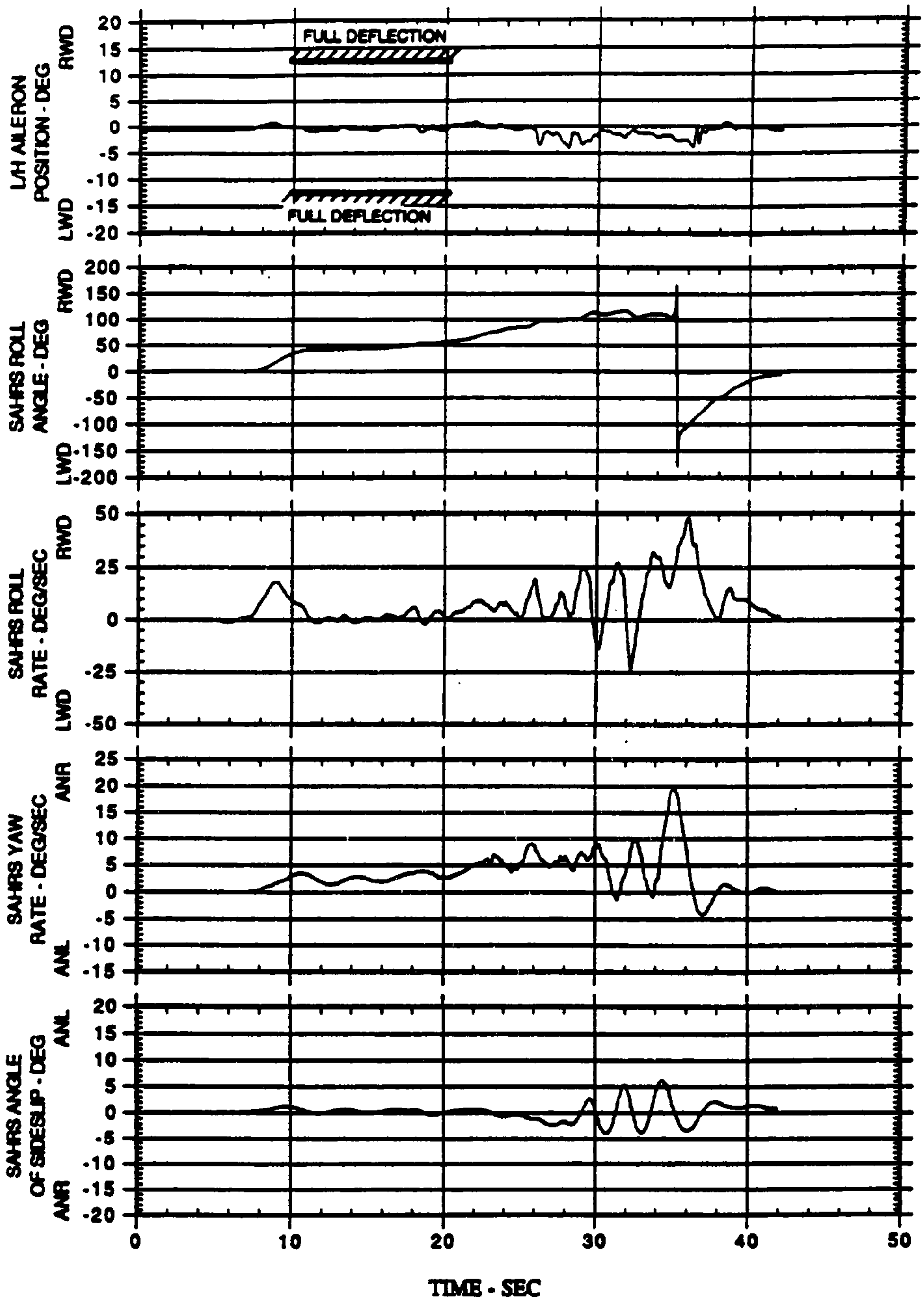


Figure 3 (Continued)

APPENDIX B

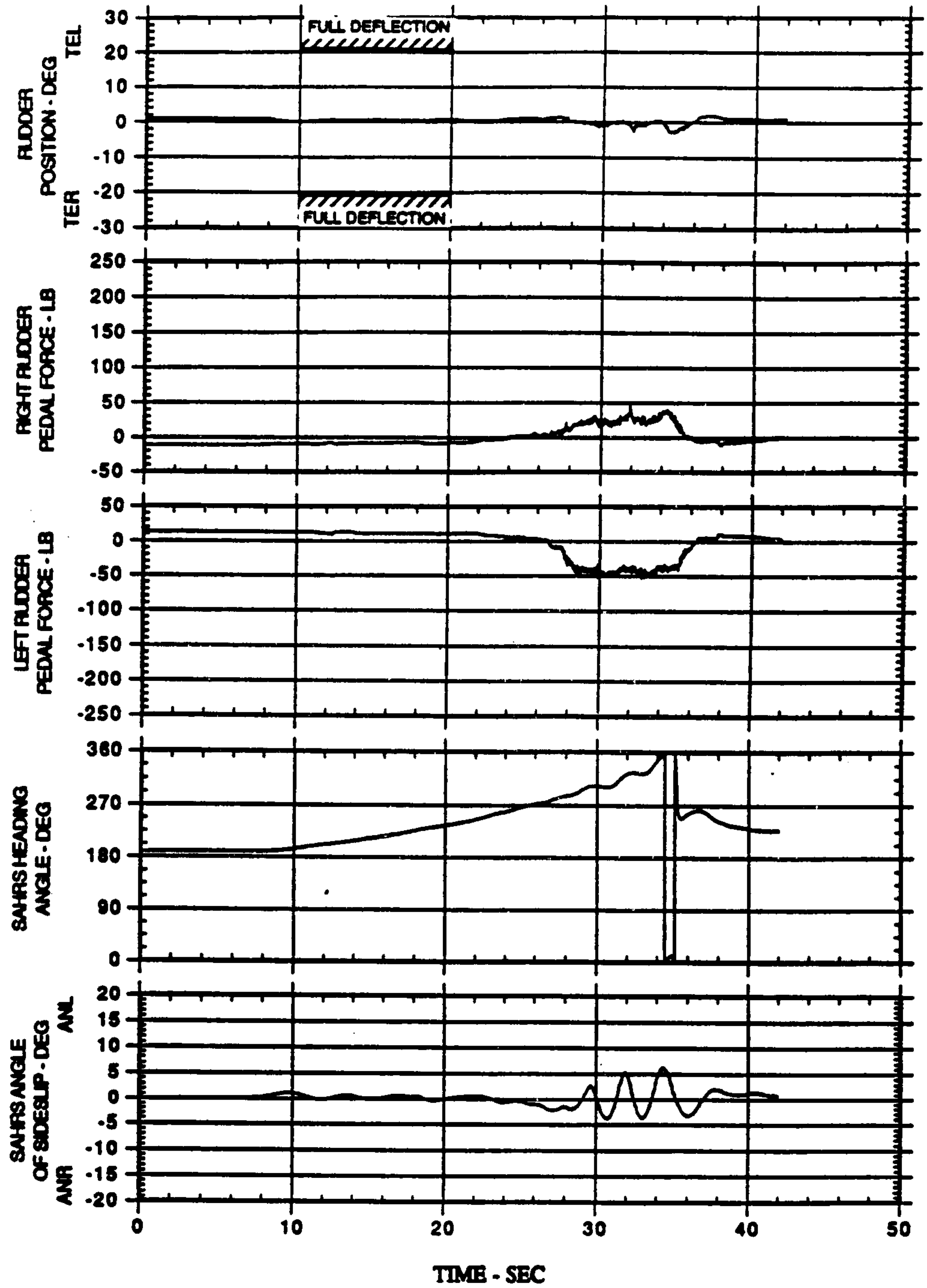


Figure 3 (Continued)

APPENDIX B

T-45A Airplane

Configuration: CR
Gross Weight: 12,750 lb
Speedbrakes: Retracted

Loading: Clean
CG: 18.9% MAC
Thrust: MIL

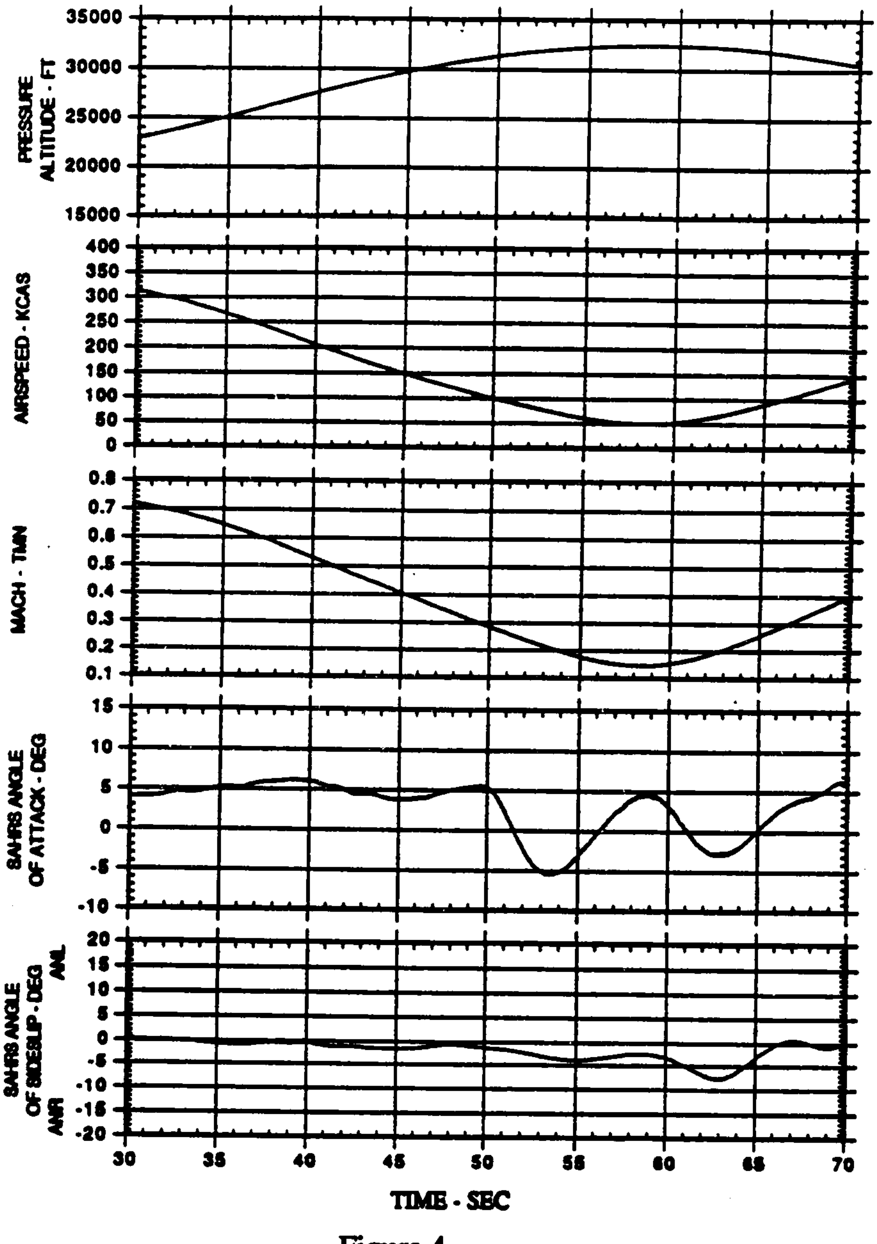


Figure 4
70 Degree Pitch Attitude Upright Maneuver

APPENDIX B

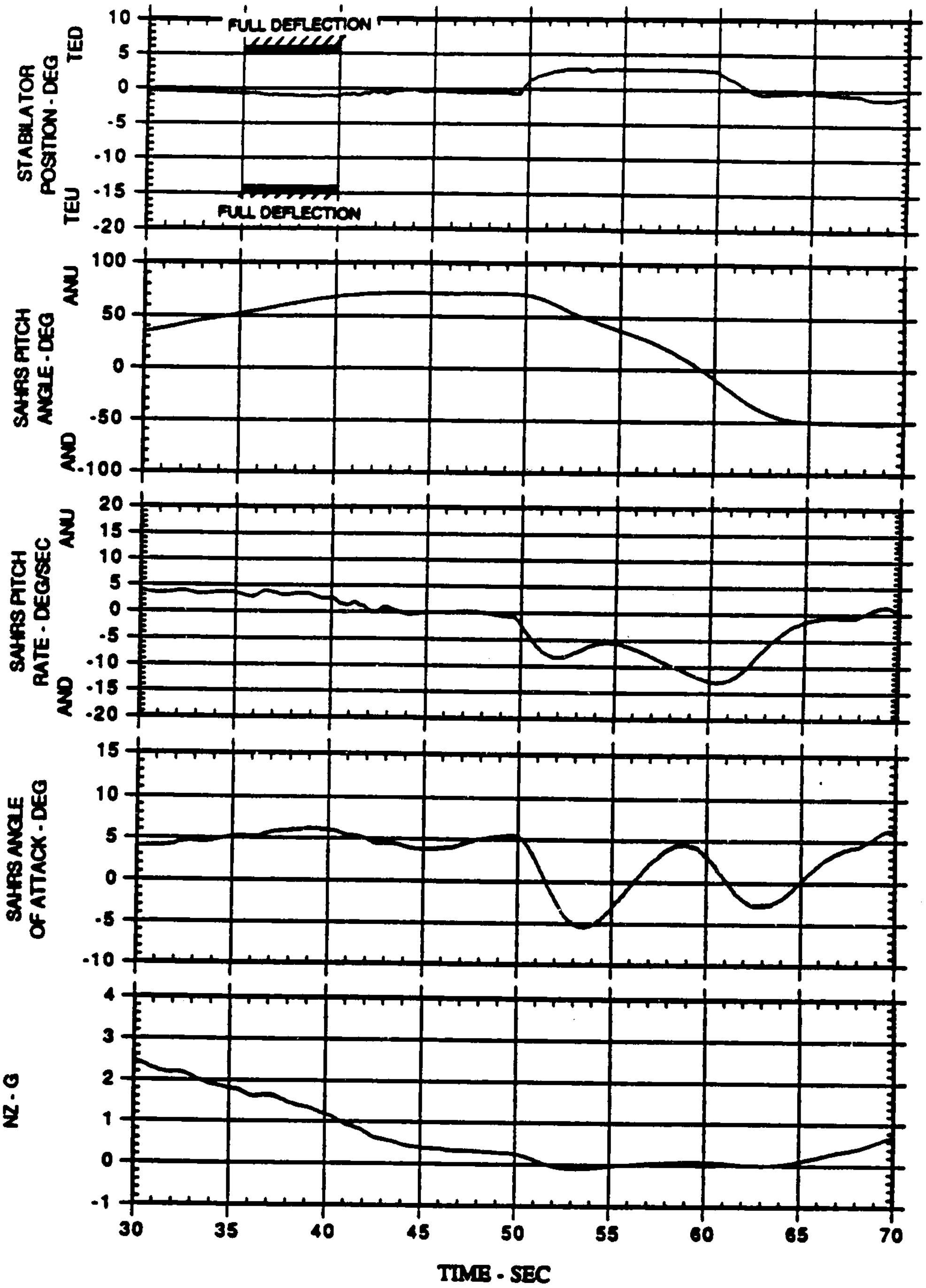


Figure 4 (Continued)

APPENDIX B

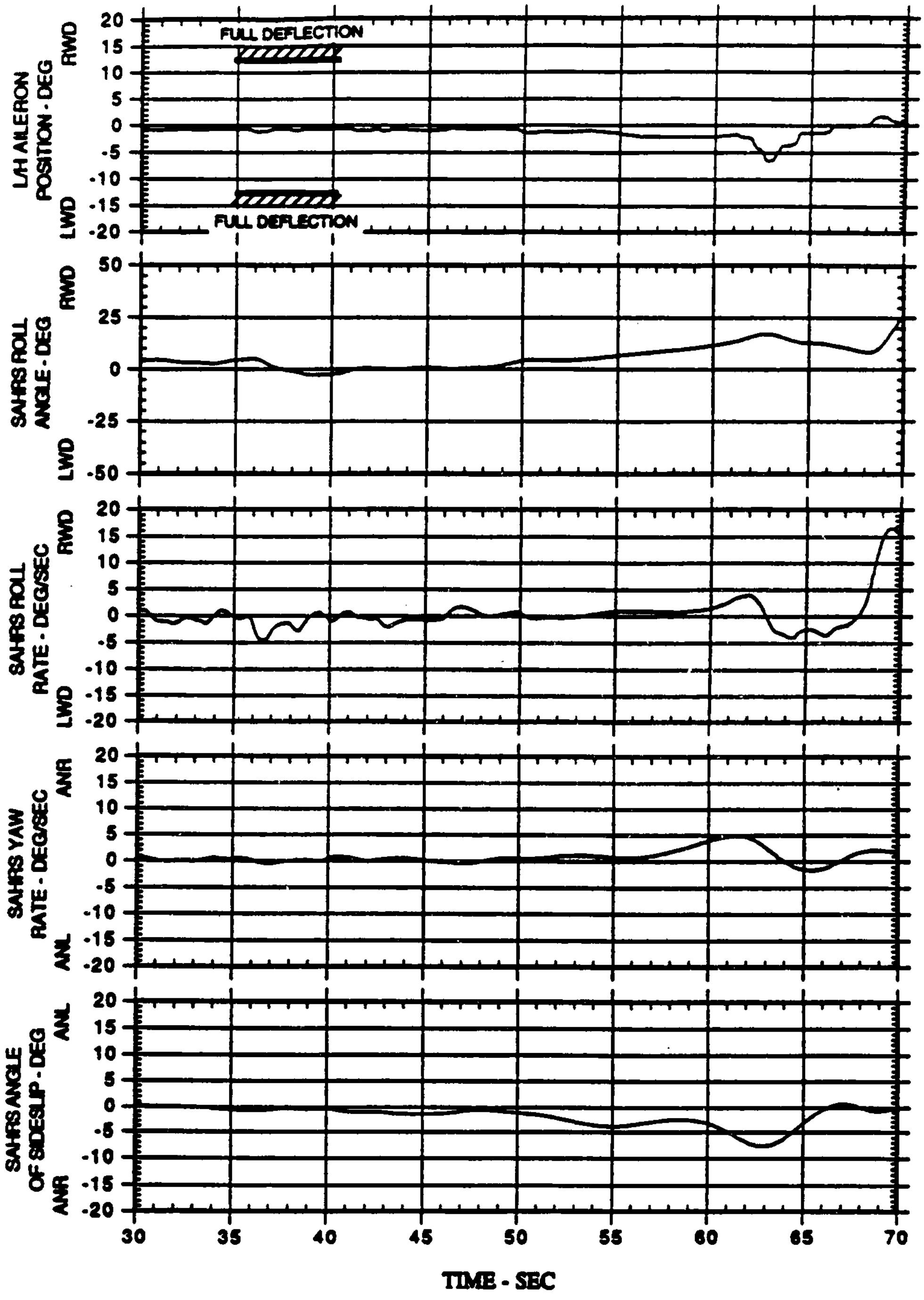


Figure 4 (Continued)

APPENDIX B

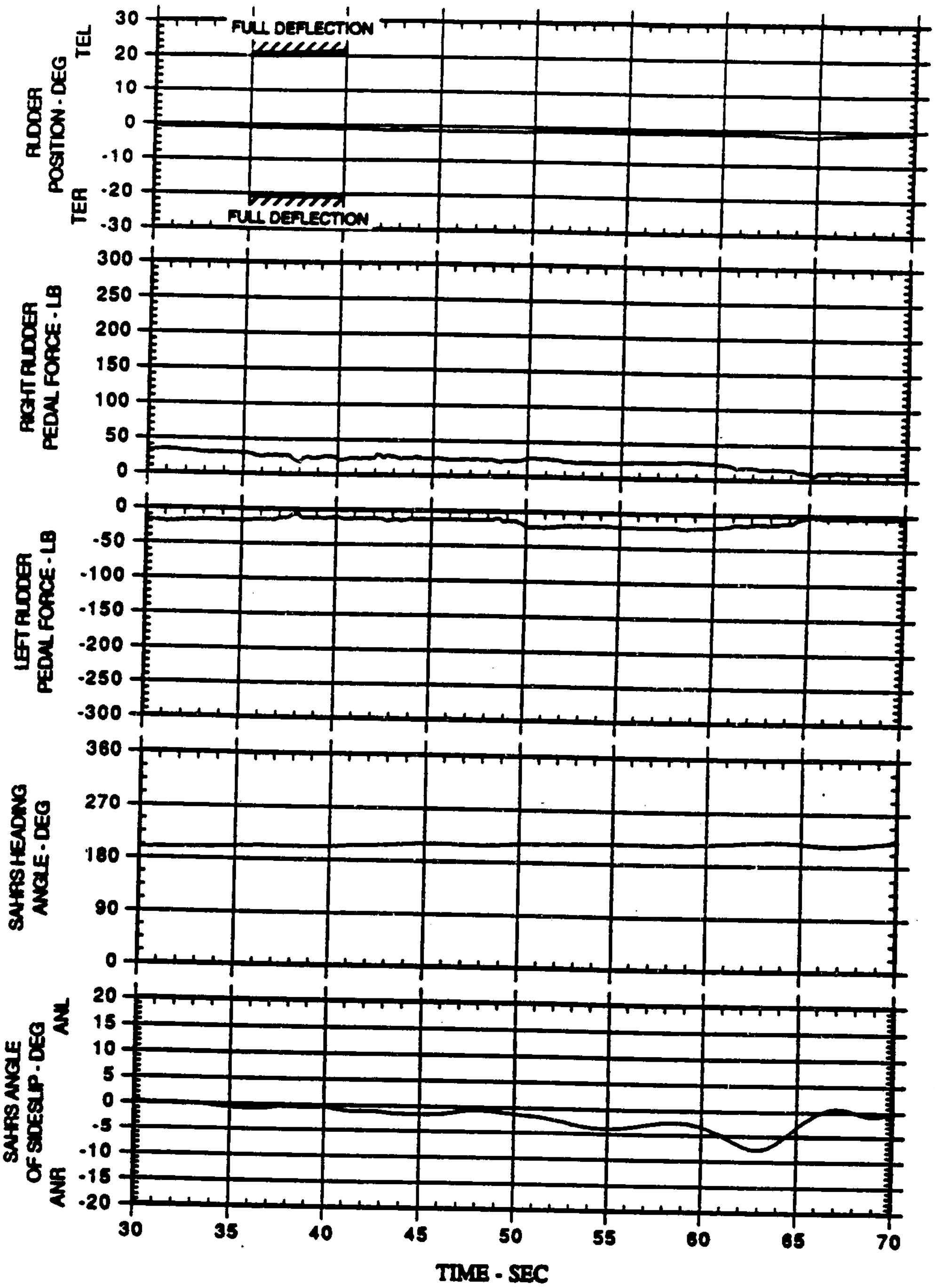


Figure 4 (Continued)

APPENDIX B

T-45A Airplane

Configuration: CR
Gross Weight: 12,100 lb
Speedbrakes: Retracted

Loading: Clean
CG: 17.9% MAC
Thrust: Idle

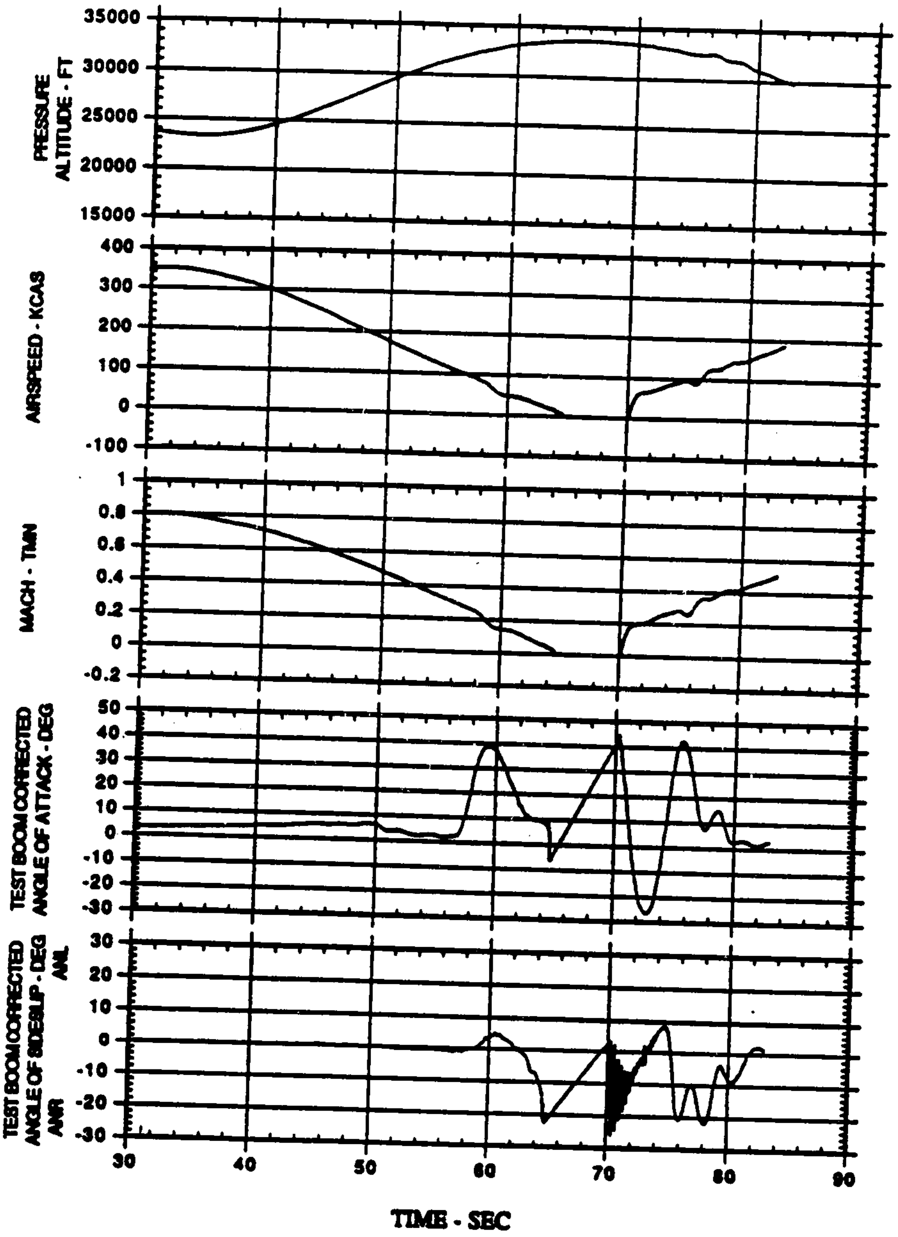


Figure 5
Vertical Maneuver Within 10 Degrees of Vertical

APPENDIX B

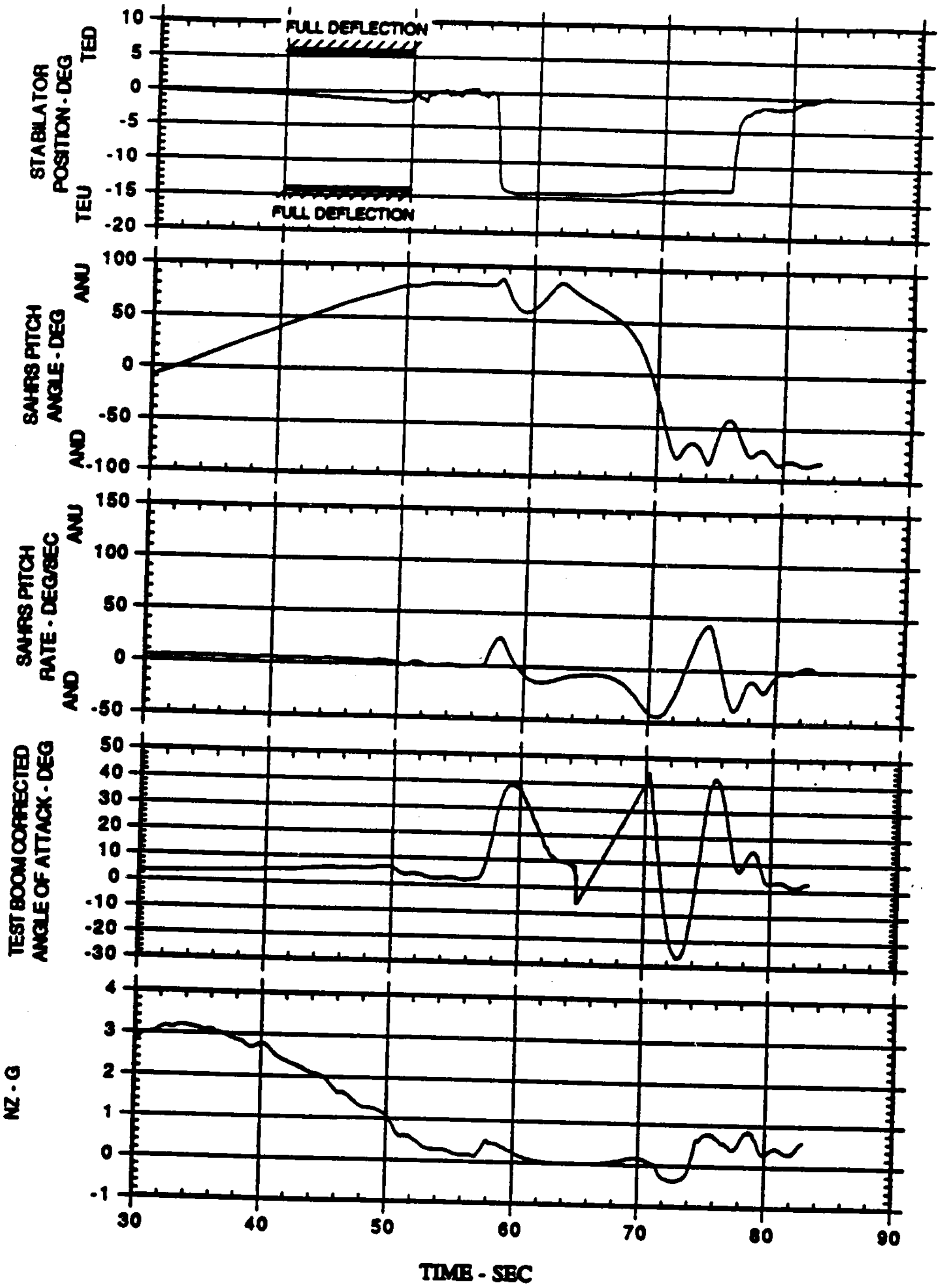


Figure 5 (Continued)

APPENDIX B

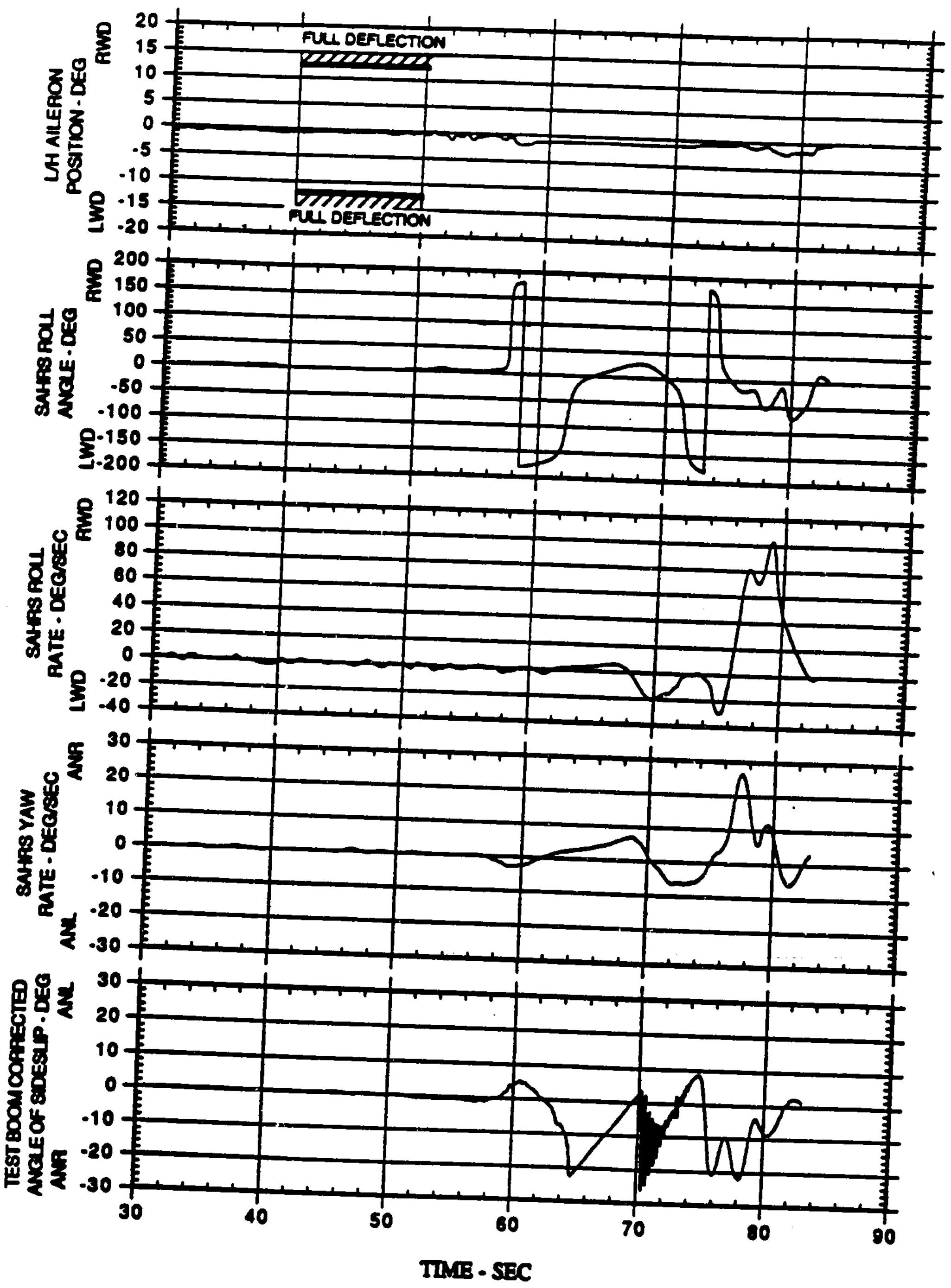


Figure 5 (Continued)

APPENDIX B

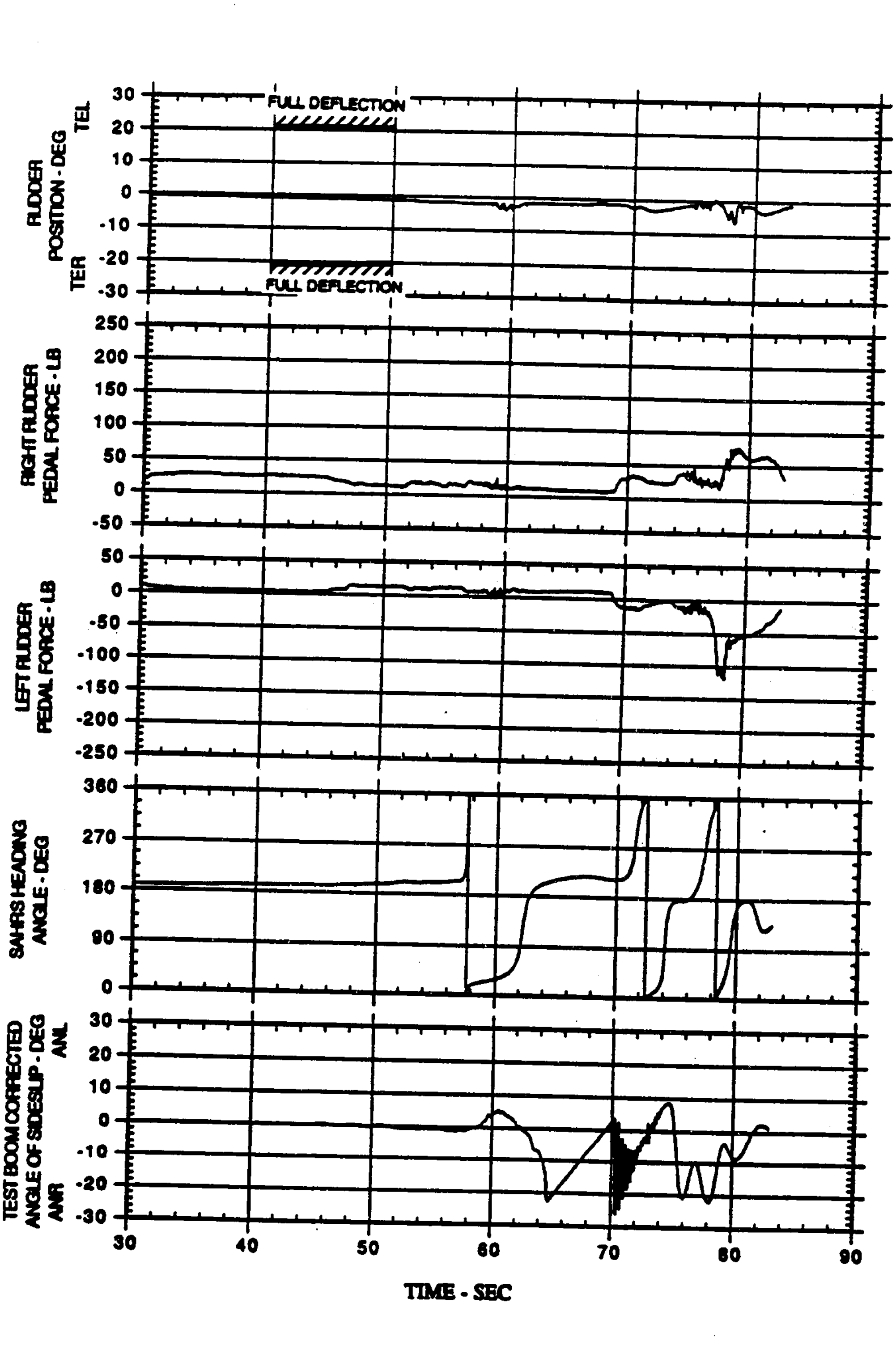


Figure 5 (Continued)

APPENDIX B

T-45A Airplane

Configuration: CR
Gross Weight: 11,900 lb
Speedbrakes: Retracted

Loading: Clean
CG: 17.4% MAC
Thrust: Idle

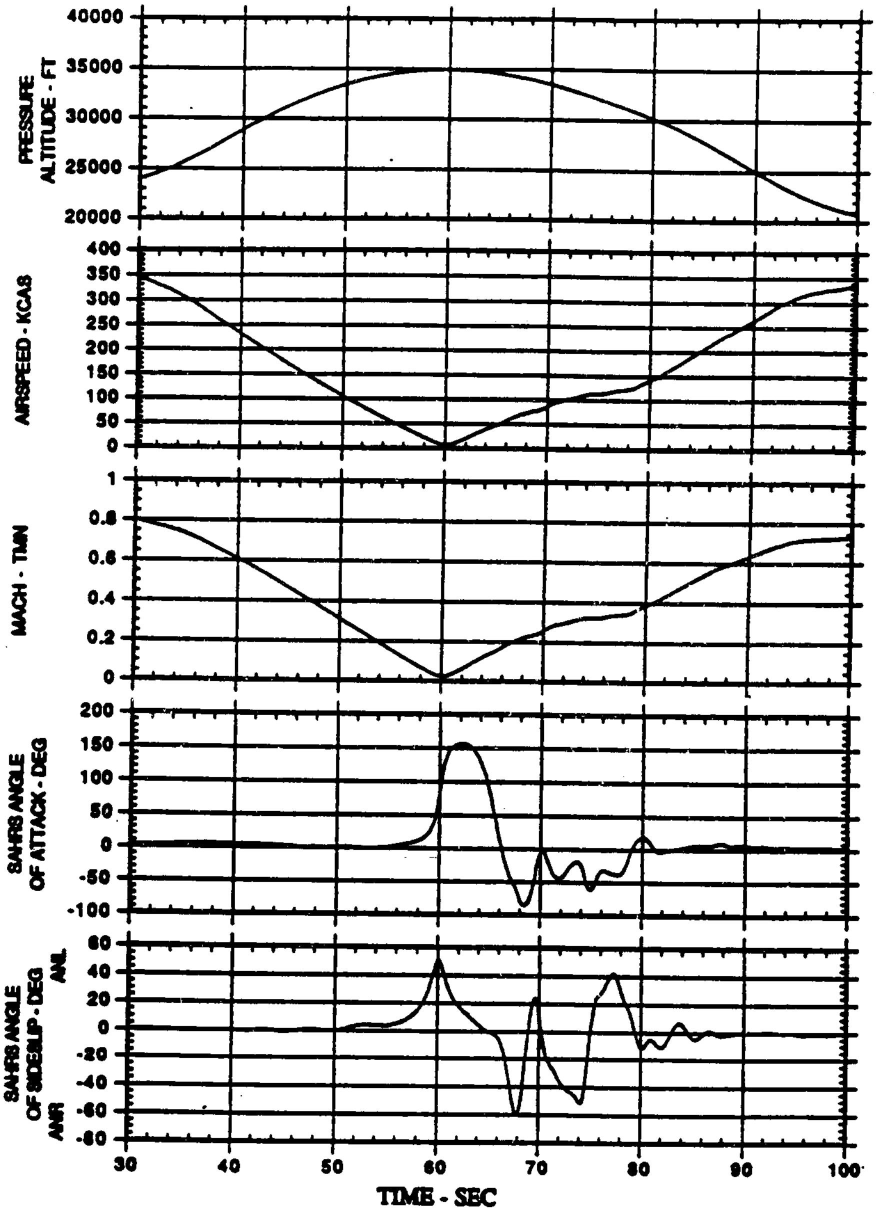


Figure 6
Inverted Spin from a Vertical Maneuver

APPENDIX B

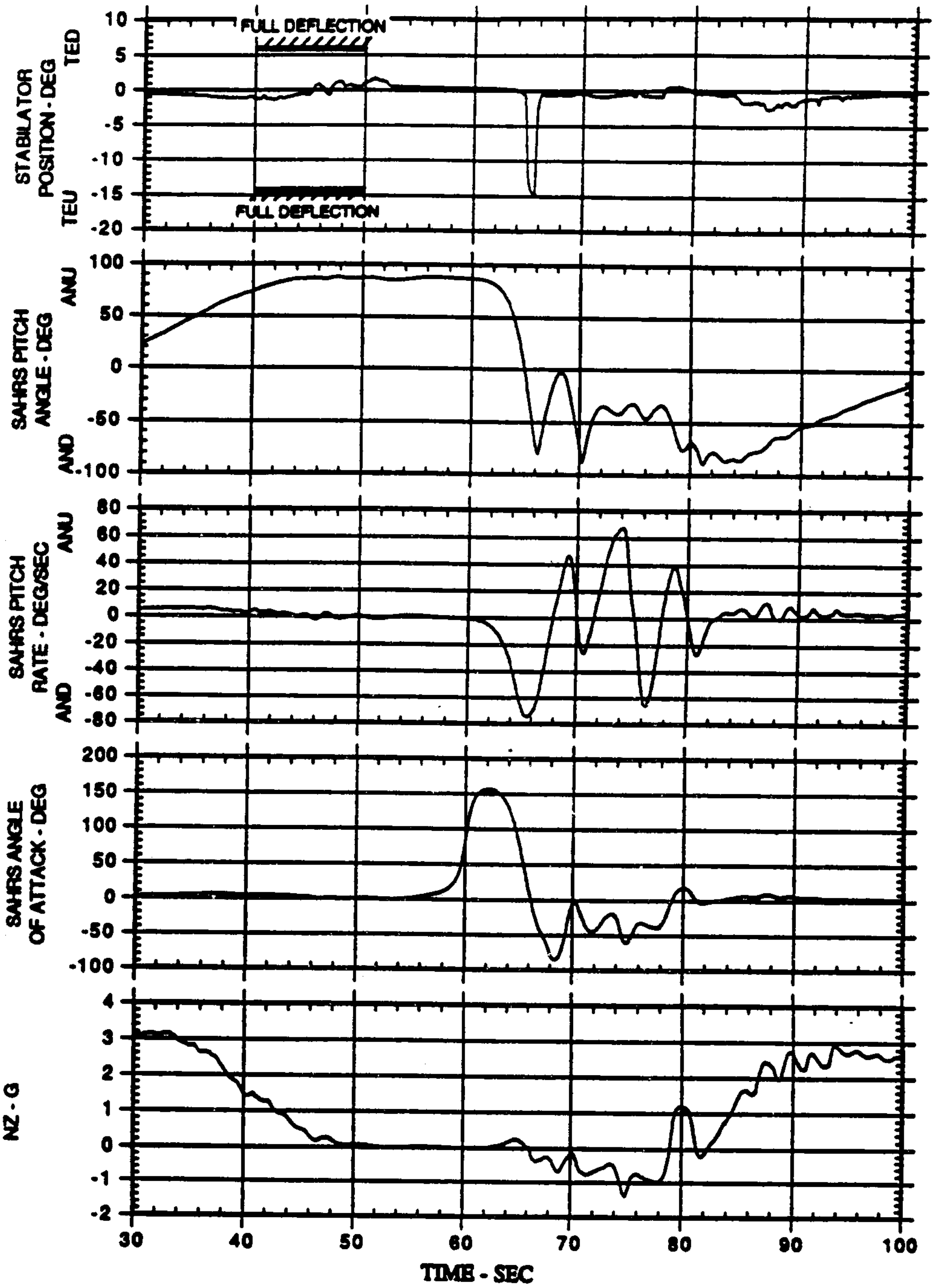


Figure 6 (Continued)

APPENDIX B

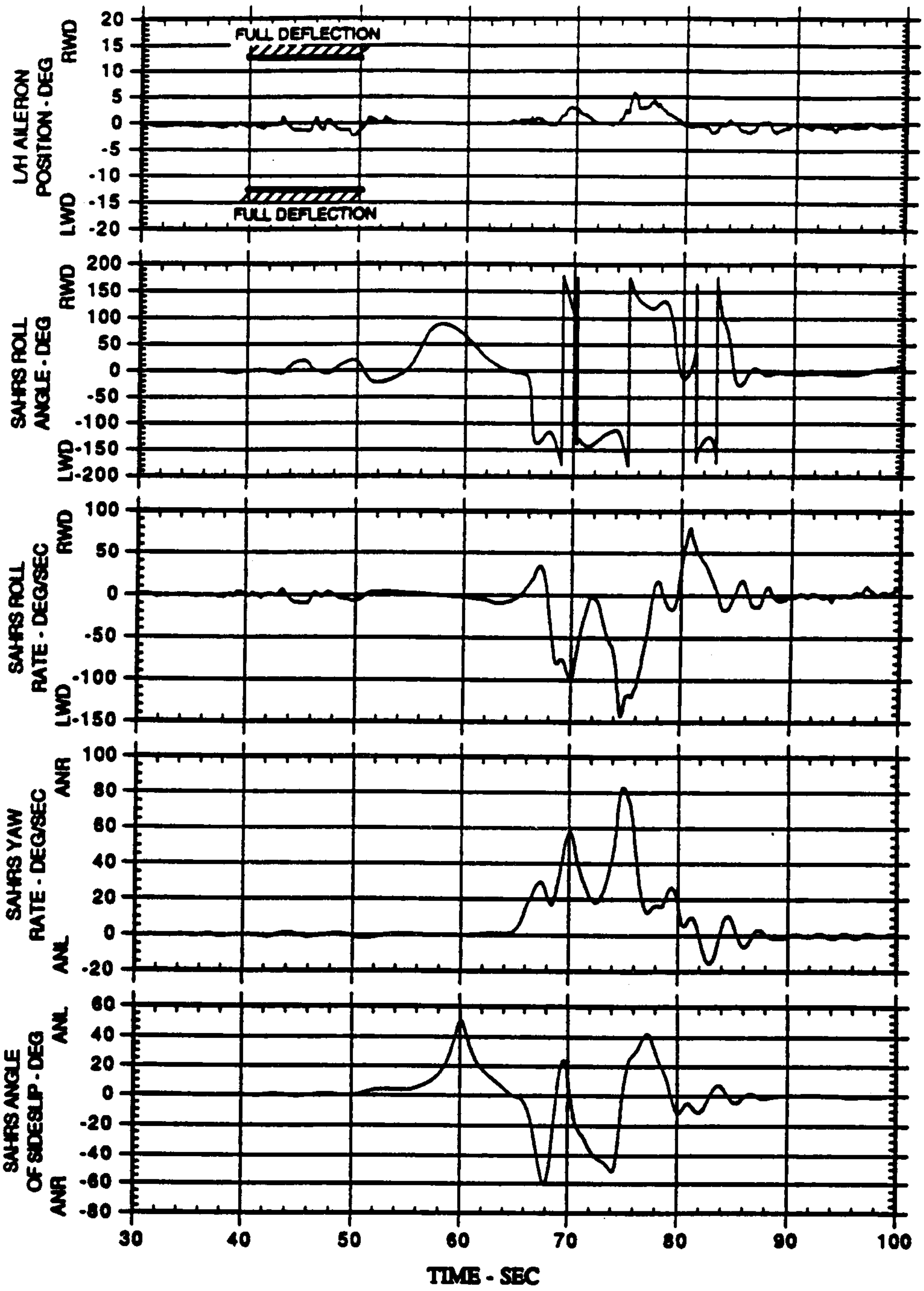


Figure 6 (Continued)

APPENDIX B

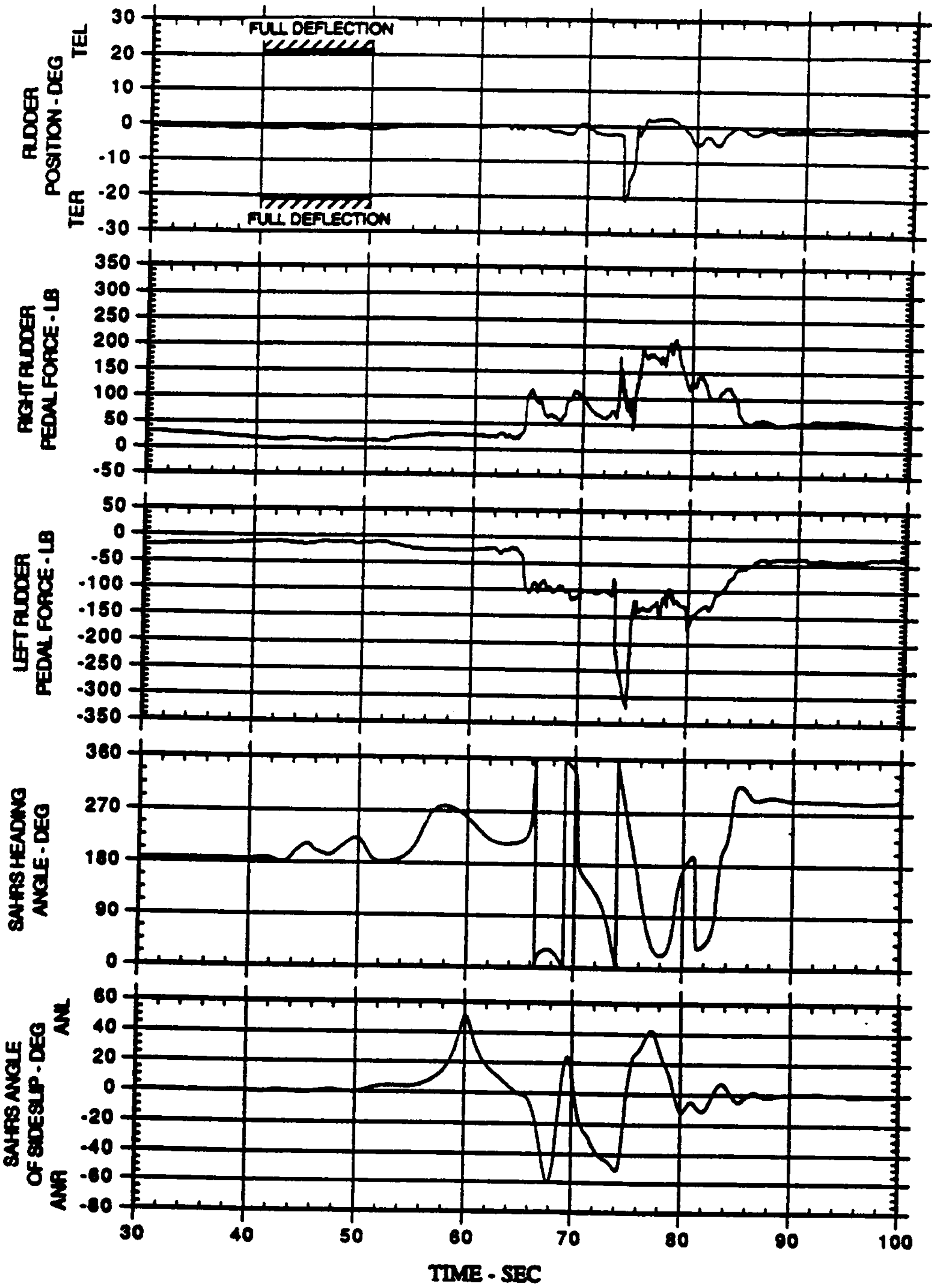


Figure 6 (Continued)

APPENDIX B

T-45A Airplane

Configuration: CR
Gross Weight: 12,000 lb
Speedbrakes: Extended

Loading: Clean
CG: 18.4% MAC
Thrust: Idle

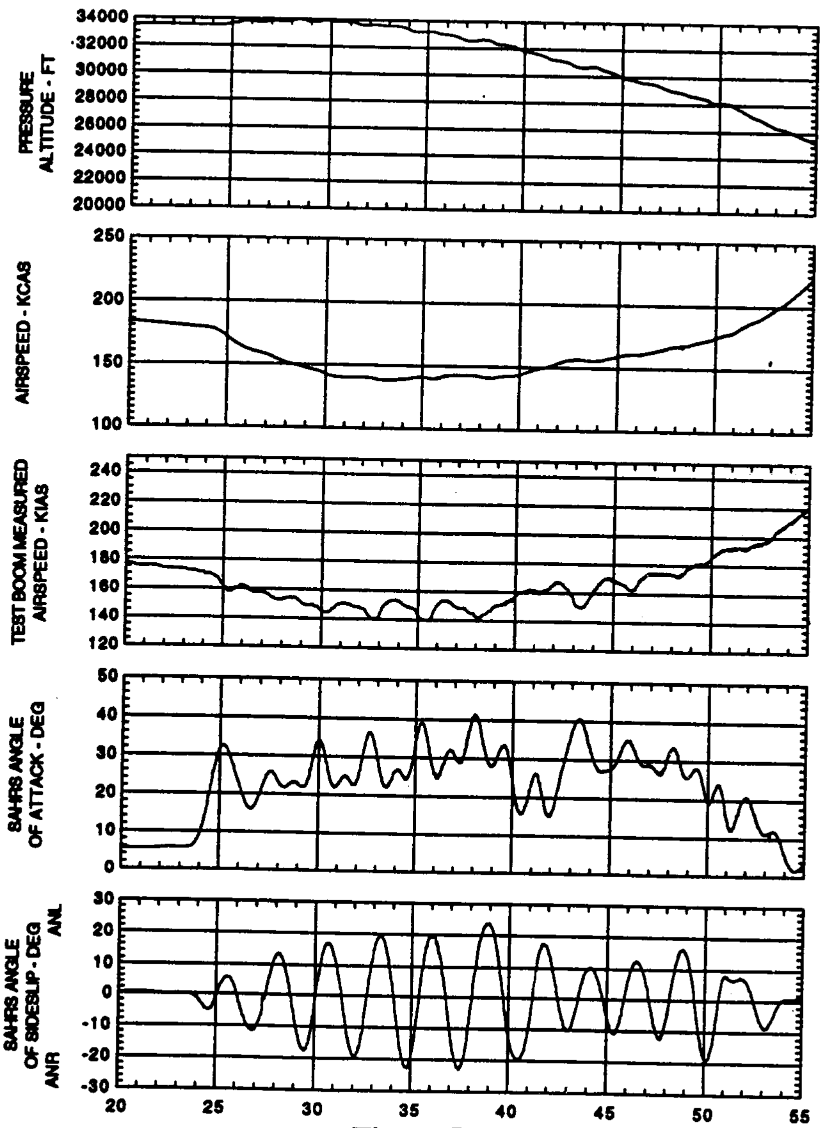


Figure 7
30 Degree Angle-of-Attack Spin

APPENDIX B

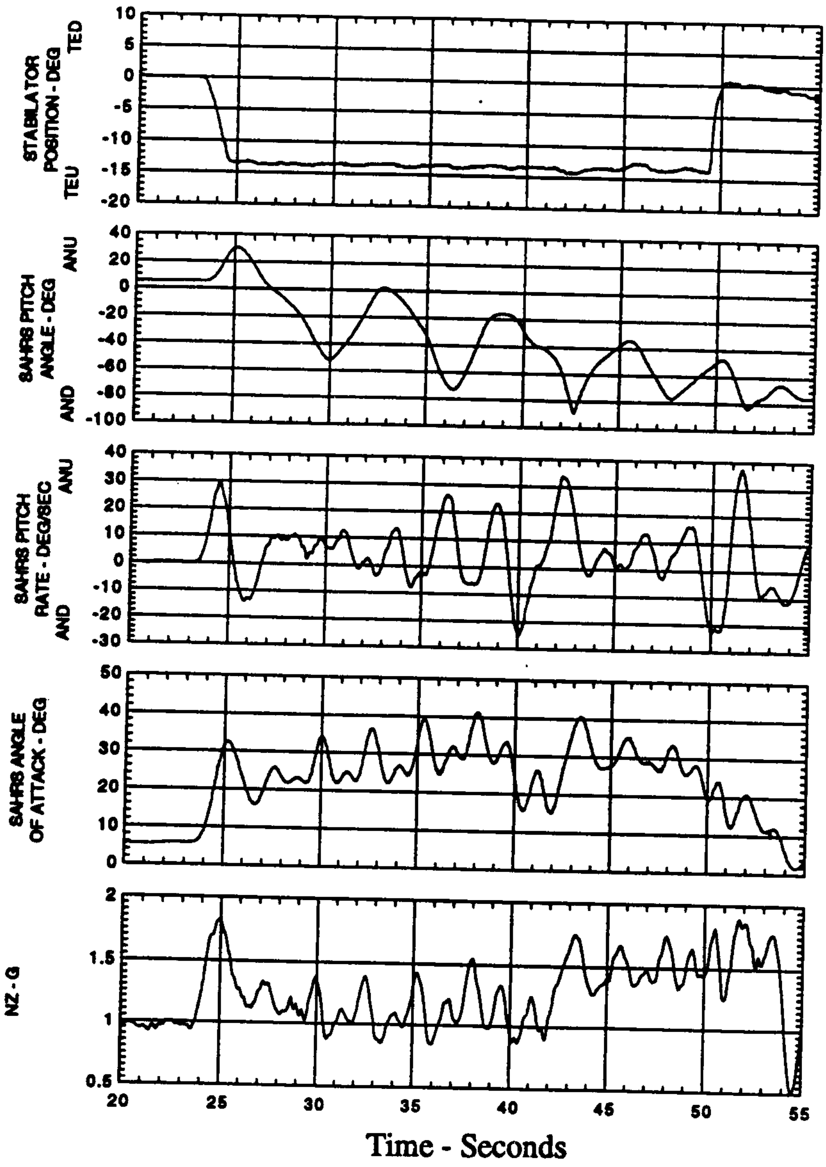


Figure 7 (Continued)

APPENDIX B

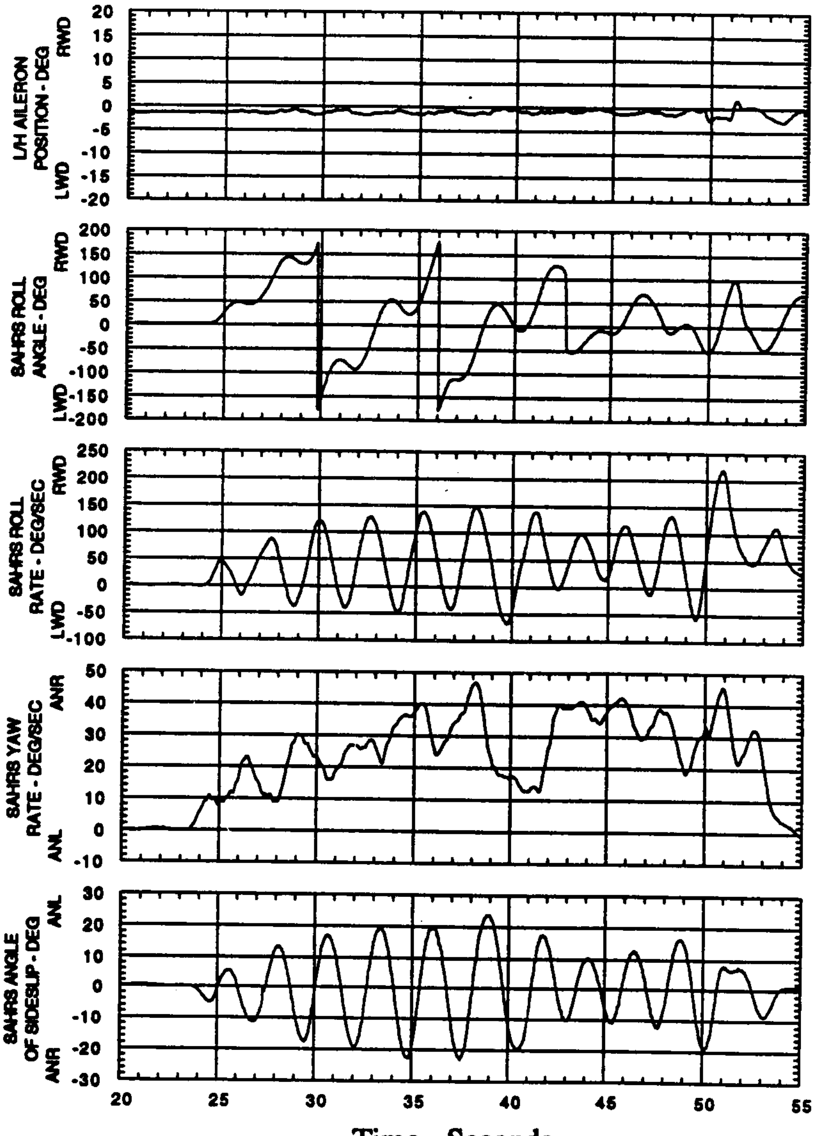


Figure 7 (Continued)

APPENDIX B

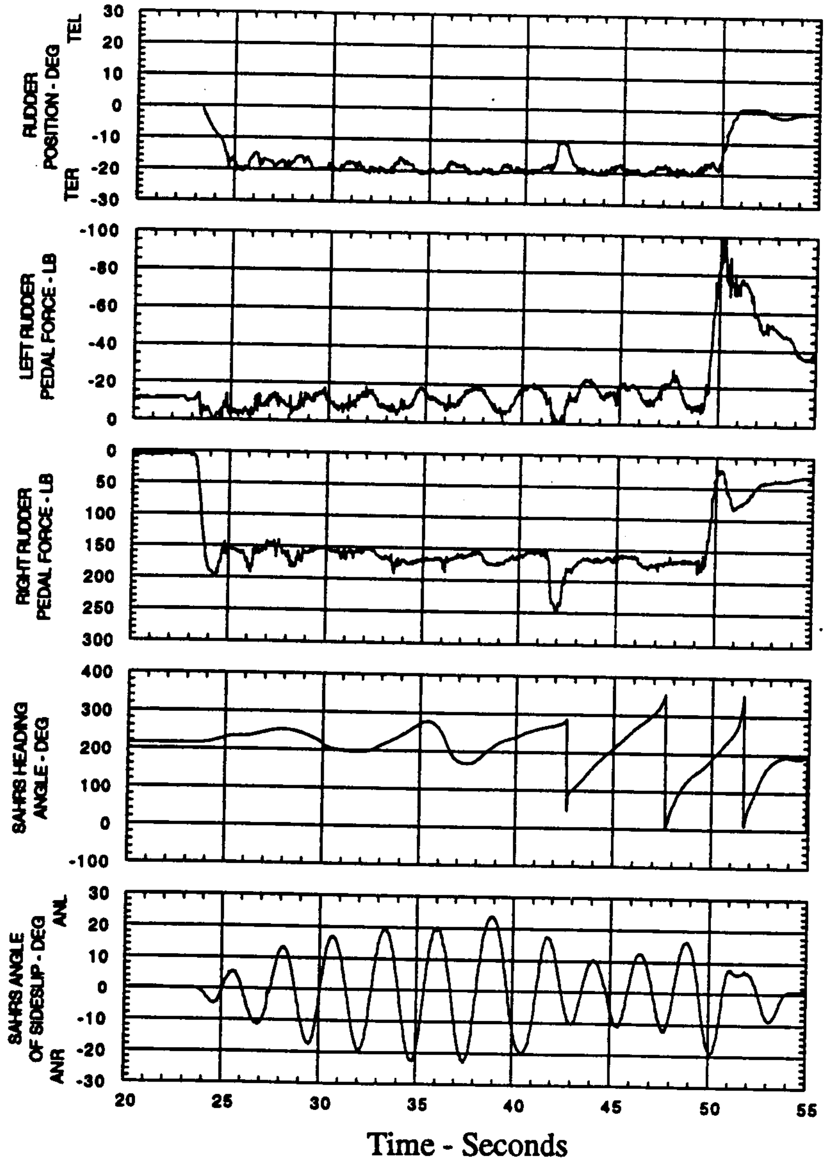


Figure 7 (Continued)

APPENDIX B

T-45A Airplane

Configuration: CR
Gross Weight: 12,410 lb
Speedbrakes: Extended

Loading: Clean
CG: 19.3% MAC
Thrust: Idle

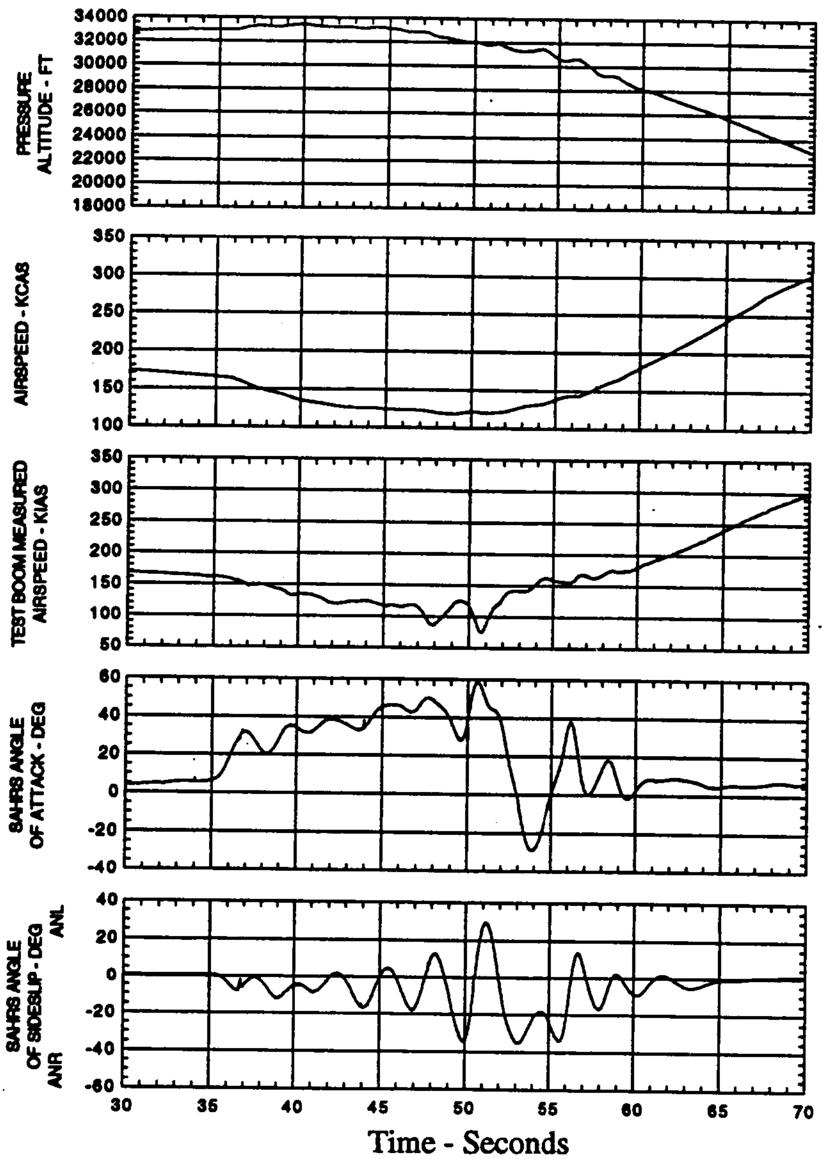


Figure 8
45 Degree Angle-of-Attack Spin

APPENDIX B

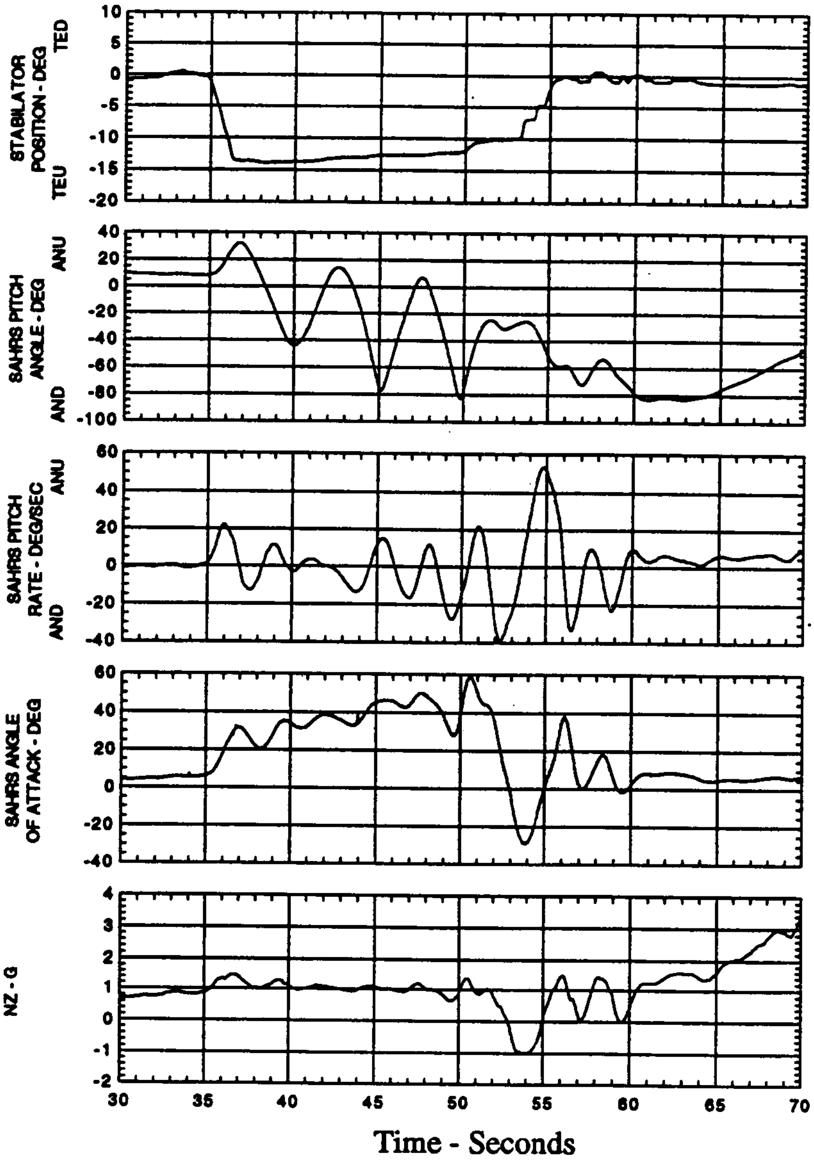


Figure 8 (Continued)

APPENDIX B

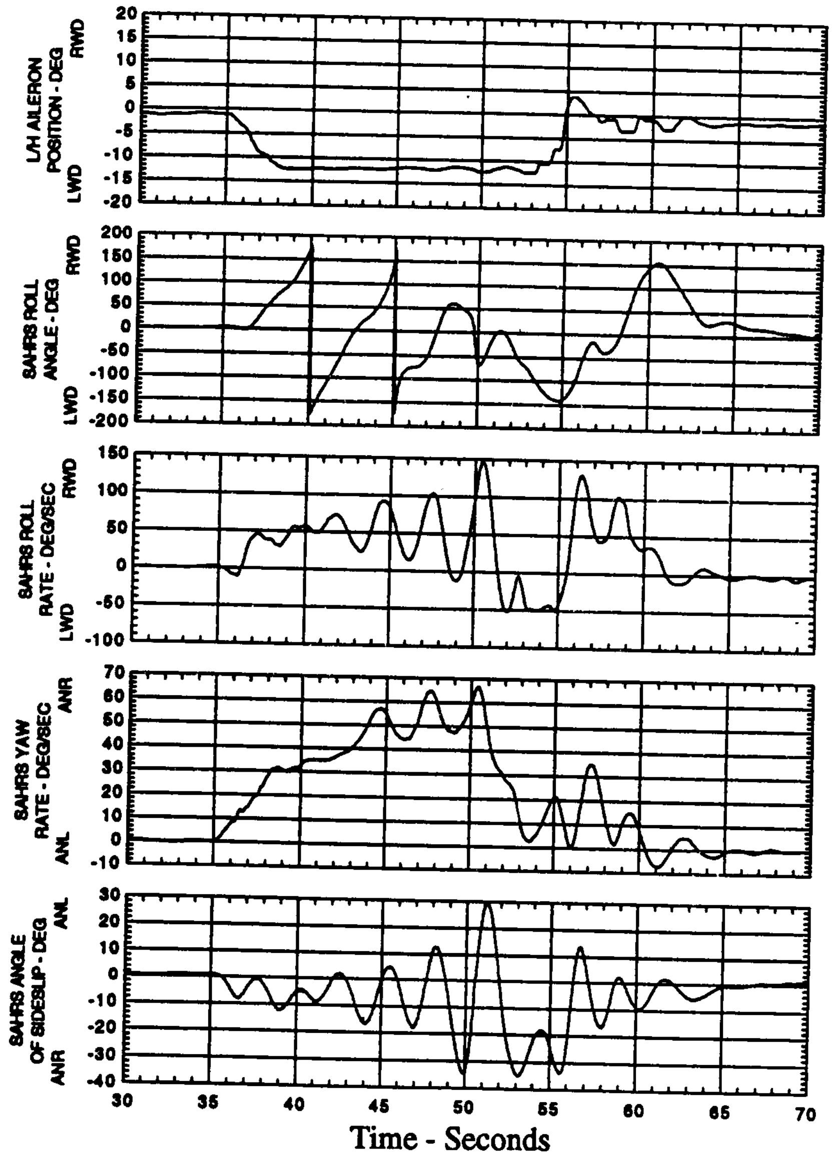


Figure 8 (Continued)

APPENDIX B

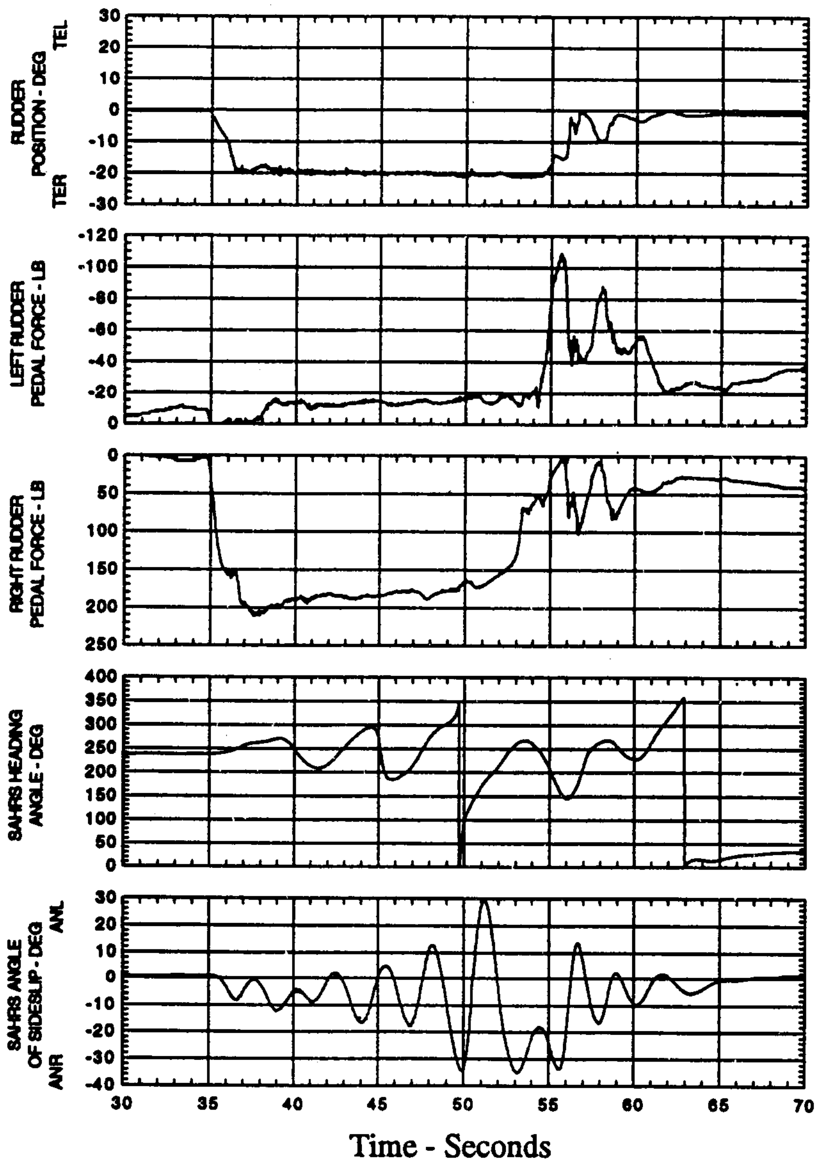


Figure 8 (Continued)

APPENDIX B

T-45A Airplane

Configuration: CR
Gross Weight: 12,260 lb
Speedbrakes: Retracted

Loading: Clean
CG: 18.9% MAC
Thrust: Idle

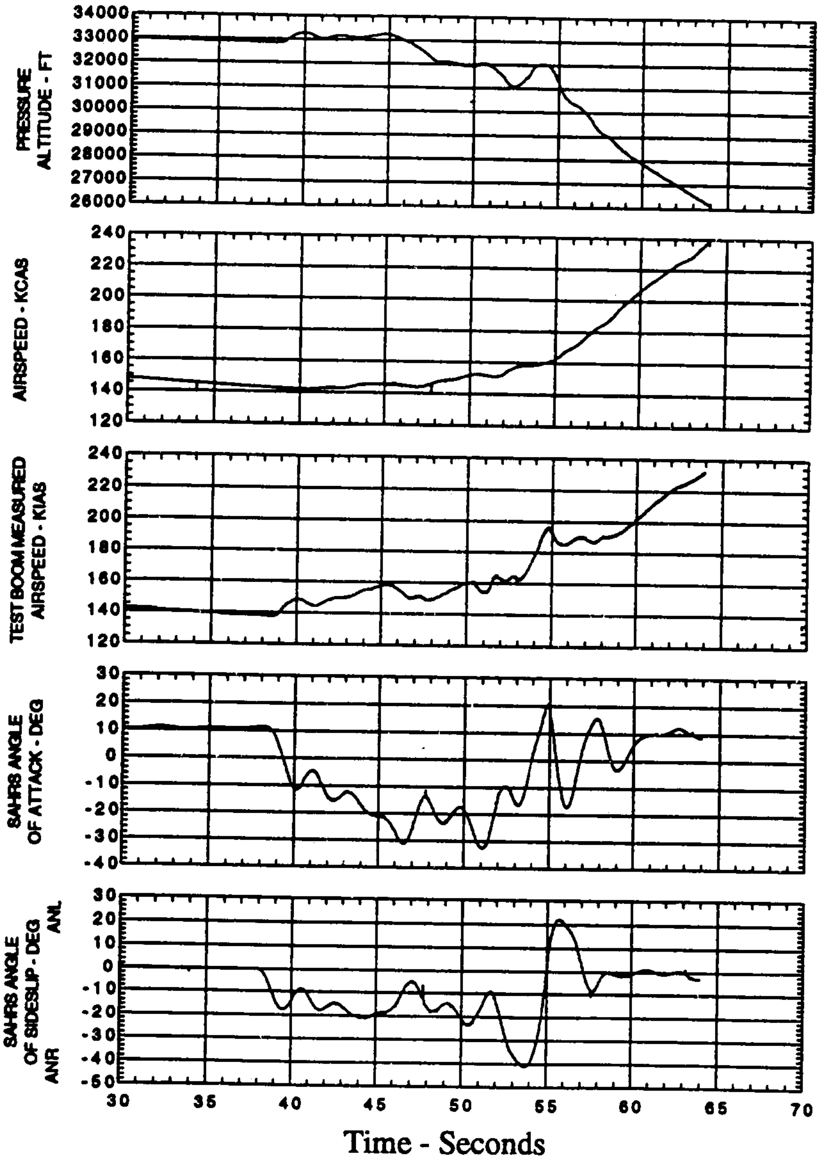


Figure 9
-25 Degree Angle-of-Attack Spin

APPENDIX B

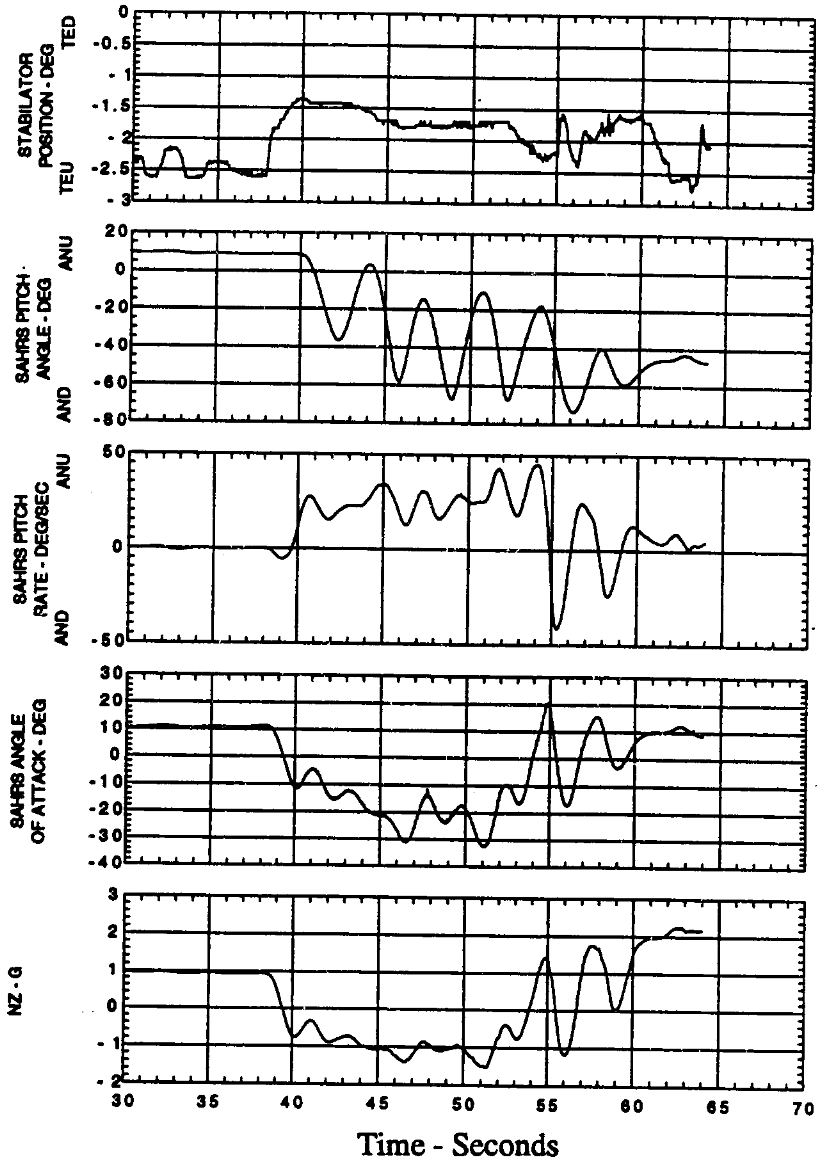
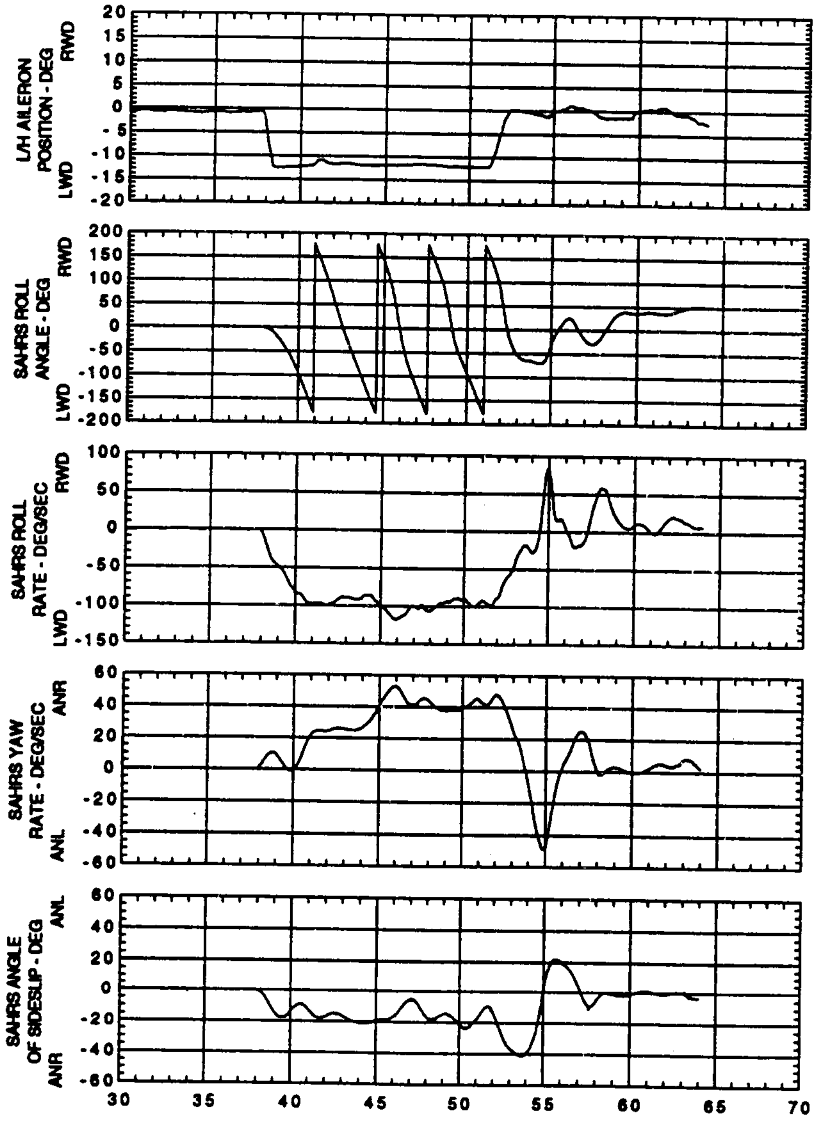


Figure 9 (Continued)

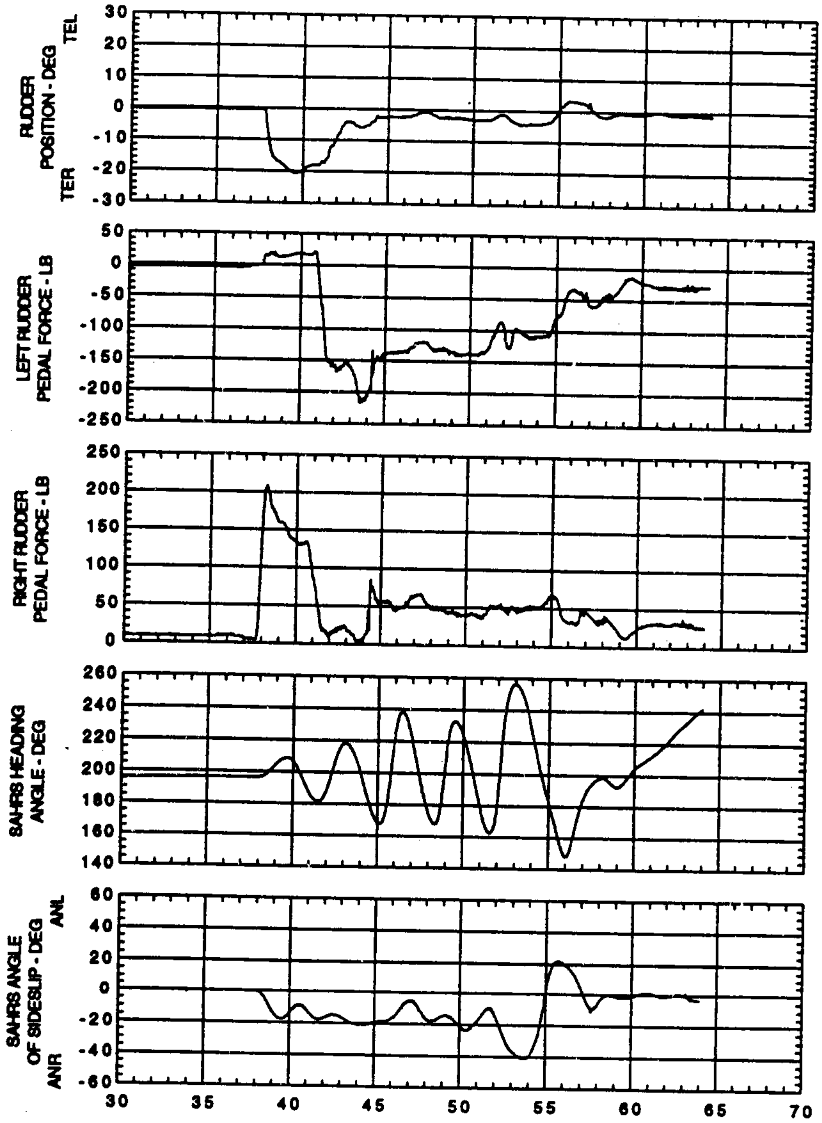
APPENDIX B



Time - Seconds

Figure 9 (Continued)

APPENDIX B



Time - Seconds

Figure 9 (Continued)

APPENDIX B

T-45A Airplane

Configuration: CR
Gross Weight: 12,060 lb
Speedbrakes: Retracted

Loading: Clean
CG: 18.4% MAC
Thrust: Idle

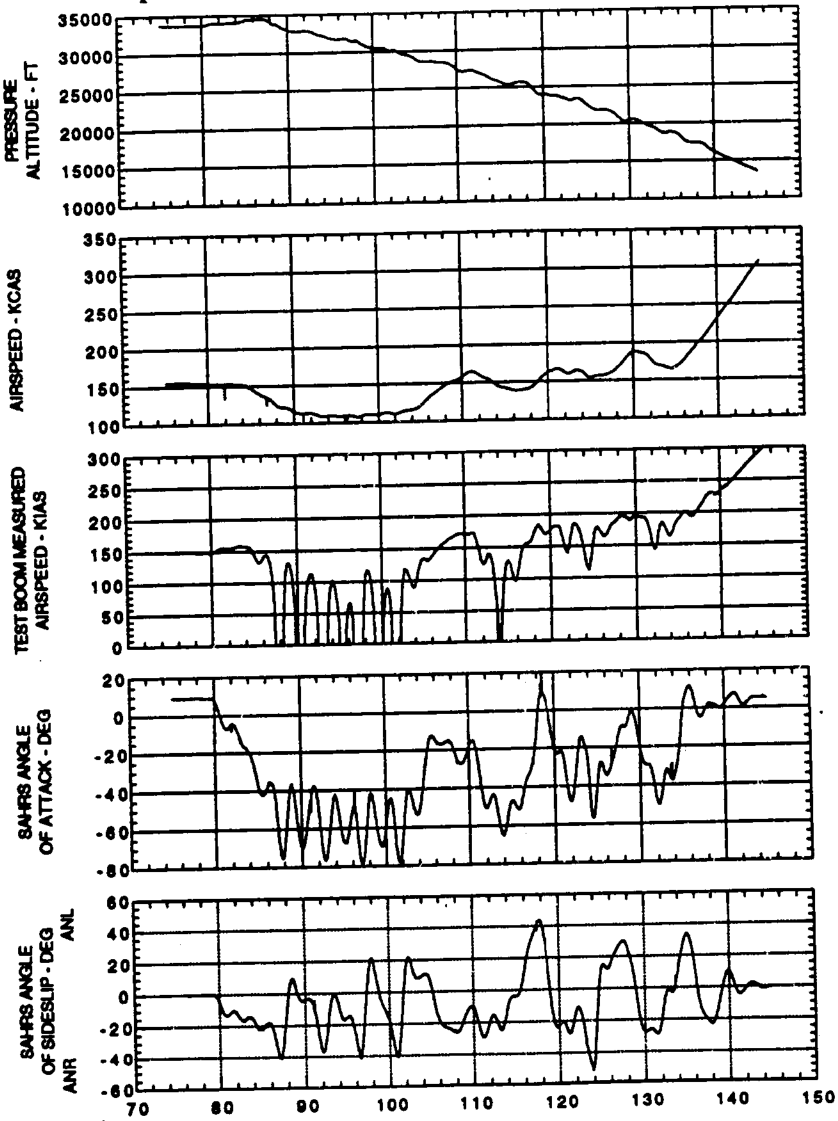


Figure 10
-60 Degree Angle-of-Attack Spin with Transition
into the -40 Degree Angle-of-Attack Spin Mode

APPENDIX B

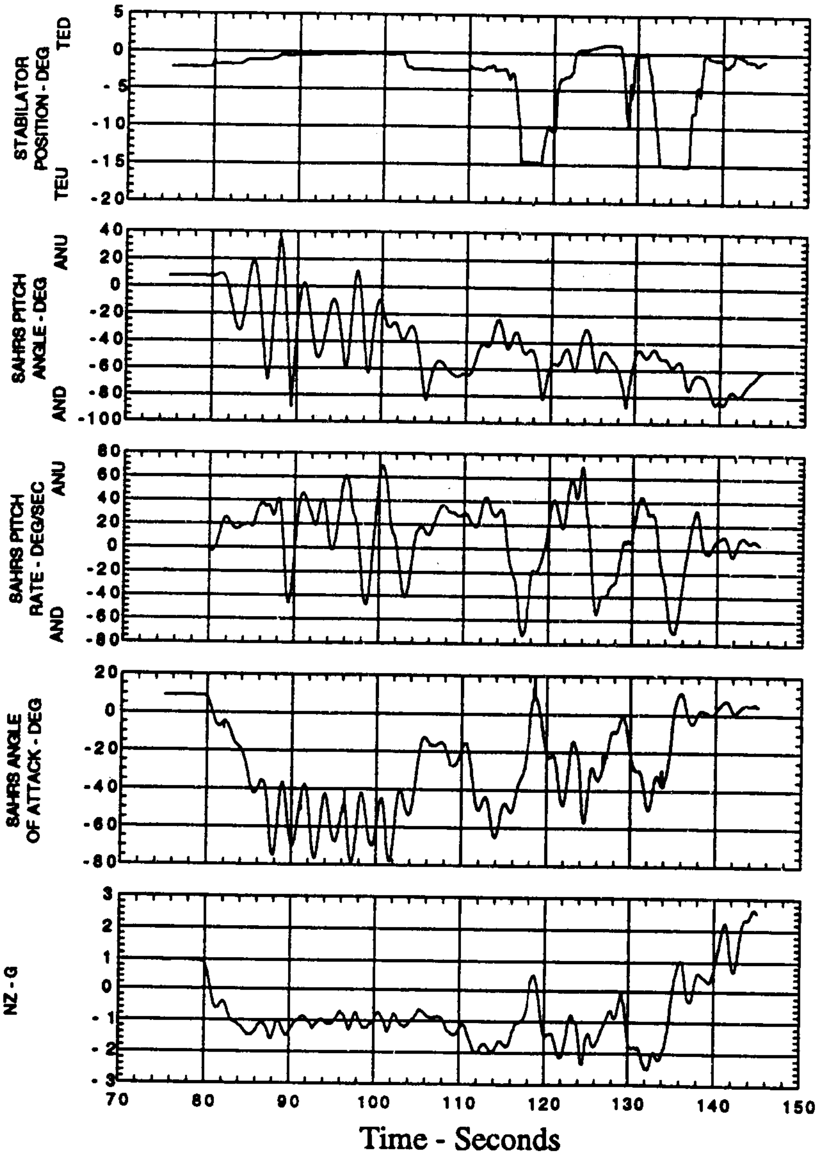


Figure 10 (Continued)

APPENDIX B

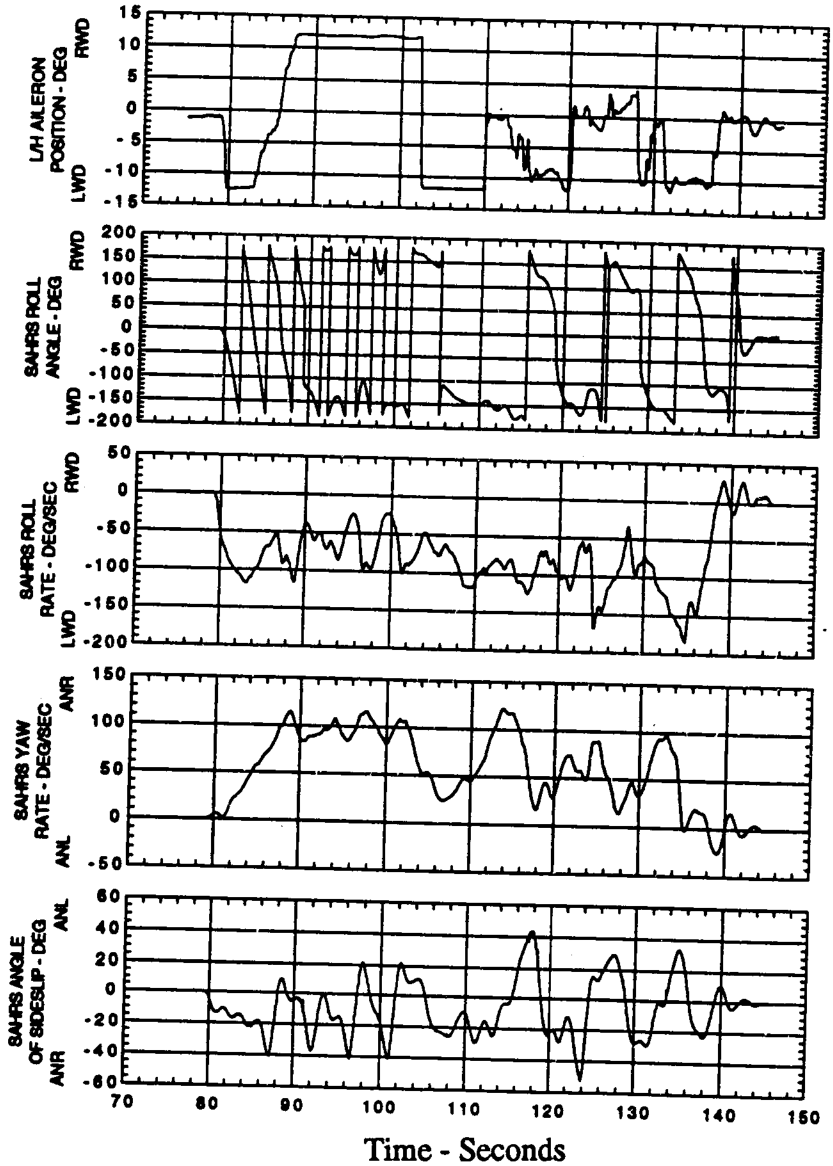


Figure 10 (Continued)

APPENDIX B

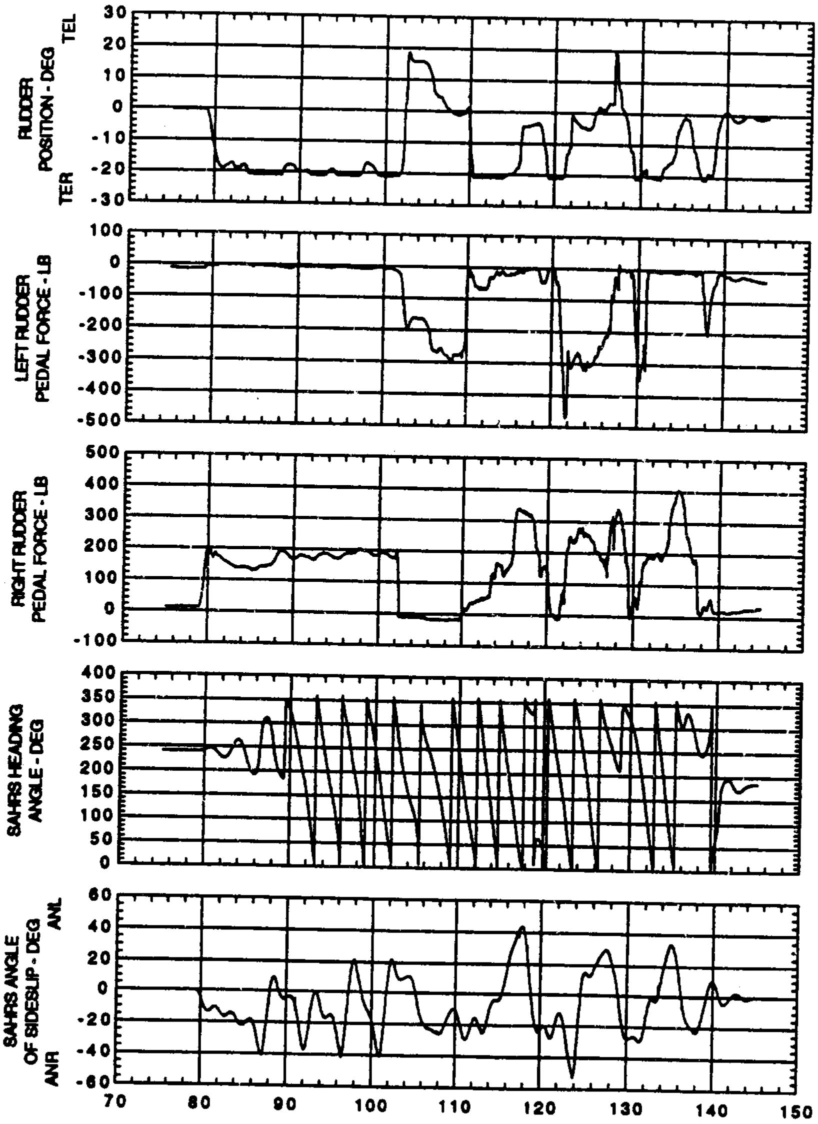


Figure 10 (Continued)

T-45A Airplane

Configuration: CR
Gross Weight: 11,700 lb
Speedbrakes: Retracted

Loading: Clean
CG: 17.5% MAC
Thrust: Idle

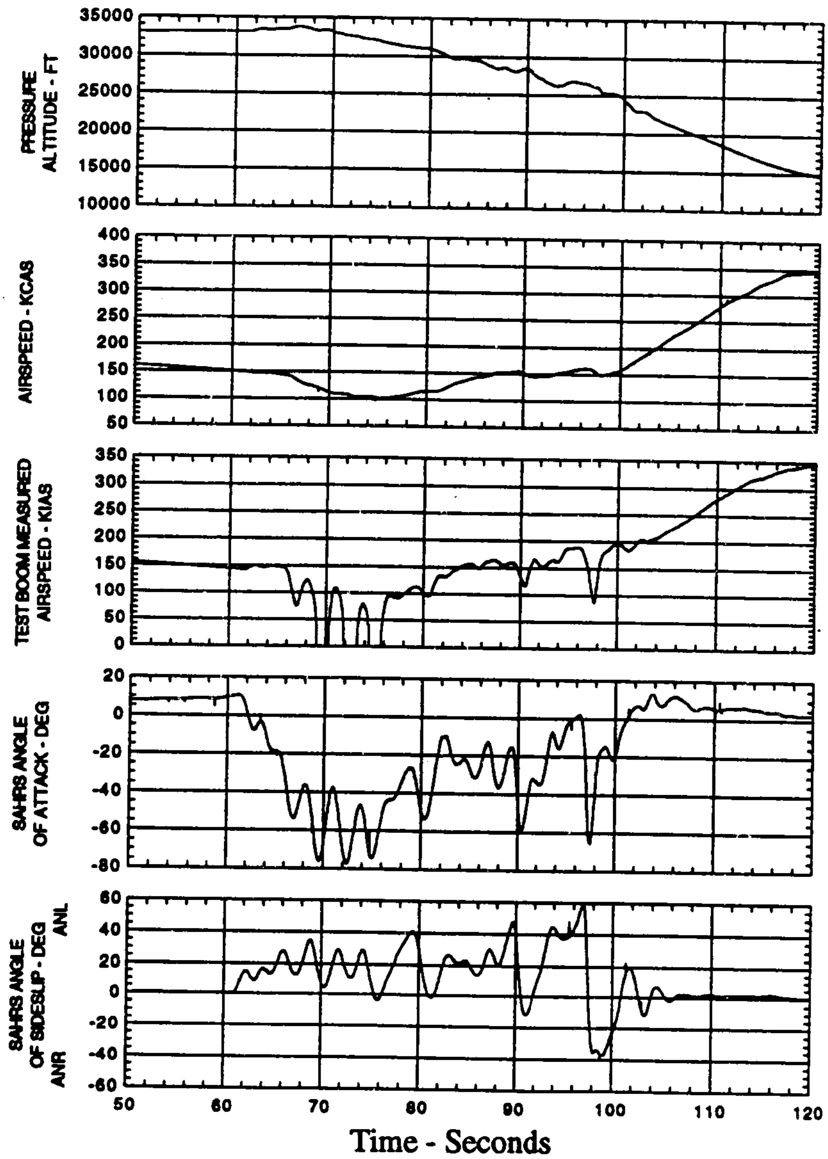
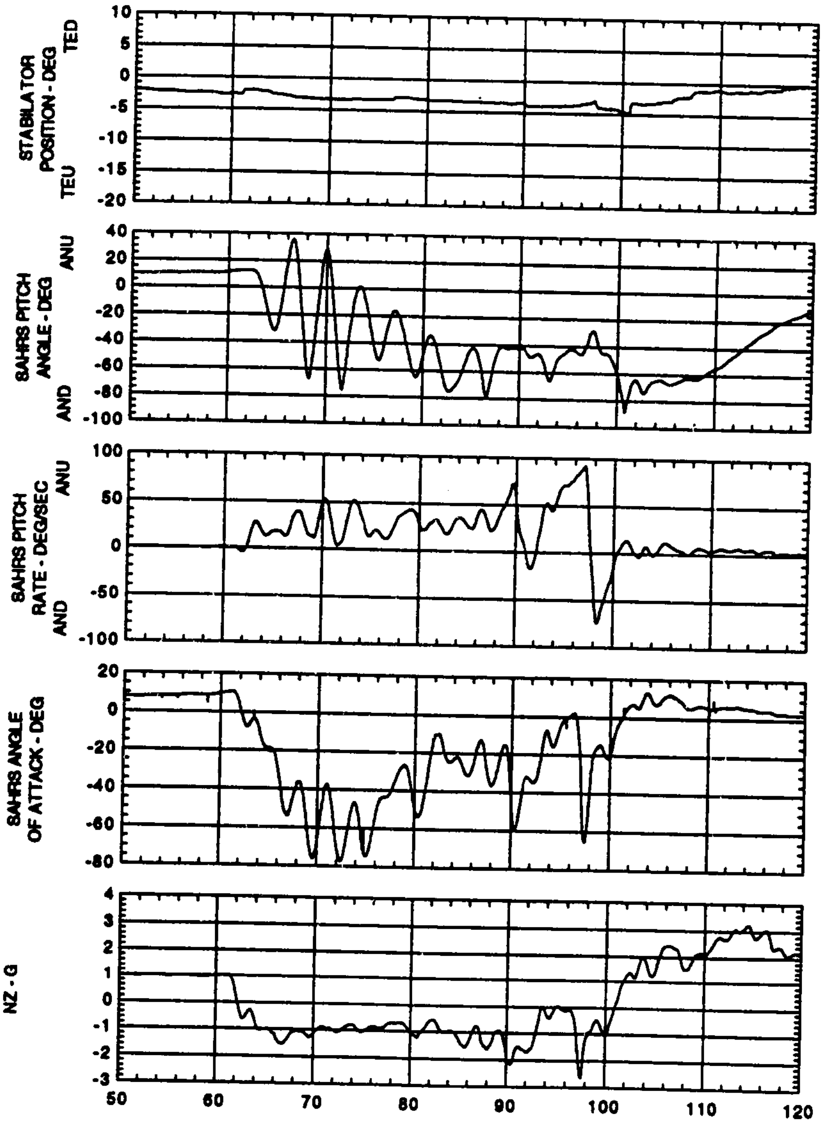


Figure 11
-40 Degree Angle-of-Attack Spin

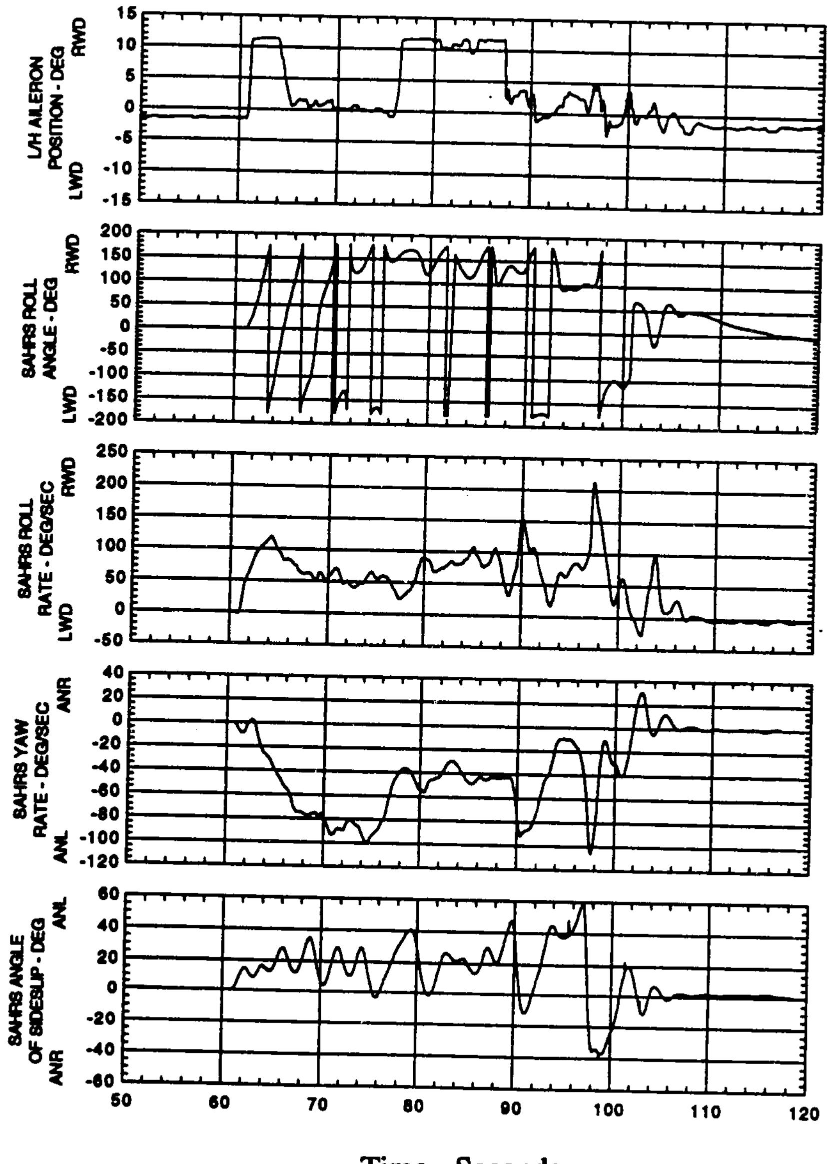
APPENDIX B



Time - Seconds

Figure 11 (Continued)

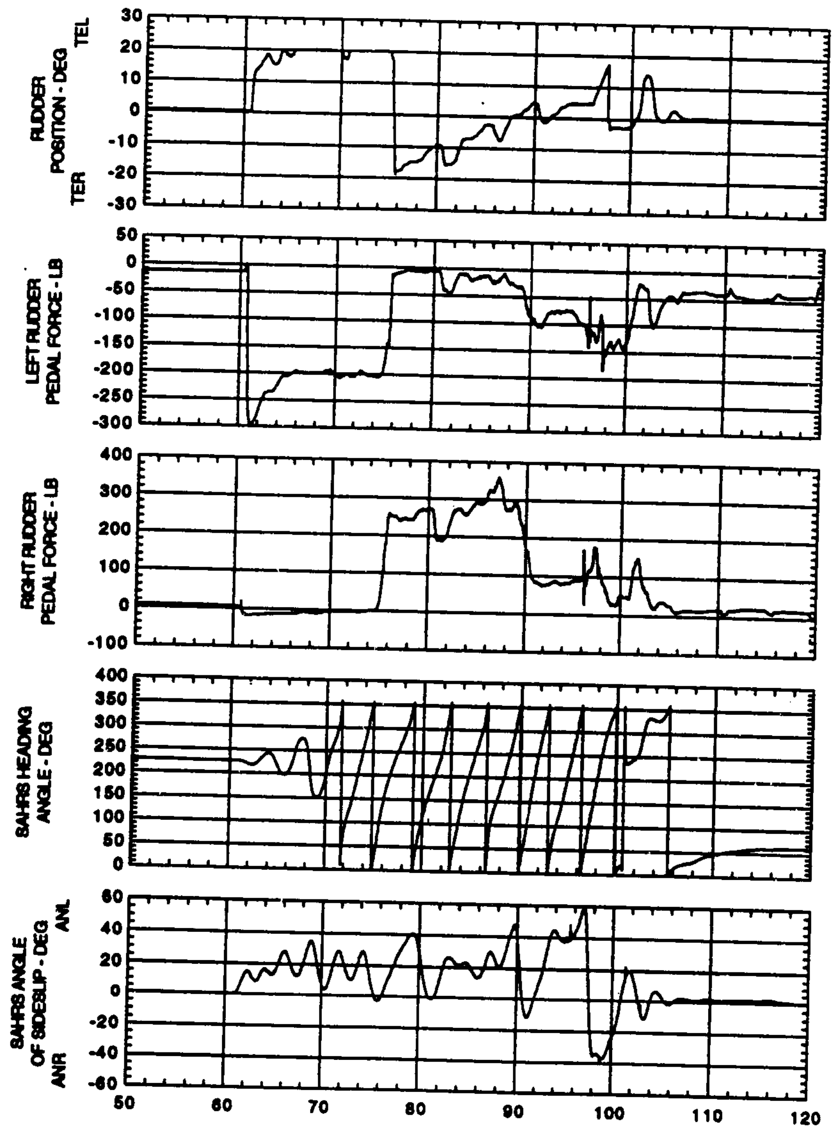
APPENDIX B



Time - Seconds

Figure 11 (Continued)

APPENDIX B



Time - Seconds

Figure 11 (Continued)

VITA

Joseph S. Wascavage was born in Washington, D. C. on January 21, 1958. He graduated from De Matha Catholic High School in May, 1976. In the summer of that same year he entered the University of Maryland and in May, 1981 received a Bachelor of Sience degree in Aerospace Engineering under the Cooperative Education Program. That same month, he commenced work in the Attack Section of Flight Systems Department at the Strike Aircraft Test Directorate, Naval Air Test Center, Patuxent River, Maryland. As a flying qualities and performance flight test engineer, he was assigned to the Navy's team evaluating the AV-8B during the Full Scale Development program. In January 1983, he was assigned to the United States Naval Test Pilot School and graduated as a member of Class 84 in December of the same year. Upon return to the Flight Systems Department at the Strike Aircraft Test Directorate, he was assigned as the lead engineer for the AV-8B Technical Evaluation. During his tenure at Flight Systems Department he also worked various projects on AV-8C, A-7E, A-6E, EA-6B, F-4S and ERA-3B airplanes. His last assignment at Flight Systems Department was the flying qualities engineer on the T-45A Full Scale Development program. In November 1986, he transferred to the T-45TS Project Office within the Strike Aircraft Test Directorate as the T-45TS Deputy Project Manager. In March 1994, he was assigned to his current position as the V-22 Deputy Project Coordinator in the Rotary Wing Test Squadron, Naval Air Warfare Center, Patuxent River, Maryland.